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First Operation of AlGaN Channel High Electron Mobility Transistors

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A channel layer substitution of a wider bandgap AlGaN for conventional GaN in high electron mobility transistors (HEMTs) is one possible method of enhancing the breakdown voltage for higher power operation. Wider bandgap AlGaN, however, should also increase the ohmic contact resistance. We utilized a Si ion implantation doping technique to achieve sufficiently low resistive source/drain contacts, and realized the first HEMT operation with an AlGaN channel layer. This result is very promising for the further higher power operation of high-frequency HEMTs. [DOI : 10.1143/APEX.1.011101]

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Continuous-Wave Operation of Blue Laser Diodes Based on Nonpolar *m*-Plane Gallium Nitride

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The continuous-wave (cw) operation of *m*-plane InGaN-based blue (460 nm) laser diodes (LDs) has been achieved. The threshold current and the corresponding threshold current density were 40 mA and 5.0 kA/cm^2, respectively, with a 459 nm lasing wavelength under cw operation. The electroluminescence peak wavelength shift in pulsed mode was only 10 nm (58 meV), from spontaneous emission (at 0.3 mA) to stimulated emission (at 32 mA), which is extremely small when compared with that of *c*-plane blue LDs. This is first clear experimental demonstration of the advantage in fabricating nonpolar InGaN-based LDs beyond the blue region. [DOI : 10.1143/APEX.1.011102]

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Effects of Traps Formed by Threading Dislocations on Off-State Breakdown Characteristics in GaN Buffer Layer in AlGaN/GaN Heterostructure Field-Effect Transistors

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The off-state breakdown characteristics of GaN layers with different thicknesses from 0.2 to 2 μm grown by metal organic chemical vapor deposition on SiC substrates were discussed using the space-charge-limited current conduction mechanism. With decreasing thickness of the GaN layer, the off-state breakdown voltage increased. The trap density in the GaN layer was estimated from the traps-filled-limit voltage, which determined the off-state breakdown voltage. We found that the thus-estimated trap density increased with decreasing thickness of the GaN layer. A higher density of threading dislocations in the thinner samples was confirmed by transmission electron microscopy observations. These results suggest that the traps formed by the threading dislocations influence the off-state breakdown voltage of the GaN layer.
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Blue Laser Diodes Fabricated on *m*-Plane GaN Substrates

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Blue laser diodes (LDs) were fabricated on *m*-plane oriented GaN substrates by atmospheric-pressure metalorganic chemical vapor deposition. Typical threshold current for stimulated emission at a wavelength λ of 463 nm was 69 mA. Blueshift of the spontaneous emission peak with increasing injection current was examined in LDs fabricated on *m*- and *c*-plane GaN substrates. Blueshifts for the *m*-plane LD (λ=463 nm) and the *c*-plane LD (λ=454 nm) with an injection current density just below threshold were about 10 and 26 nm, respectively. These results confirm that the blueshift in quantum-wells fabricated on *m*-plane oriented substrates is smaller than on *c*-plane oriented substrates due to the absence of polarization-induced electric fields.
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Vertical GaN-Based Trench Gate Metal Oxide Semiconductor Field-Effect Transistors on GaN Bulk Substrates

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Completely vertical trench gate metal oxide semiconductor field-effect transistors (MOSFETs) have been produced using gallium nitride (GaN) for the first time. These MOSFETs exhibited enhancement-mode operation with a threshold voltage of 3.7 V and an on-resistance of 9.3 mΩ·cm^2. The channel mobility was estimated to be 131 cm^2/(V·s) when all the resistances except for that of the channel are considered. Such structures, which satisfy the key words "vertical", "trench gate", and "MOSFET", will enable us to fabricate practical GaN-based power switching devices. [DOI : 10.1143/APEX.1.011105]

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Monolithic Polychromatic Light-Emitting Diodes Based on InGaN Microfacet Quantum Wells toward Tailor-Made Solid-State Lighting

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Monolithic polychromatic light-emitting diodes (LEDs) based on micro-structured InGaN/GaN quantum wells are demonstrated. The microstructure is created through regrowth on SiO_2 mask stripes along the [1$\bar{1}$00] direction and consists of (0001) and {11$\bar{2}$2} facets. The LEDs exhibit polychromatic emission, including white, due to the additive color mixture of facet-dependent emission colors. Altering the growth conditions and mask geometry easily controls the apparent emission color. Furthermore, simulations predict high light extraction efficiencies due to their three-dimensional structures. Those observations suggest that the proposed phosphor-free LEDs may lead to highly efficient solid-state lighting in which the color spectra of light sources are synthesized to satisfy specific requirements for illuminations.
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Germanium Nitride Interfacial Layer for Chalcogenide Random Access Memory Applications

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This work reports on the performance improvement of a chalcogenide random access memory device by applying germanium nitride as an interfacial layer. The device with an 8-nm-thick GeN film was fabricated using standard 0.18 μm complementary metal oxide semiconductor technology. The as-deposited GeN is in the amorphous state and has a smooth surface. An electrical test showed that this N-deficient layer induces a lower threshold voltage during the operation. It is believed that the reduction mainly originated from the excellent interfacial properties, high electrical resistivity, and low thermal conductivity of GeN, which is would be a prospective interfacial material in CRAM devices.
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Appl. Phys. Express Vol.1, No.1 (2008) 011202

Vertical Solar-Blind Deep-Ultraviolet Schottky Photodetectors Based on β-Ga_2O_3 Substrates

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A vertical-type Schottky photodetector based on a (100)-oriented β-Ga_2O_3 substrate has been fabricated with simple processes of thermal annealing and vacuum evaporation. The photodetector exhibited a rectification ratio higher than 10^6 at ±3 V, and showed deep-ultraviolet-light detection at reverse bias. The spectral response showed solar-blind sensitivity with high photoresponsivities of 2.6–8.7 A/W at wavelengths of 200–260 nm. These values were 35–150 times higher than those derived assuming the internal quantum efficiency to be unity. This fact is attributed to the carrier multiplication occurring in the highly resistive surface region that is subject to a high internal electric field of about 1.0 MV/cm at the reverse bias of 10 V. [DOI : 10.1143/APEX.1.011202]

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Current-Driven Domain Wall Motion in CoCrPt Wires with Perpendicular Magnetic Anisotropy

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We report the direct observation of current-driven domain wall (DW) motion in a CoCrPt wire with perpendicular magnetic anisotropy. Magnetic force microscopy showed that a single DW introduced in the wire is displaced back and forth by positive and negative pulsed current. This is the first demonstration of the current-driven DW motion in a metallic magnetic wire with perpendicular magnetic anisotropy in the absence of a magnetic field. [DOI : 10.1143/APEX.1.011301]

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On Effects of Gate Bias on Hole Effective Mass and Mobility in Strained-Ge Channel Structures

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The effects of gate bias on hole effective mass (m^*) and Hall mobility were studied in strained-Ge channel modulation-doped structures. Shubnikov–de Haas oscillations were analyzed with and without the bias and a significant m^* increase from 0.15 to 0.22 m_0 was observed with the increase in the carrier density due to the strong nonparabolicity of the valence band. This is a clear demonstration that modification of carrier density via gating considerably affects m^*, which may have critical effects on device properties. The gate bias dependence of Hall mobility was also investigated and the dominant scattering mechanism was clarified in various temperature and carrier density regions.
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Piezoelectric Properties of (K,Na)NbO_3 Films Deposited by RF Magnetron Sputtering

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High-piezoelectricity lead-free films of (K,Na)NbO_3 (KNN) were successfully deposited on Pt/MgO and Pt/Ti/SiO_2/Si substrates by RF magnetron sputtering. The KNN film was epitaxially grown on Pt/MgO with a high <001> orientation in the pseudo-cubic perovskite structure. The KNN film on Pt/Ti/SiO_2/Si was polycrystalline with a preferential <001> orientation in the pseudo-cubic perovskite structure. The piezoelectric properties of the KNN films were determined from the tip displacement of KNN/Pt/MgO or KNN/Pt/Ti/SiO_2/Si unimorph cantilevers. The transverse piezoelectric coefficients $e_{31}{}^*$ ($d_{31}/s_{11}{}^E$) of the KNN films on Pt/MgO and Pt/Ti/SiO_2/Si were calculated to be -3.6 and -5.5 C/m^2, respectively, which are amongst the highest values for KNN films ever reported. [DOI : 10.1143/APEX.1.011501]

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Valence State of Mn-Doped $BiFeO_3$–$BaTiO_3$ Ceramics Probed by Soft X-ray Absorption Spectroscopy

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The valence state of Mn-doped $BiFeO_3$–$BaTiO_3$ ceramics has been probed by soft X-ray absorption spectroscopy (XAS). Mn-doped $BiFeO_3$–$BaTiO_3$ has valence states of Fe^{3+} and Ti^{4+}, although $BiFeO_3$ and Mn-doped $BiFeO_3$ have mixed valence states of Fe^{2+} and Fe^{3+}. The Mn 2p-XAS peak of Mn-doped $BiFeO_3$–$BaTiO_3$ locates at a lower energy side than that of Mn-doped $BiFeO_3$ that corresponds to the Mn^{3+} valence state. These findings may indicate that the Fe^{3+} valence state of Mn-doped $BiFeO_3$–$BaTiO_3$ is stabilized by charge transfer from the Mn 3d state to the Fe 3d state through the Ti 3d state in $BaTiO_3$.
[DOI : 10.1143/APEX.1.011502]

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Superconductor-based Light Emitting Diode: Demonstration of Role of Cooper Pairs in Radiative Recombination Processes

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A light emitting diode with superconducting Nb electrodes was fabricated to investigate the contribution of cooper pairs to radiative recombination in a semiconductor. Electroluminescence observed from the active layer in which electron cooper pairs and normal holes are injected was drastically enhanced at the temperature lower than the superconducting transition temperature of the Nb electrodes. This is the first experimental evidence that cooper pairs enhance radiative recombinations by the superradiance effect. [DOI : 10.1143/APEX.1.011701]

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Dual Self-Aligned Vertical Multichannel Organic Transistors

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A dual self-aligned vertical multichannel organic transistor (DSA-VMCOT) is proposed and demonstrated. The layouts of the shadow gate and transparent source/drain are sequentially determined using dual back-surface exposure. Vertical 100-nm channel and multichannel structures are obtained using interdigital gate electrodes. This device concept is promising for use as a backplane with high current driving capability. [DOI : 10.1143/APEX.1.011801]

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Planar Avalanche Photodiode for Long-Haul Single-Photon Optic Fiber Communications

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We present a high-performance planar GaInAs/InP avalanche photodiode (APD) for long-haul single-photon optic fiber communications, that is, quantum cryptography. The APDs for single-photon communications require a high single-photon detection efficiency (η_{det}) relating to bitrate and a low ratio of dark count probability (P_{dc}) to η_{det} limiting communication distance. We fabricated the APD with the combination of a long multiplication region length and a low carrier sheet density on the basis of numerical analysis. The P_{dc}/η_{det} monotonically decreased with operation temperature lowered, and the ratio reached 5.9×10^{-6} with the η_{det} of 13 % at 77 K. The P_{dc} was 7.7×10^{-7}, which corresponds to a dark count rate of 0.38 kHz. The useful APD and the effective layer design are reported. [DOI : 10.1143/APEX.1.012001]

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Two-Dimensional Photonic Crystal Composed of Ordered Polymer Nanopillar Arrays with High Aspect Ratios Using Anodic Porous Alumina Templates

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Two-dimensional (2D) photonic crystals composed of ordered polymer nanopillar arrays were fabricated using anodic porous alumina templates. For the preparation of 2D photonic crystals with high aspect ratios, polymer pillar arrays, in which both ends of nanopillars were supported by supporting layers, were introduced. The diameter, interval and length of nanopillar arrays could be controlled by changing the preparation conditions of anodic porous alumina templates. The reflection properties of the ordered polymer nanopillar array obtained exhibited a stop band in the spectrum, which corresponds to the band gap in the 2D photonic crystals. [DOI : 10.1143/APEX.1.012002]

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Appl. Phys. Express Vol.1, No.1 (2008) 012003

Tunable Liquid Crystal Laser Using Distributed Feedback Cavity Fabricated by Nanoimprint Lithography

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Electrical tuning of laser wavelength is demonstrated using a liquid-crystal/polymer grating fabricated by nanoimprint lithography. Laser emission occurs at a wavelength near 700 nm, which corresponds to the first order of a 200 nm period grating. With increasing applied voltage, the lasing spectrum begins to shift to shorter wavelengths at 10 V, and then a 10 nm shift is achieved with an applied voltage of 30 V. This is due to the refractive index change of the liquid crystal in the trench of the polymer grating by field-induced molecular reorientation. [DOI : 10.1143/APEX.1.012003]

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Appl. Phys. Express Vol.1, No.1 (2008) 012004

Generation of Intense and Monochromatic Terahertz Radiation from Coherent Longitudinal Optical Phonons in GaAs/AlAs Multiple Quantum Wells at Room Temperature

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We have investigated time-domain signals of terahertz (THz) radiation from coherent longitudinal-optical (LO) phonons in GaAs/AlAs multiple quantum wells at room temperature, utilizing an optical gating method with a photoconductive dipole antenna. It has been found that an intense and monochromatic THz wave with a frequency of 8.7 THz is generated from coherent GaAs-like LO phonons under the condition that the energy spacing between the fundamental heavy-hole and light-hole excitons is tuned to the LO-phonon energy. The pump-energy and pump-power dependences of the THz-radiation intensity indicate that the impulsive interference of the heavy-hole and light-hole excitons dominates the generation process. [DOI : 10.1143/APEX.1.012004]

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Development of Electrooptic Modulator for Advanced Ground-Based Gravitational Wave Telescopes Using Stoichiometric MgO-Doped $LiNbO_3$ Crystals

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We have developed an electrooptic modulator (EOM) using stoichiometric MgO-doped $LiNbO_3$ (MgO-doped SLN) crystals, and evaluated this EOM for the phase control of a high-power laser whose power is over 100 W. We succeeded in the phase modulation of a 100 W laser without a decrease in phase modulation index, due to a nonlinear optical effect, which can occur when a high-power laser beam enters the EOM. We also estimated wavefront distortions caused by passing through the EOM with a Shack–Hartmann wavefront sensor, and found that the additional wavefront distortion was negligible. Thus, we confirmed that MgO-doped SLN crystals are a suitable material for use in a high-power laser system. [DOI : 10.1143/APEX.1.012005]

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Visible Anisotropic Deformation of Chalcogenide Glass by Illumination of Linearly Polarized Light

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It has been discovered that illumination of linearly-polarized bandgap light produces visible-scale anisotropic deformations in a covalent chalcogenide glass As_2S_3. X-ray diffraction and Raman-scattering measurements for deforming As_2S_3 flakes detect no microscopic structural changes. Measurements of optical torque in deforming flakes and comparative exposure experiments for crystalline As_2S_3 and amorphous Se suggest that the anisotropic deformation occurs through radiation force, photoinduced birefringence, and photoinduced fluidity. [DOI : 10.1143/APEX.1.012006]

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Appl. Phys. Express Vol.1, No.1 (2008) 012007

Kerr-Lens Mode-Locked Diode-Pumped Yb:YAG Laser with the Transverse Mode Passively Stabilized

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We have developed a Kerr-lens mode-locked diode-pumped Yb:YAG laser in which the transverse mode is passively stabilized. The mode-locking scheme can be used for various diode-pumped Yb-doped bulk lasers. The pulse duration is as short as 100 fs, which is to our knowledge the shortest pulse ever produced from an Yb:YAG laser. The center wavelength and laser output power are 1051 nm and 151 mW, respectively. [DOI : 10.1143/APEX.1.012007]

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Appl. Phys. Express Vol.1, No.1 (2008) 012008

Realization of All-fiber Tunable Filter and High Optical Power Blocker Using Thinned Fiber Bragg Gratings Coated with Carbon Nanotubes

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We propose and create a novel structure formed with thinned fiber Bragg gratings and carbon nanotubes utilizing their optical absorption characteristics. We show that the reflection band of the fiber Bragg gratings can be shifted by controlling the in-line optical power. We use the structure to realize two applications namely an all-fiber tunable filter and a high-optical-power blocker. [DOI : 10.1143/APEX.1.012008]

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Propagation of Terahertz Pulses on Coplanar Strip-lines on Low Permittivity Substrates and a Spectroscopy Application

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The authors have investigated the propagation characteristics of the terahertz electrical pulses on the coplanar strip-lines (CPSs) made on low permittivity substrates. By the use of a commercially available plastic whose permittivity is about 2.3 in 1–3 THz, the radiation loss could be made low, and the total attenuation of about 0.2 neper/mm was achieved at 1 THz. As a result, the spectra reaching 3 THz with a dynamic range of about 60 dB were realized even after the 1 mm propagation. Using the CPS device, a spectroscopy of biotin powder is demonstrated over a frequency range up to 2 THz. [DOI : 10.1143/APEX.1.012009]

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Tunneling Current–Voltage Characteristics of Graphene Field-Effect Transistor

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We develop an analytical device model for a graphene field-effect transistor. Using this model, we calculate its current–voltage characteristics at sufficiently high gate voltages when a n–p–n (p–n–p) lateral junction is formed in the transistor channel and the source–drain current is associated with the interband tunneling through this junction.
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Growth of Single-Walled Carbon Nanotubes from Ceramic Particles by Alcohol Chemical Vapor Deposition

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Al_2O_3 ceramic nano-particles, which were regarded as an inactive catalyst in the growth of carbon nanotubes in the past, have been prepared as the catalyst for single-walled carbon nanotube (SWCNT) growth using an alcohol chemical vapor deposition method. Dense SWCNTs have been successfully synthesized, indicating that Al_2O_3 serves as an efficient catalyst. Moreover, it was found that many SWCNTs were also grown from irregular large Al_2O_3 particles ranging from several tens of nanometers to hundreds of nanometers, which has never been observed in the case of metallic catalyst particles. These results give more insights into the role of catalyst in SWCNT growth.
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Behavior of Catalyst Particle at Tip of Carbon Nanotube during Field Emission

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A catalyst particle at the tip of a multi-walled carbon nanotube (MWNT) during field emission inside a transmission electron microscope was observed *in-situ*. The particle streamed from the tip like a liquid as the emission current abruptly increased from 20 to 40 μA. This was due to the temperature rise at the tip of the MWNT, resulting from the increased emission current and dipole moment in the particle caused by the electric field. Maintenance of this high emission current led to an electrical discharge, which severely damaged the MWNT electron emitter. Under high emission currents, in particular, the catalyst particle caused an unstable emission. [DOI : 10.1143/APEX.1.014002]

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Vapor–Liquid–Solid Growth of Small- and Uniform-Diameter Silicon Nanowires at Low Temperature from Si_2H_6

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We report 350 °C as a critical growth temperature for overcoming the aggregation of gold (Au) in the synthesis of high-density silicon nanowires (SiNWs) with controlled diameters in a vapor–liquid–solid (VLS) mechanism by the low-temperature decomposition of Si_2H_6. Low-temperature growth is considered essential for preserving the initial distribution of Au droplets (8±5 nm) during SiNW nucleation with small (12 nm) and uniform (±5 nm) diameters. Au–Si eutectics increase in size with aggregation at high temperatures, resulting in SiNWs with large and random diameters. The crystal quality, defect formation, and morphology of the wires, grown in the (111) direction, are size dependent.
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Highly Sensitive Detection of Carbon Monoxide at Room Temperature Using Platinum-Decorated Single-Walled Carbon Nanotubes

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We demonstrated highly sensitive detection of carbon monoxide (CO) down to 1 ppm at room temperature using platinum-decorated single-walled carbon nanotubes (Pt-SWNTs). The obtained sensitivity to CO was 3–4 orders higher than the values reported for functionalized SWNTs, and was achieved by the controlled deposition of Pt nanoparticles on SWNTs. For 1–10 ppm of CO, the sensor response linearly increased with CO concentration, affording the quantitative detection of CO in a low-concentration range. Furthermore, Pt-SWNTs exhibited detection selectivity to CO against H_2. The sensing mechanism was attributed to electron donation to the SWNTs as a result of CO oxidation on the Pt catalyst surface. [DOI : 10.1143/APEX.1.014004]

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Local Synthesis of Tungsten Oxide Nanowires by Current Heating of Designed Micropatterned Wires

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We locally synthesized tungsten oxide nanowires at predetermined positions by current heating of designed micropatterned wires. The current wires were fabricated from tungsten thin film and had two different widths in the same wire, and the narrower sections were heated more than the wider sections due to the difference in electric resistance. The temperature of the narrower sections was controlled to be optimal for nanowire synthesis in an O_2 atmosphere in a vacuum chamber. We demonstrated the synthesis of nanowires over an area of approximately $1\times1\,\mu m^2$ and successfully synthesized nanowires on a regular 20 by 20 array with narrow sections with 10 μm pitch.
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Development of 4H–SiC Epitaxial Growth Technique Achieving High Growth Rate and Large-Area Uniformity

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A vertical hot-wall epi-reactor that makes it possible to simultaneously achieve a high growth rate and large-area uniformity has been developed. A maximum growth rate of 250 μm/h is achieved with a mirror-like morphology at 1650 °C. Under a modified epi-reactor setup, a thickness uniformity of 1.1 % and a doping uniformity of 6.7 % for a 65-mm-radius area are achieved while maintaining a high growth rate of 79 μm/h. A low doping concentration of $\sim1\times10^{13}cm^{-3}$ is obtained for a 50-mm-radius area. The low-temperature photoluminescence (LTPL) spectrum shows the predominance of free exciton peaks with only few impurity-related peaks and the L_1 peak below detection limit. The deep level transient spectroscopy (DLTS) measurement for an epilayer grown at 80 μm/h shows low trap concentrations of $Z_{1/2}$: 1.2×10^{12} and $EH_{6/7}$: $6.3\times10^{11}cm^{-3}$. A 280-μm-thick epilayer with a RMS roughness of 0.2 nm and a carrier lifetime of $\sim1\,\mu s$ is obtained.
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High Mobility Titanium-Doped In_2O_3 Thin Films Prepared by Sputtering/Post-Annealing Technique

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High-electron-mobility Ti-doped In_2O_3 (ITiO) thin films were prepared on soda-lime glass substrates by rf magnetron sputtering followed by a post-annealing process. Both carrier concentration and electron mobility were considerably improved by annealing in a vacuum at 530 °C. A highest electron mobility of 105 $cm^2\,V^{-1}\,s^{-1}$ with a resistivity of $1.95\times10^{-4}\,\Omega$cm was obtained for an annealed ITiO thin film. The ITiO thin film exhibited an optical transmission of approximately 80 % at wavelengths ranging from 400 to 1800 nm. Post-annealing in a vacuum is one of the effective methods for improving the electrical properties of ITiO thin films without sacrificing optical transmission. [DOI : 10.1143/APEX.1.015002]

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Photoluminescence from Epitaxial Films of Perovskite-type Alkaline-earth Stannates

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The epitaxial films of the recently developed calcium and strontium stannates phosphors with perovskite or its related structure were fabricated by the pulsed-lased deposition method. The films were all highly transparent in the visible region, and showed intense luminescence of several colors under ultraviolet excitation. Light scattering at the substrates' surfaces varied the appearance of photoluminescence. In combination with epitaxial-film-growth technologies for many perovskite functional materials, the obtained results provide a promise for future developments of multifunctional optoelectronic devices.

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Exciton-derived Electron Emission from (001) Diamond *p*–*n* Junction Diodes with Negative Electron Affinity

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Electron emission current was observed from a hydrogen-terminated *n*-layer diamond surface of forward biased diamond *p*–*n* junction diodes, while there was no electron emission from the same surface after oxidization, suggesting that the phenomenon is related to negative electron affinity (NEA) of the hydrogen-terminated diamond surface. Since electrons in the *n*-layer flow toward to the *p*-layer due to forward bias, they cannot directly contribute to the emission current from the *n*-layer surface. In view of our previous result that the exciton-derived photoelectron emission was observed from the NEA diamond surface by total photoelectron yield spectroscopy, the phenomenon can be explained as electron emission due to exciton diffusion at the forward bias.

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Molecular Layer-by-Layer Growth of C_{60} Thin Films by Continuous-Wave Infrared Laser Deposition

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The observation of reflection high energy electron diffraction (RHEED) oscillations has been proved to be a key to open the nano-world of materials, since it definitely verifies that the film growth proceeds in layer-by-layer mode with each layer thickness controllable by simply counting the number of oscillations. This enabled the fabrication of nano-engineered hetero-junctions and devices as commonly practiced for conventional semiconductors and metals. Here we report on the first observation of clear RHEED intensity oscillation in thin film fabrication of a π-conjugated molecular solid. The observation has been achieved by coupling a novel deposition method using a continuous-wave infrared laser for evaporation and a high sensitive RHEED detector, in addition to the combinatorial optimization of film deposition parameters that facilitated our preceding first success in the layer-by-layer growth of oxide thin films. Some details of system design and experimental conditions are presented to discuss the key factors for atomically controlled film growth of molecular solids. [DOI : 10.1143/APEX.1.015005]

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Selective-Area Growth of GaN Nanocolumns on Si(111) Substrates Using Nitrided Al Nanopatterns by RF-Plasma-Assisted Molecular-Beam Epitaxy

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The selective-area growth of GaN nanocolumns using predeposited Al nanopatterns (a 300-nm-period triangular lattice of 85-nm-diameter Al nanodots) on Si(111) substrates by rf-plasma-assisted molecular-beam epitaxy (rf-MBE) was demonstrated. GaN nanocolumns were grown at the edge of each nitrided Al dot after nitridation, forming a nanotubular structure in the growth temperature range from 941 to 966°C. The size fluctuation of the sidewall thickness in the nanotubular structure was less than that of the diameters of nanocolumns grown on the Si surface outside the nitrided Al nanopatterns. At a high growth temperature of 966°C, nanocolumn growth on the Si surface was completely suppressed. [DOI : 10.1143/APEX.1.015006]

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Thermal Stability of Giant Thermoelectric Seebeck Coefficient for $SrTiO_3/SrTi_{0.8}Nb_{0.2}O_3$ Superlattices at 900 K

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Herein we report the carrier transport properties of $[(SrTiO_3)_x/(SrTi_{0.8}Nb_{0.2}O_3)_1]_{20}$ (x=0–50) superlattices at high temperatures (T=300–900 K). Significant structural changes were not observed in the superlattices after annealing at 900 K in a vacuum. The Seebeck coefficient of the $[(SrTiO_3)_{20}/(SrTi_{0.8}Nb_{0.2}O_3)_1]_{20}$ superlattice, which was 300 $\mu V \cdot K^{-1}$ at room temperature, gradually increased with temperature and reached 450 $\mu V \cdot K^{-1}$ at 900 K, which is ~3 times larger than that of bulk $SrTi_{0.8}Nb_{0.2}O_3$. These observations provide clear evidence that the superlattice is stable and exhibits a giant Seebeck coefficient even at high temperature. [DOI : 10.1143/APEX.1.015007]

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Study on Injection Efficiency in InGaN/GaN Multiple Quantum Wells Blue Light Emitting Diodes

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The dependence of the electrical efficiency on the injection current was studied in detail in InGaN/GaN multiple quantum wells (MQWs) blue light emitting diodes. When the InGaN quantum well thickness increased from 2 to 3.5 nm, or the Al component in p-AlGaN changed from 0.1 to 0.2, it was found that the electrical efficiency decreased dramatically, while a thin Mg-doped GaN layer inserted between p-AlGaN and MQWs with optimized Mg concentration can enhance the electrical efficiency effectively. Analysis shows that the injection efficiency was dramatically affected by the interface states due to the strong stress at the interface between p-AlGaN blocking layer and MQWs active region and the capability of electrons arriving at the interface.
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Appl. Phys. Express Vol.1, No.2 (2008) 021102

Improvement of Al-Polar AlN Layer Quality by Three-Stage Flow-Modulation Metalorganic Chemical Vapor Deposition

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Improvement of Al-polar AlN layer quality was accomplished by three-stage flow-modulation metalorganic chemical vapor deposition (FM-MOCVD). In this method, the unit of the FM-MOCVD sequence was composed of three stages; Stage I for simultaneous source supply, Stage II for trimethylaluminum supply, and Stage III for ammonia supply, which were cyclically repeated. The AlN quality revealed by X-ray diffraction strongly depended on the time of Stage I. A growth model was proposed considering the surface coverage of the islands nucleated during Stage I. Exciton fine structures were eventually observed by low-temperature cathodoluminescence reflecting the tremendously improved crystalline quality. [DOI : 10.1143/APEX.1.021102]

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AlGaN/GaN Heterostructure Field-Effect Transistors on 4H-SiC Substrates with Current-Gain Cutoff Frequency of 190 GHz

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We report on state-of-the-art AlGaN/GaN heterostructure field-effect transistor (HFET) technology in the scope of millimeter-wave applications. 60-nm-long-gate HFETs having 4- and 6-nm-thick $Al_{0.4}Ga_{0.6}N$ barrier layers and SiN passivation layers formed by catalytic chemical vapor deposition (Cat-CVD) were fabricated on 4H-SiC substrates. Both structures had low sheet resistances of 200–220 Ω/sq that were due to not only high mobilities of 1900–2000 $cm^2/(V \cdot s)$ but also high electron densities of (1.4–1.7)×10^{13} cm^{-2}, which were provided by the high-Al-composition barrier layers and the Cat-CVD SiN. The devices with the 4- and 6-nm-thick barriers had maximum drain current densities of 1.4 and 1.6 A/mm and peak extrinsic transconductances of 448 and 424 mS/mm, respectively. Maximum f_T and f_{max} reached 190 and 251 GHz, respectively. [DOI : 10.1143/APEX.1.021103]

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GaN-Based Trench Gate Metal Oxide Semiconductor Field-Effect Transistor Fabricated with Novel Wet Etching

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A novel method for fabricating trench structures on GaN was developed. A smooth non-polar $(1\bar{1}00)$ plane was obtained by wet etching using tetramethylammonium hydroxide (TMAH) as the etchant. A U-shape trench with the $(1\bar{1}00)$ plane side walls was formed with dry etching and the TMAH wet etching. A U-shape trench gate metal oxide semiconductor field-effect transistor (MOSFET) was also fabricated using the novel etching technology. This device has the excellent normally-off operation of drain current–gate voltage characteristics with the threshold voltage of 10 V. The drain breakdown voltage of 180 V was obtained. The results indicate that the trench gate structure can be applied to GaN-based transistors. [DOI : 10.1143/APEX.1.021104]

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Appl. Phys. Express Vol.1, No.2 (2008) 021201

Epitaxial Lift-Off of InGaAs/InAlAs Metamorphic High Electron Mobility Heterostructures and Their van der Waals Bonding on AlN Ceramic Substrates

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We have carried out epitaxial lift-off (ELO) of $In_{0.57}Ga_{0.43}As/In_{0.56}Al_{0.44}As$ metamorphic high electron mobility heterostructures and their van der Waals bonding (VWB) on AlN ceramic substrates. Using a metamorphic heterostructure with an AlAs sacrificial layer and an InGaAs graded buffer grown on GaAs(001), thin film Hall-bar devices on AlN ceramic substrates were successfully fabricated by ELO and VWB. The Hall-bar devices exhibit very high electron mobilities, such as 11000 $cm^2/(Vs)$ at room temperature (RT) and 84000 $cm^2/(Vs)$ at 12 K. The RT mobility is the highest ever reported for ELO devices. This is the first report on ELO for metamorphic devices.
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Tunnel Magnetoresistance Effect in Magnetic Tunnel Junctions Using a $Co_2MnSi(110)$ Electrode

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Magnetic tunnel junctions (MTJs) with half-metallic electrodes are expected to show a large tunnel magnetoresistance (TMR) ratio, according to Julliere's model. A Co_2MnSi Heusler alloy is theoretically expected to possess a half-metallic electronic state. Experimentally, at low temperature, $Co_2MnSi(100)$/Al-oxide/CoFe junctions exhibited a large TMR ratio. We fabricated MTJs with high-quality (110)-oriented Co_2MnSi electrodes and investigated the TMR effects. We obtained a TMR ratio of about 40 % at room temperature and 120 % at 2 K, respectively. However, we observed degradation of the energy gap of Co_2MnSi in the minority spin band from the conductance–voltage characteristics. We infer that the interface of $Co_2MnSi(110)$ possesses no half-metallic property. [DOI : 10.1143/APEX.1.021301]

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Enhanced Interlayer Coupling and Magnetoresistance Ratio in $Fe_3Si/FeSi_2$ Superlattices

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$[Fe_3Si/FeSi_2]_{20}$ superlattices were prepared on Si(111) at an elevated substrate temperature of 300 °C, and the magnetoresistance ratio and interlayer coupling strengths were enhanced by approximately 100 and 34 %, respectively, as compared to those of superlattices deposited at room temperature. While the elevated substrate temperature degraded the interface sharpness, the crystalline orientation and the crystallinity of the Fe_3Si layers were apparently enhanced. The latters strongly influence on the interlayer coupling and the magnetoresistance ratio. This implies that quantum well states are tightly formed under the well-ordered crystalline planes, and the spin diffusion lengths are improved due to the enhanced crystallinity. [DOI : 10.1143/APEX.1.021302]

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Quantitative Evaluation of Silicon Displacement Induced by Arsenic Implantation Using Silicon Isotope Superlattices

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We established a new method for evaluating quantitatively the silicon atomic displacement as a function of the depth from the surface induced by arsenic implantation into a silicon wafer. A simulation based on a convolution integral was developed successfully to reproduce the experimental depth profiles of isotopes in the arsenic-implanted $^{28}Si/^{30}Si$ isotope superlattices, from which the average distance of the silicon displacements due to the collisions with implanted arsenic is obtained. We show that it takes the average displacement of ~0.5 nm to make the structure appear amorphous by transmission electron microscopy.

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Room-temperature Transport Properties of High Drift Mobility Two-dimensional Electron Gas Confined in a Strained Si Quantum Well

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The drift mobility, carrier density and conductivity of the two-dimensional electron gas (2DEG) confined in the tensilely strained 15 nm Si quantum well (QW) of SiGe heterostructures were obtained by mobility spectrum analysis at room-temperature. The highest 2DEG drift mobility of 2900 $cm^2\ V^{-1}s^{-1}$ with carrier density of $1\times10^{11} cm^{-2}$ were observed in the Si QW with -0.9 % tensile strain. However, the increase of strain up to -1.08 % resulted in the decline of 2DEG drift mobility down to 2670 $cm^2,V^{-1}s^{-1}$ and the pronounced increase of carrier density up to $4.4\times10^{11} cm^{-2}$. Nevertheless, the pronounced enhancement of 2DEG conductivity was observed. [DOI : 10.1143/APEX.1.021402]

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Improved Room-Temperature 1.6 μm Electroluminescence from *p*-Si/β-$FeSi_2$/*n*-Si Double Heterostructures Light-Emitting Diodes

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We have epitaxially grown *p*-Si/β-$FeSi_2$/*n*-Si double heterostructures light-emitting diodes (LEDs) on Si(111) substrates by molecular-beam epitaxy. The 1.6 μm electroluminescence intensity measured at room temperature (RT) was improved significantly for LEDs constructed using a thick β-$FeSi_2$ active layer (190 nm) embedded in heavily-doped Si *p*–*n* diodes formed on floating-zone Si(111) substrates. The external quantum efficiency was increased up to approximately 0.02 % at RT.

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Un-stability of Sputtered $Ge_2Sb_2Te_5$ Films in Electrical Phase Changes

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Microscopic structures of amorphous $Ge_2Sb_2Te_5$ films, electrically phase-changed using co-planar electrodes, have been studied through electrical and structural investigations. Microscope images show a structured phase-change region consisting of a narrow channel, banks on both sides, and rough peripheral regions. The room-temperature resistivity is ~$10^{-3}\Omega$·cm, which has a metallic temperature dependence. Micro-Raman scattering spectra at the channel and the bank exhibit peaks due to crystalline Te and tellurides. X-ray diffraction patterns from the films, which contain many channels, present crystalline peaks ascribable to cubic GeTe and other compounds. These observations suggest that the $Ge_2Sb_2Te_5$ melt is liable to phase-separate under electrical self-heating. [DOI : 10.1143/APEX.1.021501]

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Appl. Phys. Express Vol.1, No.2 (2008) 021701

Improvement of Superconductive Properties of Mesoscopic Nb Wires by Ti Passivation Layers

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We have investigated superconductive properties of nano-scale Nb wires fabricated by a simple lift-off process with magnetron sputtering. The superconductive properties of the Nb wires were remarkably improved by employing highly plasma resistant electron-beam resist ZEP520A combined with a thin Ti passivation layer. This optimized fabrication process yielded a 300-nm-wide Nb wire with the same transition temperature as that of the reference Nb film. Thereby, a highly transparent Nb/Cu junction was successfully fabricated.

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MgB_2 Thin Films Fabricated by a Precursor and Post-annealing Method Have a High J_c in High Magnetic Fields

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The critical current densities (J_c) of MgB_2 thin films deposited on α-Al_2O_3 fabricated by a precursor and post-annealing process have been investigated in high magnetic fields of up to 30T. J_c values of 2.8×10^5, 3.0×10^4, and 3.7×10^3A/cm^2 were obtained at 4.2K in external magnetic fields of 10, 20, and 26T respectively, applied parallel to the film surface. These values were comparable to those seen for Nb_3Sn in fields up to 18T, and surpassed them in fields over 18T. The superconducting transition temperature was T_c^{onset}=29.6K and T_c^{zero}=28.5K. Grain connectivity was estimated to be 38.4%. The $H_{c2}(0)$ estimated from the resistivity measurements was 45T. Transmission electron microscope (TEM) observations of the microstructures suggested that grains 10–20nm in size exist that show no epitaxial growth relationship to the sapphire substrate. J_c enhancements in fields up to ~26T are due to the strong grain boundary pinning associated with the small grains and the small size of MgO precipitates. [DOI : 10.1143/APEX.1.021702]

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Characterization of Depletion Layer using Photoluminescence Technique

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The depletion layer formed at the interface of aluminum (Al) with poly(3-hexylthiophene-2, 5-diyl) (P3HT) has been studied, using the bias dependent photoluminescence (PL) spectra in indium tin oxide (ITO)/P3HT/Al sandwiched cells. A quenching in the PL intensity has been observed under the reverse bias conditions, which has been attributed to the increase in the depletion layer width. A direct relationship between the depletion layer width and the PL quenching has been derived and explained. [DOI : 10.1143/APEX.1.021801]

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Improvement of Hole Mobility in Organic Field-Effect Transistors Based on Octyl-substituted Oligo-*p*-phenylenevinylene by Thermal Treatment at Smectic Liquid Crystalline Phase

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Organic field-effect transistors based on octyl-subustituted oligo-*p*-phenylenevinylene have been studied. We have succeeded in improving field-effect hole mobilities by thermal treatment at liquid crystalline phase characterized as a highly ordered smectic phase. The field-effect mobility of the device as vacuum-evaporated was calculated to be 6.9×10^{-3}cm^2 V^{-1} s^{-1} whereas the mobility was enhanced to 1.7×10^{-1}cm^2 V^{-1} s^{-1} after annealing the device at 100°C for 12h. From the surface morphology of the films observed by using atomic force microscope, the enhancement is found to be attributed to reduction of defect density in the film because of the thermal movement of liquid-crystal molecules. [DOI : 10.1143/APEX.1.021802]

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Complementary Two-input NAND Gates with Low-voltage-operating Organic Transistors on Plastic Substrates

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We fabricated two-input NAND gates composed of p-channel pentacene and n-channel C_{60} transistors. The logic devices were prepared on flexible polymer substrates through a shadow mask process. Correct NAND logic functionality was demonstrated at a wide voltage range of 2–7V. From voltage transfer characteristics of the NAND gates, we obtained impressive signal gains up to 120 and large noise margins in the given voltage range. [DOI : 10.1143/APEX.1.021803]

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Appl. Phys. Express Vol.1, No.2 (2008) 021804

Whitening of Polymer Light-Emitting Diodes by Dispersing Vapor of an Orange Fluorescent Dye into a Blue-Emitting Polymer Film

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(Received December 28, 2007; accepted January 11, 2008; published online February 1, 2008)

Whitening of polymer light-emitting diodes (PLEDs) based on the blue-emitting poly(9,9-dioctylfluorene) (PDOF) films was possible by dispersing vapor of an orange fluorescent dye 4-(dicyanomethylene)-2-methyl-6-(4-dimethylaminostyryl)-4*H*-pyran (DCM) into the film by means of the solution-free vapor transportation method (VTM). Devices prepared with this method showed good color stability with bias voltage increase, while those formed with conventional spin-coating, where dyes and polymers were mixed in a solution (solution-mixed), showed color change from yellow to white-yellow. The maximum luminance of the PLED formed by the VTM was higher than that formed by conventional spin-coating process. [DOI : 10.1143/APEX.1.021804]

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Appl. Phys. Express Vol.1, No.2 (2008) 021805

Highly Efficient Phosphorescent Organic Light-Emitting Diodes Using Alkyl-Substituted Iridium Complexes as a Solution-Processible Host Material

Toshimitsu Tsuzuki* and Shizuo Tokito
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We fabricated highly efficient organic light-emitting diodes (OLEDs) using the solution processible iridium complexes which have long alkyl or cycloalkyl substituents in an ancillary ligand as a host material and a red phosphorescent iridium complex as an emitting guest by spin coating method. The OLEDs emitted red phosphorescence from the guest and the luminance reached around 10,000 cd/m^2. The efficiency of the OLED improved after we added an electron transport material (ETM) to the emitting layer. The OLED using a mixture of the alkyl substituted iridium complex and ETM as the host showed an external quantum efficiency of 10 %. [DOI : 10.1143/APEX.1.021805]

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Waveguide-Integrated Si Nano-Photodiode with Surface-Plasmon Antenna and its Application to On-chip Optical Clock Distribution

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We developed a waveguide-integrated Si nano-photodiode (PD) with a surface plasmon (SP) antenna for on-chip optical clock distribution. The interfacial periodic nano-scale metal–semiconductor–metal Schottky electrodes were shown to function as an SP optical antenna and also as an optical coupler between a SiON waveguide and a very thin Si-absorption layer. Furthermore, a very high speed response of 17 ps as well as enhanced photoresponsivity was achieved for a 10-μm coupling length. By using this technology, we fabricated a prototype of a large-scale-integration (LSI) on-chip optical clock system and demonstrated 5 GHz of optical clock circuit operation connected with a 4-branching H-tree structure. [DOI : 10.1143/APEX.1.022001]

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Appl. Phys. Express Vol.1, No.2 (2008) 022002

Semiconductor Waveguide Optical Isolator Incorporating Ferromagnetic Epitaxial MnSb for High Temperature Operation

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(Received November 26, 2007; accepted December 9, 2007; published online January 25, 2008)

A 1.5-μm nonreciprocal-loss waveguide optical isolator having improved transverse-magnetic-mode (TM-mode) isolation ratio was developed. The device consisted of an InGaAlAs/InP semiconductor optical amplifier waveguide covered with a ferromagnetic epitaxial MnSb layer. Because of the high Curie temperature (T_c = 314 °C) and strong magneto-optical effect of MnSb, the nonreciprocal propagation of 11–12 dB/mm has been obtained at least up to 70 °C.
[DOI : 10.1143/APEX.1.022002]

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Appl. Phys. Express Vol.1, No.2 (2008) 022003

New Precise Fabrication Technology for Lenticular Lens Sheet with Black Stripe Patterns by Using Photo-Sensitive Material with Surface Modifier

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(Received December 6, 2007; accepted December 22, 2007; published online January 25, 2008)

We have developed a new precise fabrication technology of a lenticular lens sheet with black stripe patterns for a rear-projection television. The black stripe patterns have to be accurately aligned to cylindrical lenses on the lenticular lens sheet and be able to absorb ambient light. Our proposed technology utilized a photo-sensitive material with a surface modifier which controls surface free energy for surface modification. Using this material, we could obtain two patterned areas which had different surface free energies. Furthermore, fabrication of black stripe patterns on the lenticular lens sheet was carried out by a self-alignment method. This lenticular lens sheet with black stripe patterns had similar optical properties compared with a conventional one.
[DOI : 10.1143/APEX.1.022003]

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Appl. Phys. Express Vol.1, No.2 (2008) 022004

Single-Mode Vertical-Cavity Surface-Emitting Lasers with a Deep-Etched Half-Ring-Shaped Holey Structure

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A single-mode oxide-confined vertical-cavity surface-emitting laser (VCSEL) with deeply-etched half-ring-shaped holey structure for fiber-optic applications is demonstrated. Single fundamental mode continuous-wave output power of 2.6 mW has been achieved in the 850 nm range, with a threshold current of approximately 1 mA. Side-mode suppression ratio (SMSR) larger than 26 dB has been measured. Contrary to the previously reported surface relief methods, the deep-etched (approximately 2.2 μm in depth) holey structure in this paper provides another approach to achieve single-mode operation of the VCSEL with a larger oxide aperture. [DOI : 10.1143/APEX.1.022004]

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Appl. Phys. Express Vol.1, No.2 (2008) 022005

Generation of Periodic Sawtooth Optical Intensity by Phase-Shifting Mask

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A new simple interference exposure method using a phase-shifting mask was discussed on the basis of Fourier synthesis for fabricating blazed gratings. Phase-shifting mask was designed with 244 nm exposure-light wavelength to launch multiple diffraction beams so that resultant interference pattern fit to required optical intensity profile. Fine surface-relief pattern on SiO_2 mask for 3-μm-period sawtooth optical-intensity profile was fabricated by electron-beam direct-writing lithography with 30 nm scanning step and relief height of 65 nm. Sawtooth-like intensity profile was demonstrated with theoretically predicted interference visibility. [DOI : 10.1143/APEX.1.022005]

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Appl. Phys. Express Vol.1, No.2 (2008) 022006

Three-Dimensional Profiling of Refractive Index Distribution inside Transparent Materials by Use of Nonresonant Four-Wave Mixing Microscopy

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We propose that four-wave mixing (FWM) microscopy can be applied to three-dimensional mapping of refractive index (RI) structure inside transparent samples. We derive an analytical relationship between the RI and the intensity of the FWM signal that is due to nonresonant optical nonlinearity. By using the relationship, the RI profile can be directly and quantitatively obtained from the intensity distribution of the FWM signal. We experimentally demonstrate the RI profiling of a phase grating fabricated in a non-alkali glass.
[DOI : 10.1143/APEX.1.022006]

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Appl. Phys. Express Vol.1, No.2 (2008) 022007

Generation of High Efficiency 2μm Laser Pulse from a Periodically Poled 5mol% MgO-Doped $LiNbO_3$ Optical Parametric Oscillator

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We report on an optical parametric oscillator (OPO) based on a large aperture periodically poled 5mol% MgO-doped $LiNbO_3$ (PPMgLN). A high average power Q-switched Nd:YAG laser operating at 1.064μm producing 10ns pulses at a repetition rate of 10Hz was used to pump the OPO. Total output pulse energy of 126mJ at 2μm with 62% slope efficiency was achieved at relatively low pump power intensity. Temperature tuning behavior of the quasi-phase matched OPO was also observed. [DOI : 10.1143/APEX.1.022007]

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Appl. Phys. Express Vol.1, No.2 (2008) 022008

Cylindrical Vector Laser Beam Generated by the Use of a Photonic Crystal Mirror

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A concentrically patterned photonic crystal mirror with polarization selectivity fabricated by the autocloning technique was used for the generation of radially and azimuthally polarized beams from an Nd:YAG laser cavity. By adopting the photonic crystal mirror as the output coupler of the cavity, both radially and azimuthally polarized beams were obtained with similar output power as that of an unpolarized beam generated by a conventional, non-polarization-selective output coupler. [DOI : 10.1143/APEX.1.022008]

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Octave Spanning High Quality Super Continuum Generation Using 10nJ and 104fs High Energy Ultrashort Soliton Pulse

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Octave spanning high quality super continuum is generated in all fibre system. A 10nJ and 104fs high energy ultrashort soliton pulse is generated from 1ps fiber chirped pulse amplification laser using large mode area photonic crystal fibre. The conversion efficiency from 1ps pulse into ultrashort soliton pulse is 33%. A 1.05–2.20μm over one octave spanning high quality super continuum with ±5dB uniformity is generated using the high energy soliton pulse and highly nonlinear fiber. [DOI : 10.1143/APEX.1.022009]

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Nearly Temperature-Independent Saturation Drain Current in a Multi-Mesa-Channel AlGaN/GaN High Electron Mobility Transistor

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We fabricated a multi-mesa-channel (MMC) structure by forming a periodic trench just under a gate electrode to improve the uniformity of effective electric field in the channel in an AlGaN/GaN high electron mobility transistor (HEMT). A unique performance, i.e., a nearly temperature-independent saturation drain current, was observed in the MMC device in a wide temperature range. A two-dimensional (2D) potential calculation indicates that the mesa-side gate effectively modulates the potential, resulting in a field surrounding 2D electron gas. Such a surrounding-field effect and a relatively lower source access resistance may be related to a unique current behavior in the MMC HEMT. [DOI : 10.1143/APEX.1.023001]

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Coulomb Blockade Oscillations in Narrow Corrugated Graphite Ribbons

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We report Coulomb blockade oscillations in an atomically thin graphite ribbon fabricated by the micromechanical cleavage technique. Aperiodic current oscillations as a function of the gate voltage indicate the formation of multiple Coulomb islands inside the thin graphite ribbon. We conclude that the Coulomb islands originate from puddles of electrons and holes caused by the inhomogeneous interface between the ribbon and the substrate. [DOI : 10.1143/APEX.1.024001]

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Performance Estimation of Graphene Field-Effect Transistors Using Semiclassical Monte Carlo Simulation

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A semiclassical Monte Carlo simulation was run to estimate the performances of a monolayer and a bilayer (with vertical electric field of 1 V/nm applied) graphene-channel field-effect transistor (FET). The vertical field produces a band gap of 0.16 eV and gives semiconductive properties in the bilayer graphene. Electrons in monolayer graphene show a notable velocity overshoot of up to 7.6×10^7 cm/s. A sub-0.1 ps transit time is also expected in a 65-nm channel device. The performance of a bilayer graphene-channel FET is inferior to a monolayer graphene one, but comparable with that of an InP high electron mobility transistor (HEMT). This lower performance may be attributed to the electron effective mass produced by the vertical field. [DOI : 10.1143/APEX.1.024002]

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Electrostatic Imprint Process for Glass

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In usual thermal imprint process, mold patterns are transferred by applying mechanical pressures at elevated temperatures. We have developed a new imprint process for glass, which utilizes electrostatic force as a driving force for deformation. In the method, high dc voltage is applied between a mold and a glass specimen so that the mold becomes an anode. This method enables glass forming at lower temperatures with smaller mechanical force compared to usual thermal imprint process. In addition, this method is suitable for small patterns less than 1 μm. It is expected that this method realizes large-area and high-efficiency nanoforming process for glass. [DOI : 10.1143/APEX.1.024003]

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Nitrogen–Oxygen Complexes Associated with Shallow Thermal Donors in Silicon

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A structural model is described for the shallow thermal donors (STDs), which typically consist of seven identical absorption peaks that are caused by electronic transition. In the STD family, attention was paid to the 247 cm^{-1} peak that appears to strongly depend on the condition of both the crystal growth and the annealing. We examined NO configuration and the six kinds of NO+O_i configuration. Semi-empirical molecular orbital calculations for these complexes suggested that not only the complex with the C_{2v} symmetry but also the asymmetric NO+O_i complexes could simultaneously exist in the Si crystal. We concluded that the 247 cm^{-1} peak, which was highly unstable and behaved oddly during annealing, might be the NO complex and that the other six STD peaks might correspond to the six kinds of NO+O_i complexes.
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Point Spread Function for the Calculation of Acid Distribution in Chemically Amplified Resists for Extreme Ultraviolet Lithography

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The process simulator is a key technology in extreme ultraviolet (EUV) lithography, which is regarded as the ultimate in projection lithography. The requirement for the accuracy of process simulators has become increasingly strict with the shrinkage of feature size. In chemically amplified EUV resists, acid generators decompose through a reaction with thermalized electrons (~25 meV). This sensitization mechanism of EUV resists is analogous to that induced by an electron beam (EB). However, the acid distribution in EUV resists is different from that in EB resists because of the multispur effect, which is caused by the charged intermediates narrowly distributed around the absorption points of EUV photons. In this work, the authors formulate a proposed point spread function for the EUV lithography process based on chemically amplified resists. [DOI : 10.1143/APEX.1.027001]

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Hyper Rheology Measurement by Emission and Collision of Micro-Fluid Particles

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We introduce a system to measure the mechanical properties of fluids under high shear deformation rates of up to $10^6 s^{-1}$. The newly developed micro-fluid emission nozzle remarkably extended the variety of liquids to, for example, organic solvents, strong alkalis and acids, and viscous fluids. The dynamic behavior of a fluid after the head-on collision of the two emitted particles was observed by the stroboscopic method. The surface tension and viscosity were determined from the resonant frequency and decay constant of the resonant oscillation by comparison with numerical simulation. An approximate theory to describe the large-amplitude oscillation is also presented. [DOI : 10.1143/APEX.1.027002]

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Extremely Small Proximity Effect in 30 keV Electron Beam Drawing with Thin Calixarene Resist for 20 × 20 nm^2 Pitch Dot Arrays

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We studied proximity effect in 30 keV electron beam (EB) drawing with calixarene resist for patterned media and quantum devices. Using about 15-nm-thick calixarene resist on Si substrate in conventional EB drawing system, the proximity effect has been studied by forming and observing 20-, 25-, 30-, and 40-nm-pitch resist dot arrays and measuring exposure dosage intensity distribution (EID) function. As a result, the proximity effect is negligible small due to comparing with some dot sizes in center, side and corner of 2 μm square with 25×25 nm^2 pitch dot arrays. In addition, the proximity effect parameter η in EID function is less than 0.3. It is clear that the EB drawing and calixarene resist system is very suitable for forming ultrahigh packed dot arrays pattern. We demonstrated 20×20 nm^2 pitch resist dot arrays (about 1.6 Tb/in.^{2}) with a dot diameter of about 14 nm and the same size as everywhere in the pattern. [DOI : 10.1143/APEX.1.027003]

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Dependence of Acid Generation Efficiency on Molecular Structures of Acid Generators upon Exposure to Extreme Ultraviolet Radiation

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The trade-off between resolution, sensitivity, and line edge roughness (LER) is the most serious problem for the development of sub-30 nm resists based on chemical amplification. Because of this trade-off, the increase in acid generation efficiency is essentially required for high-resolution patterning with high sensitivity and low LER. In this study, we investigated the dependences of acid generation efficiency on the molecular structure and concentration of acid generators upon exposure to extreme ultraviolet (EUV) radiation. The acid generation efficiency (the number of acid molecules generated by a single EUV photon) was obtained within the acid generator concentration range of 0–30 wt % for five types of ionic and nonionic acid generators.
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Longitudinal and Transverse Coupling of the Beam Temperature Caused by the Laser Cooling of $^{24}Mg^{+}$

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A laser-cooling experiment of a 40 keV $^{24}Mg^{+}$ beam was carried out in the small laser-equipped storage ring (S-LSR). A laser co-propagating with the beam and an induction accelerator were utilized in the experiment. The lowest longitudinal temperature achieved in the present experiment was 3.6 K for 3×10^4 ions stored in the ring. It was found that the number of stored ions is related to the temperature at the final equilibrium state of the laser cooling. This relation shows that the longitudinal temperature of the laser-cooled beam linearly couples with the transverse one through intra-beam scattering.
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Synthesis and Thermoelectric Properties of Silicon Clathrates $Sr_8Al_xGa_{16-x}Si_{30}$ with the Type-I and Type-VIII Structures

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Nominal composition $Sr_8Al_xGa_{16-x}Si_{30}$ ($0 \leq x \leq 16$) samples were prepared by powder metallurgy. The samples with x=0–7 exhibited the type-I clathrate structure ($Pm\bar{3}n$, No.223), while the samples with x = 8–13 almost exhibited the type-VIII clathrate structure ($I\bar{4}3m$, No.217). These samples possessed the electrical conductivities and Seebeck coefficients typical of n-type degenerated semiconductors. The results on their thermoelectric properties indicate that the type-VIII SrAlGaSi clathrate would be a more efficient thermoelectric material than the type-I SrAlGaSi clathrate. For example, the type-VIII $Sr_8Al_9Ga_7Si_{30}$ sample had a maximum power factor of 11 $\mu W cm^{-1} K^{-2}$ at 1000 K and a room temperature Hall mobility of 24 $cm^2 V^{-1} s^{-1}$, while those of the type-I $Sr_8Al_6Ga_{10}Si_{30}$ sample were 7 $\mu W cm^{-1} K^{-2}$ and 5 $cm^2 V^{-1} s^{-1}$, respectively.
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Appl. Phys. Express Vol.1, No.3 (2008) 031301

Ferroelectric Polarization Reversal by a Magnetic Field in Multiferroic Y-type Hexaferrite $Ba_2Mg_2Fe_{12}O_{22}$

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Coexistence of the ferroelectric polarization and spontaneous magnetization has been found in Y-type hexaferrite $Ba_2Mg_2Fe_{12}O_{22}$. The reversal of magnetization by a small magnetic field below ~0.02 T accompanies an electric polarization reversal through the clamping of ferrimagnetic and ferroelectric domain walls. This behavior can be potentially used as a magnetically rewritable ferroelectric memory and an electrically rewritable magnetic memory.
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Appl. Phys. Express Vol.1, No.3 (2008) 031302

Determination of Penetration Depth of Transverse Spin Current in Ferromagnetic Metals by Spin Pumping

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(Received February 7, 2008; accepted February 21, 2008; published online March 14, 2008)

Spin pumping in nonmagnetic/ferromagnetic metal multilayers is studied both theoretically and experimentally. We show that the line widths of the ferromagnetic resonance (FMR) spectrum depend on the thickness of the ferromagnetic metal layers, which must not be in resonance with the oscillating magnetic field. We also show that the penetration depths of the transverse spin current in ferromagnetic metals can be determined by analyzing the line widths of their FMR spectra. The obtained penetration depths in NiFe, CoFe, and CoFeB were 3.7, 2.5, and 12.0 nm, respectively.
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Appl. Phys. Express Vol.1, No.3 (2008) 031501

Microcrystalline $Si_{1-x}Ge_x$ Solar Cells Exhibiting Enhanced Infrared Response with Reduced Absorber Thickness

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Thin film $p-i-n$ junction solar cells incorporating hydrogenated microcrystalline $Si_{1-x}Ge_x$ (μc-$Si_{1-x}Ge_x$:H) absorber i layers (1 μm) have been fabricated by plasma-enhanced chemical vapor deposition in the composition range of $0 \leq x \leq 0.35$. By increasing Ge content from x=0 to 0.15–0.2, short-circuit current density increases by ~5 mA/cm^2 with spectral sensitivities extending into the infrared wavelengths (>600 nm). However, solar cell parameters for larger Ge contents (x>0.2) are lowered by the increased charge carrier recombination in the μc-$Si_{1-x}Ge_x$:H i layer. As a result, a 6.3 % efficient solar cell is obtained at x=0.2, exhibiting infrared response even higher than that of double-thickness μc-Si:H solar cells. The solar cell shows excellent performance stability under prolonged light soaking. [DOI : 10.1143/APEX.1.031501]

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Rare-Earth-Dependent Magnetic Anisotropy in $REBa_2Cu_3O_y$

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We report magnetic anisotropies ($\Delta\chi$) depending on rare earth (RE) element in the paramagnetic $REBa_2Cu_3O_y$ (RE123) system as an important finding of magneto-scientific grain-orientation. The c-axis-oriented RE123 powder samples using static or rotating magnetic fields were fabricated at room temperature to clarify $\Delta\chi$. Their easy axes of magnetization were mainly dominated by second-order Stevens factors, whereas $|\Delta\chi|$ largely depended on y and RE elements. Especially for heavy RE elements, $|\Delta\chi|$ reached the order of 10^{-4}, indicating that appropriate choice of RE directly leads to a drastic reduction of required magnetic fields for grain-orientation of RE123. [DOI : 10.1143/APEX.1.031701]

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Time Resolution Improvement of Superconducting NbN Stripline Detectors for Time-of-Flight Mass Spectrometry

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We have applied superconducting stripline detectors (SSLDs) for time-of-flight mass spectrometry (TOF-MS) as molecule detectors. Two SSLDs, which consist of 7-nm-thick niobium nitride (NbN) striplines with different linewidths of 200 or 300 nm on a MgO substrate, were fabricated to investigate the effects of kinetic inductance on time resolution. We have observed ultrafast ion detection signals with risetimes of 360–640 ps, and successfully obtained mass spectra for a peptide, Angiotensin I, and a protein, bovine serum albumin (BSA) at an energy of 17.5 keV. It has been confirmed that the response time is governed by the kinetic inductance of the nano-striplines.
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Appl. Phys. Express Vol.1, No.3 (2008) 031703

Effect of c-Axis-Correlated Disorders on the Vortex Diagram of the Pinning State

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The introduction of the c-axis-correlated disorder is a promising technique for the improvement of the critical current density J_c for $B//c$ of $REBa_2Cu_3O_y$ (RE123) films and tapes. In order to understand the vortex pinning mechanism with the different variety of the c-axis-correlated disorder, the angular dependence of J_c was measured in detail for an Y123 film with $BaZrO_3$ nano-rods, a Sm123 film with fine nano-particles and edge dislocations and an Y123 film with columnar defects introduced by the heavy-ion irradiation parallel to the c-axis. We found that the vortex pinning state for the variety of the c-axis-correlated pinning is similar in low fields below the matching field, but it shows different behaviors in high fields above the matching field. It is considered that the interstitial vortices interacted with the c-axis-correlated disorders through the vortex interaction may play an important role for the appearance of the c-axis-correlated pinning behavior in a high-field region above the matching field. [DOI : 10.1143/APEX.1.031703]

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Appl. Phys. Express Vol.1, No.3 (2008) 032001

Reduction of Viewing-Angle Dependent Color Shift in a Reflective Type Cholesteric Liquid Crystal Color Filter

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The reflective type color filter for the liquid crystal displays (LCDs) was produced using cholesteric liquid crystal monomers whose phase is characterized by the unique optical features of *selective reflection*. Periodic micrometer scale hemi-spherical photoresist (PR) patterns were formed on glass substrates by thermal reflow method after photolithography. Cholesteric color filter films for red, green, and blue light reflections were then produced and the viewing angle dependence was investigated and compared with that of reflected light on the non-patterned substrates. Computer simulations using "*LightTools*" were also carried out, and it was confirmed that the color shifts were much smaller on the patterned substrates by bare eyes and Commission Internationale de'Eclairage (CIE) chromaticity coordination analysis qualitatively.
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Appl. Phys. Express Vol.1, No.3 (2008) 032002

Lowering Threshold by Energy Transfer between Two Dyes in Cholesteric Liquid Crystal Distributed Feedback Lasers

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Lowering lasing threshold based on the Förster-type energy transfer process has been studied in distributed feedback (DFB) lasers of cholesteric liquid crystals (CLCs) containing two dyes. We found that the lasing threshold in the energy transfer process was lowered to less than half of that in direct excitation processes. This effect is attributed to the suppression of self-absorption of a dye (acceptor). This provides a method for lowering threshold in CLC-DFB lasers containing multiple dyes particularly with a small Stokes shift. [DOI : 10.1143/APEX.1.032002]

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Second Harmonic Generation with High Conversion Efficiency and Wide Temperature Tolerance by Multi-Pass Scheme

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We proposed a multi-pass second harmonic generation scheme in which condensed fundamental light passed through a nonlinear crystal many times. The multi-pass scheme was realized by using a wide periodically-poled MgO:$LiNbO_3$, concave mirrors and condensing optics. The total wavelength conversion efficiency of the multi-pass scheme was increased because non-converted fundamental light which had passed through the nonlinear crystal was re-injected and condensed into the nonlinear crystal and converted. Moreover the total temperature tolerance of the multi passes was widened because the fundamental beam passes had different phase-matching temperature and compensated for miss conversions of other passes. In this work, continuous-wave 5 W green light (532 nm) with 66 % conversion efficiency and wide temperature tolerance were obtained. [DOI : 10.1143/APEX.1.032003]

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Appl. Phys. Express Vol.1, No.3 (2008) 032004

Green Photoluminescence from GaInN Photonic Crystals

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We have investigated green-emitting GaInN two-dimensional photonic crystals with air holes that penetrate through the active layer. At room temperature, the observed photoluminescence intensity from the photonic crystal is approximately three times that of a sample with no photonic crystal structure. This is due to the low surface recombination velocity (1.4×10^3 cm/s) of GaInN at the air hole edges and a higher degree of light extraction by the diffraction effect.
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Position-Controlled Si Nanocrystals in a SiO_2 Thin Film Using a Novel Amorphous Si Ultra-Thin-Film "Nanomask" due to a Bio-Nanoprocess for Low-Energy Ion Implantation

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A nano-size and position controlling technique of silicon-nanocrystal (Si-NC) assemblies in a SiO_2 thin film has been investigated by using low-energy ion implantation (0.6keV) through a novel amorphous silicon (a-Si) ultra-thin-film "nanomask". This a-Si nanomask was developed on the basis of a self-assembled bio-nanoprocess with proteins "ferritin". Si NCs were synthesized from the excess Si^+ ions implanted in a SiO_2 matrix by annealing with a Nd:YAG pulsed laser. As a result, almost ordered Si-NC assemblies with very small and uniform size (3.0±0.3nm) and inter-particle separation (5 to 6nm) were obtained by the transcription of the a-Si nanomask pattern. [DOI : 10.1143/APEX.1.034001]

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Carbon Nanotubes from a Divided Catalyst: the Carbon Transmission Method

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We have fabricated carbon nanotubes (CNTs) using a catalyzed growth technique that we call the carbon transmission method (CTM). We could control independently functions for carbon source gas supply and CNT growth by using a foil barrier (Ag) penetrated by pure Fe fibers. CNTs grew on one end of the Fe fibers, formed from diffused carbon that originates in carbon source gas at the other end of the fibers. Long CNTs with length over 100μm were obtained on the end of the Fe fibers in the carbon transmitted side. [DOI : 10.1143/APEX.1.034002]

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Optical and Conductive Characteristics of Metallic Single-Wall Carbon Nanotubes with Three Basic Colors; Cyan, Magenta, and Yellow

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We present protocols to prepare high-purity metallic single-wall carbon nanotubes (SWCNTs) with three basic colors, cyan, magenta, and yellow, through density gradient centrifugations. Addition of deoxycholate sodium salts as a co-surfactant could improve separation capability for metallic SWCNTs in centrifugations. We applied the improved separation protocols to the SWCNTs with different average diameters (1.34, 1.0, and 0.84nm), and obtained the metallic SWCNTs with cyan, magenta, and yellow colors. Their optical/conductive characteristics were revealed, and conductive color films were formed from the metallic SWCNTs. [DOI : 10.1143/APEX.1.034003]

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High-Quality Carbon Nanotube Growth at Low Temperature by Pulse-Excited Remote Plasma Chemical Vapor Deposition

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Carbon nanotube (CNT) growth at temperatures below 400°C by pulse-excited remote plasma chemical vapor deposition was demonstrated. Reduction of plasma power was carried out in order to decrease the amount of all particles, ions, electrons, and radicals. In addition, a biased plate-type screening electrode was introduced to removal of charged particles, ions, and electrons. The negative bias below 50V was most effective for growth rate. High-quality CNT growth with the growth rate of 98nm/min was successfully obtained at 400°C. The results suggest that both removal of charged particles and control of the amount of radicals are important for high-quality CNT growth at temperatures below 400°C. [DOI : 10.1143/APEX.1.034004]

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Real-Time Observation of Growth of Tungsten Oxide Nanowires with a Scanning Electron Microscope

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We observed the growth process of tungsten oxide nanowires in real-time with a field emission scanning electron microscope (SEM). The observation was performed by a new *in-situ* observation system designed to perform two functions: heating of tungsten film and local supply of O_2 gas. The nanowires grew after the nucleation on the surface. Their length extended with time keeping the direction constant. The growth rate decreased with exponential. [DOI : 10.1143/APEX.1.034005]

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Appl. Phys. Express Vol.1, No.3 (2008) 034006

Adsorption Properties of a Gold-Binding Peptide Assessed by its Attachment to a Recombinant Apoferritin Molecule

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The adsorption properties of a recombinant apoferritin protein fused to a gold-binding peptide were characterized. The results of quartz crystal microbalance measurements showed that the fusion protein preferentially adsorbs to gold surfaces. Scanning electron microscopy also revealed that the protein selectively adsorbed onto a nanometer-scale gold pattern on a SiO_2 surface fabricated by electron-beam lithography. Our results indicate that nanodots and nanowires synthesized using a biotemplate can be selectively placed onto a gold surface by genetically modifying the outer surface of the biotemplate. This technique represents an important step toward biotemplate-mediated fabrication of a nanometer-scaled device that utilizes gold electrodes.
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Appl. Phys. Express Vol.1, No.3 (2008) 034007

Inter-Layer Screening Length to Electric Field in Thin Graphite Film

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Electric conduction in thin graphite film was tuned by two gate electrodes to clarify how the gate electric field induces electric carriers in thin graphite. The graphite was sandwiched between two gate electrodes arranged in a top and bottom gate configuration. A scan of the top gate voltage generates a resistance peak in ambiploar response. The ambipolar peak is shifted by the bottom gate voltage, where the shift rate depends on the graphite thickness. The thickness-dependent peak shift was clarified in terms of the inter-layer screening length to the electric field in the double-gated graphite film. The screening length of 1.2 nm was experimentally obtained. [DOI : 10.1143/APEX.1.034007]

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A Heterojunction Photodiode Operating at Inorganic Nanosheet Interfaces

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A heterojunction photodiode was fabricated by forming two contact regions on a glass substrate: one side was a cast film of perovskite-type niobate [$(CH_3)_3NHSr_2Nb_3O_{10}$] as a n-type photosemiconductor and the other side a cast film of Zn-saponite ($Na_{0.96}[Si_{7.18}Al_{0.64}]Zn_{6.20}O_{20}(OH)_2$) as a p-type semiconductor under oxygen atmosphere. Diode-type current–voltage characteristics were obtained under the illumination of light (340 nm) and oxygen atmosphere (1 atm) at 25–100 °C. The interfacial structure was studied by means of focused ion-beam and transmission electron microscopy techniques, confirming the contact of the two different nanosheets on a nanometer scale. The results are discussed on the basis of the nanosheet band structures.
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Appl. Phys. Express Vol.1, No.3 (2008) 035002

Influence of Substrates on Initial Growth of Diamond-Like Carbon Films

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We investigated the influence of substrate materials on bonding structure of diamond-like carbon (DLC) films, fabricated by filtered cathodic vacuum arc, by using X-ray photoelectron spectroscopy and secondary ion mass spectroscopy. Two kinds of substrate materials, Si and NiFe, were evaluated. The results showed that sp^3 ratio of DLC films on NiFe was lower than that on Si by approximately 10%, and implies that the diffusion of Ne and Fe into DLC films inhibits sp^3 bonding formation. [DOI : 10.1143/APEX.1.035002]

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Near-Surface Defects in Boron-Doped Diamond Schottky Diodes Studied From Capacitance Transients

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Transient capacitance spectroscopy of deep energy levels (DLTS) in the band gap of boron-doped homoepitaxial diamond displays two types of defect when temperature is raised from 250 to 650K. The first trap is a strongly attractive center for holes while the second one is repulsive, with respective activation energies of 1.57 and 1.15eV. Concentration profile is non-monotonic for the first trap and changes when the diode undergoes repetitive temperature cycles. Analysis of all the data shows that the deep centers found in this study come from structural defects, eventually associated with a charged impurity.
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Nitrogen Gas Flow Driven Unintentional Incorporation of Al during the Growth of Dilute Nitride Semiconductor by Plasma-Assisted Molecular Beam Epitaxy

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We report the unintentional incorporation of Al during the growth of molecular beam epitaxy using RF plasma source, driven by N_2 gas flow. The concentrations of N, Al, O, and C within GaNAs/GaAs/AlAs structure are investigated by secondary ion mass spectrometry. In spite of the closed shutter of Al cell, we observe Al incorporation with a concentration up to $1\times10^{18}cm^{-3}$ in GaNAs layer and characteristically in the bottom side GaAs. Its concentration is solely dependent on N_2 gas flow rate. Remarkably, the operation of the RF plasma has no impact on that. C and O show their concentrations corresponding to the extrinsic Al. The complex interactions between those elements predict a possible origin of material deteriorations and difficulty for the precise doping control.
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Difference in Reaction Schemes in Photolysis of Triphenylsulfonium Salts between 248nm and Dry/Wet 193nm Resists

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Chemically amplified (CA) resists are important in the semiconductor industry because of their high orders of magnitude of sensitivity enhancement. The key components of CA resists are a polymer with an acid labile group and a photoacid generator (PAG) that produces an acid upon exposure to radiation. Although the photolysis of PAGs has been intensively studied, the difference in reaction schemes between 248 and 193nm resists had not been clarified. In this work, we have focused on the reaction of $Ph_2S^{\bullet+}$, which is one of the major intermediates in the photolysis of triphenylsulfonium triflate. It was revealed that the difference in reaction schemes between 248 and 193nm resists is caused by the ion molecular reactions of a polymer radical cation produced by electron transfer from the polymer to $Ph_2S^{\bullet+}$.
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Correlation Imaging of Magnetic Recorded Patterns and Grain Structures of Perpendicular Magnetic-Recording Media

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An observation technique to image polycrystalline and magnetic structures at the same sub-micron area of perpendicular magnetic-recording media has been developed. The granular grain structures and magnetically recorded bit patterns were imaged by transmission electron microscopy and magnetic force microscopy, respectively. The small guide marks fabricated on a disk sample with a focused ion beam apparatus were used for aligning the images with each other. By applying this technique to analyze the magnetically recorded CoCrPtSiO thin film layers of a hard disk medium, the correlation between the positions of the clustered grains and the percolation of the magnetic bit patterns could be discussed. [DOI : 10.1143/APEX.1.037001]

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New Technique of Manipulating a Protein Crystal Using Adhesive Material

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We have developed Crystal Catcher, a new device for manipulating protein crystals. Crystal Catcher directly captures a crystal with an adhesive. The easy and stable removal of a protein crystal from a drop has been achieved using the Crystal Catcher. The crystal picked up on the Crystal Catcher is positioned in the cryostream on a goniometer and flash-cooled. Various protein crystals can be captured and mounted without causing significant damage. This new approach will replace nylon loops for picking up protein crystals.
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Enhanced Transfection Efficiency in Laser-Induced Stress Wave-Assisted Gene Transfer at Low Laser Fluence by Increasing Pressure Impulse

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To improve transfection efficiency in gene delivery based on nanosecond pulsed laser-induced stress waves, we examined different types of transparent materials, a poly(ethylene terephthalate) sheet, poly(vinyl alcohol) gel, and water, which were placed on a laser target for plasma confinement. We found that the use of water was most effective for maintaining a large pressure impulse during multipulse laser irradiation and, as a result, high transfection efficiency was demonstrated in rat skin *in vivo* at a relatively low laser fluence of 0.7 J/cm^2. At this fluence, steady laser transmission through quartz fibers was confirmed, allowing endoscopic application of our gene delivery technique.
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Compositional Dependence of Nonpolar *m*-Plane $In_xGa_{1-x}N$/GaN Light Emitting Diodes

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Characteristics of *m*-plane InGaN/GaN light emitting diodes (LEDs) with various indium compositions were investigated. X-ray diffraction revealed that indium compositions in the InGaN multi quantum wells (MQWs) on *m*-plane substrate were 2–3 times lower than those on *c*-plane substrate. The optical polarization ratio for *m*-plane LEDs increased from 0.27 to 0.89 with increasing emission wavelength from 383 to 476 nm due to compressively strained InGaN QWs. The output power of electroluminescence decreased above 400 nm although polarization-related internal electric fields were eliminated.
[DOI : 10.1143/APEX.1.041101]

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Appl. Phys. Express Vol.1, No.4 (2008) 041102

Hydrogen Sensing Characteristics of a Pd/AlGaN/GaN Schottky Diode

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In this paper, the interesting hydrogen sensing properties of a Pd-gate AlGaN/GaN Schottky diode are investigated. A significantly low detection limit of 850 ppb H_2/air gas can be observed with increasing the temperature to 423 K. The experimental results indicate that hydrogen molecules cause great influences on the diode breakdown voltage. Also, the diode exhibits an ultrahigh sensing response of 2.04×10^5 at 423 K when exposure to a 9660 ppm H_2/air gas. The transient response time and reversibility of the studied device can be improved by increasing the operating temperature. [DOI : 10.1143/APEX.1.041102]

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Enhanced Conversion Efficiencies of Cu_2ZnSnS_4-Based Thin Film Solar Cells by Using Preferential Etching Technique

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Cu_2ZnSnS_4 (CZTS) thin film solar cells have been fabricated by co-sputtering technique using three targets of Cu, SnS, and ZnS. CZTS-based thin film solar cells over 6.7 % efficiency were obtained for the first time by soaking the CZTS layer on the Mo coated soda-lime glass substrate in deionized water (DIW) after forming the CZTS layer. It was found that DIW-soaking had the effect of preferential etching, which eliminated selectively metal oxide particles in the CZTS layer, by electron probe X-ray micro analysis. [DOI : 10.1143/APEX.1.041201]

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Enhancement-Mode ZnO Thin-Film Transistor Grown by Metalorganic Chemical Vapor Deposition

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We developed a method to control threshold voltage and on/off ratio of ZnO thin-film transistor (TFT) grown by metalorganic chemical vapor deposition (MOCVD). ZnO usually shows oxygen deficiency, which shows up as n-type defects of zinc interstitial or oxygen vacancy. In order to reduce these defects, we allowed sufficient oxidation time during growth. Instead of one long oxidation step, we repeated thin-layer growth and oxidation, until desired thickness is achieved. By using this method, we could obtain high quality ZnO TFT by MOCVD. Our ZnO TFT grown at 450 °C showed 15 $cm^2/(Vs)$ mobility and 10^7 on/off ratio, with +5 V threshold voltage, which enables enhancement mode TFT operation. [DOI : 10.1143/APEX.1.041202]

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Enhanced Temperature Characteristics of InGaAs/InAlGaAs Multi-Quantum-Well Lasers on Low-In-Content InGaAs Ternary Substrates

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Temperature characteristics of multi-quantum-well lasers on InGaAs ternary substrates are investigated. By using InAlGaAs barriers and low-In-content InGaAs substrates, the characteristic temperature of the laser can reach as high as 150 K between 25 and 85 °C due to the enhancement of the material gain. Calculated characteristic temperatures are in good agreement with those obtained by experiment, showing the validity of the results presented here. [DOI : 10.1143/APEX.1.041203]

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Appl. Phys. Express Vol.1, No.4 (2008) 041301

X-ray Magnetic Circular Dichroism and Photoemission Study of the Diluted Ferromagnetic Semiconductor $Zn_{1-x}Cr_xTe$

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We have performed X-ray magnetic circular dichroism (XMCD) and valence-band photoemission studies of the diluted ferromagnetic semiconductor $Zn_{1-x}Cr_xTe$. XMCD signals due to ferromagnetism and paramagnetism and/or superparamagnetism were observed at the Cr 2p absorption edge. Comparison with atomic multiplet calculations suggests that the magnetically active component of the Cr ion was divalent under the tetrahedral crystal field with tetragonal distortion along the crystalline *a*-, *b*-, and *c*-axes. In the valence-band spectra, spectral weight near the Fermi level was strongly suppressed, suggesting the importance of Jahn–Teller effect and the strong Coulomb interaction between the Cr 3d electrons. [DOI : 10.1143/APEX.1.041301]

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Spin-Transfer Switching and Thermal Stability in an FePt/Au/FePt Nanopillar Prepared by Alternate Monatomic Layer Deposition

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We fabricated a current-perpendicular-to-plane giant magnetoresistance (CPP-GMR) nanopillar with a 1-nm-thick FePt free layer having perpendicular anisotropy using the alternate monatomic layer deposition method. Nanopillars consisting of [Fe (1 monolayer (ML))/Pt (1 ML)]$_n$ (n: the number of the alternation period) ferromagnetic layers and an Au spacer layer showed spin-transfer induced switching at room temperature. An average critical switching current density (J_c0) of 1.1×10^7 A/cm^2 with a large thermal stability parameter (Δ) of 60 was obtained in a nanopillar with a free-layer thickness of 1.02 nm (n=3) and a pillar diameter of 110 nm. The ultrathin free-layer with high perpendicular anisotropy is effective to obtain both large Δ and small J_c.
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Reduction of Optical Loss in Hydrogenated Amorphous Silicon/Crystalline Silicon Heterojunction Solar Cells by High-Mobility Hydrogen-Doped In_2O_3 Transparent Conductive Oxide

Takashi Koida*, Hiroyuki Fujiwara, and Michio Kondo

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Hydrogen-doped In_2O_3 (IO:H) films with high electron mobility and improved near-infrared transparency have been applied as a transparent conducting oxide (TCO) electrode in hydrogenated amorphous silicon (a-Si:H)/crystalline silicon heterojunction solar cells. The incorporation of IO:H, instead of conventional Sn-doped In_2O_3, improved the short-circuit current density (J_{sc}) and the resulting conversion efficiency. Detailed optical analysis of the solar cells revealed that the improvement in J_{sc} is due to the reduction of reflection loss at the TCO/a-Si:H interface and less optical absorption in the TCO layer. [DOI : 10.1143/APEX.1.041501]

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Optically Controlled Bimorph Cantilever of Poly(vinylidene difluoride)

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Optically driven actuators are a non-contact method for the remote application of light energy. We propose a new optically driven actuator that employs bimorph poly(vinylidene difluoride) (PVDF) cantilevers. PVDF is an effective polymer from which to prepare actuators since it has both pyroelectric and piezoelectric properties. We have produced a bimorph cantilever from a PVDF film with a thin Ag electrode on one side. A bending model of the PVDF cantilever has been established and its bending characteristics have been experimentally measured. The mechanism can be explained by taking into consideration the model and its dielectric breakdown. [DOI : 10.1143/APEX.1.041601]

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Microstructure Analysis of Solid-State Reaction in Synthesis of $BaTiO_3$ Powder Using Transmission Electron Microscope

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The kinetics and mechanism of the solid-state reaction in $BaTiO_3$ powder synthesis were investigated microstructurally. An equimolar mixture of $BaCO_3$ and TiO_2 (rutile) powders calcinated at 600 and 800 °C in air was observed by using transmission electron microscopy (TEM). During the reaction, layered $BaTiO_3$ was formed over the TiO_2 particles with a structurally and compositionally sharp interface. The crystallographic orientation relationship between TiO_2 and $BaTiO_3$ was universally observed as $[001]_{TiO_2}//[1\bar{1}0]_{BTO}$, $(100)_{TiO_2}//(111)_{BTO}$. The perovskite phase $BaTiO_3$ was formed by inward diffusion of barium and oxygen ions into the rutile lattice, maintaining a topotaxial relationship with the rutile structure. [DOI : 10.1143/APEX.1.041602]

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Annealing Effect of 80 K-Class Superconductivity of Ca-Doped $B_2S_2CuO_{6+\delta}$ in Bi-2201 Phase

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Annealing effect on magnetic properties of superconductivity is investigated for the crystals of $Bi_{1.9}Ca_ySr_{1.9-y}CuO_{6+\delta}$ ($0 \leq y \leq 1.8$) in Bi-2201 phase. It is found that carrier density is reduced with Ca doping in Ca-poor region of $y \leq 0.8$. In contrast, the excess oxygen δ is saturated with doping at about the optimal T_c in Ca-rich region of $y > 0.8$. The results indicate possible oxygen deficiencies with Ca doping, which gives a new aspect to a model for the appearance of 80 K-class superconductivity. [DOI : 10.1143/APEX.1.041701]

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Grain Size Increase and Field-Effect Mobility Enhancement of Pentacene Thin Films Prepared in a Low-Pressure H_2 Ambient

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Pentacene films were grown by thermal evaporation in different gas atmospheres at a relatively low vacuum of about 3 Pa, and the effects of the gas ambient on the performance of thin film transistors (TFTs) were investigated. The TFT mobility of film deposited in H_2 was twice the typical value of 0.3 $cm^2/(V \cdot s)$ for film deposited in vacuum, while the mobility values of films deposited in N_2 and O_2 were almost the same as that of vacuum-deposited film. No significant changes in on/off ratio, threshold voltage, or hysteresis behavior were observed in pentacene TFTs prepared by evaporation in gas ambient. The improved mobility of pentacene film prepared in H_2 can be explained by an increase in grain size of the first layer on the SiO_2/Si substrate.
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Photon Correlation in GaAs Self-Assembled Quantum Dots

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We report on photon coincidence measurement in a single GaAs self-assembled quantum dot (QD) using a pulsed excitation light source. At low excitation, when a neutral exciton line was present in the photoluminescence (PL) spectrum, we observed nearly perfect single photon emission from an isolated QD at 670 nm wavelength. For higher excitation, multiple PL lines appeared on the spectra, reflecting the formation of exciton complexes. Cross-correlation functions between these lines showed either bunching or antibunching behavior, depending on whether the relevant emission was from a biexciton cascade or a charged exciton recombination. [DOI : 10.1143/APEX.1.042001]

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Terahertz-Wave Generation Using a 4-Dimethylamino-*N*-methyl-4-stilbazolium tosylate Crystal Under Intra-Cavity Conditions

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We succeeded in generating terahertz waves using difference-frequency generation (DFG) in an organic 4-dimethylamino-*N*-methyl-4-stilbazolium tosylate (DAST) crystal under intra-cavity conditions. We constructed a dual wavelength output optical parametric oscillator (OPO) with two potassium titanium oxide phosphate (KTP) crystals for the DFG pumping source, and placed the DAST crystal inside the OPO cavity to act as a nonlinear wavelength conversion element. Our experimental measurements confirmed that intra-cavity generation was possible and that the output level was approximately the same as that of normal excitation using the external OPO output. [DOI : 10.1143/APEX.1.042002]

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Frequency Increase of Resonant Tunneling Diode Oscillators in Sub-THz and THz Range Using Thick Spacer Layers

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We obtained frequency increase of resonant tunneling diode (RTD) oscillators using thick spacer layers at the collector in sub-terahertz range. This is attributed to reduction of parasitic capacitance due to the increase of spacer layer thickness. The oscillation frequency increased from 325 to 425 GHz by the change of spacer layer thickness from 5 to 45 nm in reasonable agreement with theoretical calculation. Frequency switching with bias direction was also obtained for an RTD having an asymmetric structure with the thickness of the collector and emitter spacer layers of 30 and 5 nm, respectively. The oscillation frequency was 394 GHz under forward bias, whereas 336 GHz under reverse bias in which the role of the emitter and collector spacers was exchanged.

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Appl. Phys. Express Vol.1, No.4 (2008) 045001

Time-Resolved Investigation of Nanosecond Crystal Growth in Rapid-Phase-Change Materials: Correlation with the Recording Speed of Digital Versatile Disc Media

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The crystallization process in digital versatile disc (DVD) media was investigated using a time-resolved X-ray diffraction apparatus coupled with *in situ* photoreflectivity measurement. The time profiles of crystallization were found to be consistent with the changes in photoreflectivity. The phase changes were characterized by the start and end time; 90±1 and 273±1 ns for $Ge_2Sb_2Te_5$, and 85±1 and 206±1 ns for $Ag_{3.5}In_{3.8}Sb_{75.0}Te_{17.7}$, respectively. The faster crystallization time in $Ag_{3.5}In_{3.8}Sb_{75.0}Te_{17.7}$ is ascribed to its characteristic crystallization process; its X-ray diffraction profile shows a significant sharpening during the crystallization process, whereas the peak width of $Ge_2Sb_2Te_5$ remained unchanged. The present findings suggest that crystal growth control is another key for designing faster phase-change materials.

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Super-High Brightness and High-Spin-Polarization Photocathode

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Using a newly developed transmission-type photocathode, an electron beam of super-high brightness [$(1.3\pm0.5)\times10^7 A\cdot cm^{-2}\cdot sr^{-1}$] was achieved. Moreover, the spin-polarization was as high as 90 %. We fabricated a transmission-type photocathode based on a GaAs–GaAsP strained superlattice on a GaP substrate in order to enhance the brightness and polarization greatly. In this system, a laser beam is introduced through the transparent GaP substrate. The beam is focused on the superlattice active layer with a short focal length lens. Excited electrons are generated in a small area and extracted from the surface. The shrinkage of the electron generation area improved the brightness. In addition, a GaAs layer was inserted between the GaP substrate and the GaAsP buffer layer to control the strain relaxation process in the GaAsP buffer layer. This design for strain control was key in achieving high polarization (90 %) in the transmission-type photocathode.

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Appl. Phys. Express Vol.1, No.4 (2008) 045003

Self-Separation of a Thick AlN Layer from a Sapphire Substrate via Interfacial Voids Formed by the Decomposition of Sapphire

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A technique for separating a thick AlN layer grown by hydride vapor phase epitaxy (HVPE) on a (0001) sapphire substrate was developed. By heat treatment at 1450 °C in a gas flow containing H_2 and NH_3, many voids could be formed at the interface between a thin (100 nm) AlN layer grown at 1065 °C and the sapphire substrate due to the preferential decomposition of sapphire. During the cooling process after the subsequent growth of a thick (85 μm) AlN layer, the thick AlN layer separated from the sapphire substrate with the aid of the interfacial voids. The freestanding AlN substrate thus obtained had a smooth (0001) surface, a dislocation density of $1.1\times10^9 cm^{-2}$, and an optical transparency for wavelengths above 208.1 nm. [DOI : 10.1143/APEX.1.045003]

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Determination of the Twist Angle of GaN Film by High Resolution X-ray Diffraction

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As an azimuthal scan method, ϕ-scans preformed by X-ray diffraction are usually used to determine the twist angle in GaN films. However, both twist and tilt contribute to full width at half maximum (FWHM) of ϕ-scan curves. So far no model has been proposed to distinguish the contributions of tilt and twist to FWHM of these curves. A geometrical model is presented to distinguish their contributions, which is very important to precisely determine the dislocation densities in GaN. Based on this model, FWHM of ϕ-scans can be expressed as a simple explicit function of the original twist angle and an additional twist angle induced by tilt. These twist angles are then simply and effectively determined for various GaN films according to this simple function, and are in good agreement with those deduced from ω-scan data fitting.

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Gas-Temperature-Dependent Characteristics of Cryo-Dielectric Barrier Discharge Plasma under Atmospheric Pressure

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In the present work, cryo-dielectric barrier discharge (DBD) plasma was generated continuously below room temperature down to liquid nitrogen temperature (296 to 78 K) under atmospheric pressure using parallel indium–tin-oxide (ITO)-coated electrodes. Gas-temperature-dependent optical emission spectroscopy (OES) measurements and discharge pattern observation of cryo-DBD plasma were performed. In the case of helium gas, the discharge mode of cryo-DBD plasma changed from filamentary mode to glow mode as the gas temperature decreased. When introducing a small amount of nitrogen in helium gas, the filamentary discharge mode persisted upon decreasing the gas temperature, although the discharge pattern changed from concentric rings (296 K) to a hexagon-like pattern (78 K). [DOI : 10.1143/APEX.1.046001]

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Discharge Characteristics of Microwave and High-Frequency In-Liquid Plasma in Water

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The plasma in water is generated by applying high-frequency (HF) irradiation of 27.12 MHz or microwave (MW) radiation of 2.45 GHz from an electrode. The electrode is heated by joule heating by the HF or MW irradiation, and vapor bubbles are generated simultaneously. The plasma is then ignited inside the bubbles on the electrode. The glow discharge plasma can be maintained in spite of atmospheric pressure due to the cooling effect of the liquid itself. The electron temperature of the plasma generated by the 27.12 MHz radiation is higher than that generated by the 2.45 GHz radiation. [DOI : 10.1143/APEX.1.046002]

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Enhancement of Acid Production in Chemically Amplified Resist for Extreme Ultraviolet Lithography

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The trade-off among sensitivity, resolution, and line edge roughness (LER) is the most serious problem for the realization of extreme ultraviolet (EUV) lithography. A solution to this problem is the enhancement of acid generation efficiency per unit volume. In chemically amplified EUV resists, not the acid generators but the polymer mainly absorbs EUV photons. The secondary electrons generated by EUV absorption sensitize the acid generators. Therefore, an increase in the polymer absorption coefficient is expected to lead to the enhancement of acid production. The incorporation of fluorine atoms is a promising way for the increase in the absorption coefficient of EUV resists. However, fluorinated compounds decrease the acid generation efficiency by interfering with the reaction of acid generators with low-energy electrons. We investigated which effect prevails in acid generation. Using a spectroscopic method, it was confirmed that the incorporation of fluorine atoms leads to an increase in acid generation efficiency per unit volume.

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Organic Contaminant Detection of Silicon Wafers Using Negative Secondary Ions Induced by Cluster Ion Impacts

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Emission yields of carbon and hydrogenated carbon cluster secondary ions $C_pH_q^{\pm}$ ($p \geq 1$, $q \geq 0$) originating from organic contaminants on a silicon wafer are compared between monoatomic (0.5-MeV/atom C_1^+) and cluster ion (0.5-MeV/atom C_8^+) impacts using time-of-flight (TOF) secondary ion mass spectrometry. $C_pH_q^-$ for the cluster ion impact exhibits the highest emission yield per incident atom among $C_pH_q^{\pm}$ with the same p number. The highest relative $C_pH_q^-$ emission yield for the cluster ion impact reaches ~20 and ~60 times higher in comparison with those of $C_pH_q^-$ and $C_pH_q^+$ with the same p number for the impact of the monoatomic ion with the same velocity, respectively. Combination of negative secondary ion TOF measurements with cluster impact ionization is a promising tool for highly sensitive detection of organic-contaminants on silicon wafers. [DOI : 10.1143/APEX.1.047002]

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Erratum: "Local Synthesis of Tungsten Oxide Nanowires by Current Heating of Designed Micropatterned Wires"

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