

## Abstracts of Express Letters

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### Current-Induced Magnetization Switching in MgO Barrier Based Magnetic Tunnel Junctions with CoFeB/Ru/CoFeB Synthetic Ferrimagnetic Free Layer

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We report the intrinsic critical current density ( $J_{c0}$ ) in current-induced magnetization switching and the thermal stability factor ( $E/k_B T$ , where  $E$ ,  $k_B$ , and  $T$  are the energy potential, the Boltzmann constant, and temperature, respectively) in MgO based magnetic tunnel junctions with a  $\text{Co}_{40}\text{Fe}_{40}\text{B}_{20}$ (2 nm)/Ru(0.7–2.4 nm)/ $\text{Co}_{40}\text{Fe}_{40}\text{B}_{20}$ (2 nm) synthetic ferrimagnetic (SyF) free layer. We show that  $J_{c0}$  and  $E/k_B T$  can be determined by analyzing the average critical current density as a function of coercivity using the Slonczewski's model taking into account thermal fluctuation. We find that high antiferromagnetic coupling between the two CoFeB layers in a SyF free layer results in reduced  $J_{c0}$  without reducing high  $E/k_B T$ . [DOI : 10.1143/JJAP.45.L1057]

**Keywords:** current-induced magnetization switching, synthetic free layer, magnetic tunnel junction, MgO barrier, CoFeB

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### An Organic Light Emitting Device Employing Transparent Rutile $\text{TiO}_2$ as an Anode

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(Received July 19, 2006; accepted September 15, 2006; published online October 6, 2006)

Organic light emitting devices (OLEDs) using a transparent semiconductor rutile  $\text{TiO}_2$  film on *r*-sapphire substrate as an anode shows fine surface emission. The OLED structure is  $\text{TiO}_2$ /poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS)/N,N'-Di-[(1-naphthalenyl)-N,N'-diphenyl]-(1,1'-biphenyl)-4,4'-diamine ( $\alpha$ -NPD)/tris(8-hydroxyquinoline) aluminum ( $\text{Alq}_3$ )/LiF/Al. The obtained maximum luminance and current efficiency are  $1340\text{cd/m}^2$  at 21.0V and  $1.6\text{cd/A}$  at 15.0V, respectively. Current efficiency and turn-on voltage of the OLEDs systematically depend on the resistivity of the  $\text{TiO}_2$  anode. This trend can be explained by dependence of hole injection efficiency on the resistivity. [DOI : 10.1143/JJAP.45.L1061]

**Keywords:** organic light emitting device,  $\text{TiO}_2$ , anode, oxide semiconductor, hole injection,  $\text{Alq}_3$

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### Ultra-High Efficiency White Light Emitting Diodes

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We fabricated the high luminous efficiency white light emitting diode (LED) and the high power white LED by using the patterned sapphire substrates and an indium–tin oxide (ITO) contact as a p-type electrode. The high luminous efficiency white LED was the yellow YAG-phosphors-coated small-size ( $240 \times 420\mu\text{m}^2$ ) high efficiency blue LED with the quantum efficiency of 63.3% at a forward-bias current of 20mA. The luminous flux ( $\Phi$ ), the forward-bias voltage ( $V_f$ ), the correlated color temperature ( $T_{cp}$ ), the luminous efficiency ( $\eta_L$ ), and the wall-plug efficiency (WPE) of the high luminous efficiency white LED are 8.6lm, 3.11V, 5450K, 138lm/W, and 41.7%, respectively. The luminous efficiency is 1.5 times greater than that of a tri-phosphor fluorescent lamp (90lm/W). The high power white LED was fabricated from the larger-size ( $1 \times 1\text{mm}^2$ ) blue LED with the output power of 458mW at 350mA.  $\Phi$ ,  $V_f$ ,  $T_{cp}$ ,  $\eta_L$ , and WPE of the high power white LED are 106lm, 3.29V, 5200K, 91.7lm/W, and 27.7%, respectively, at 350mA. The WPE is greater than that of a fluorescent lamp (25%) in the visible region. Moreover, the luminous flux of the high power white LED reaches to 402lm at 2A, which is equivalent to the total flux of a 30W incandescent lamp. [DOI : 10.1143/JJAP.45.L1084]

**Keywords:** GaN, InGaN, LED, YAG, white LED, blue LED

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## Cr-Doping Effects to Electrical Properties of BiFeO<sub>3</sub> Thin Films Formed by Chemical Solution Deposition

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(Received July 25, 2006; accepted September 13, 2006; published online October 13, 2006)

Cr-doped BiFeO<sub>3</sub> (BFO) thin films were formed by depositing sol-gel solutions on Pt/Ti/SiO<sub>2</sub>/Si(100) structures. Cr-doping up to 6at% was effective in suppressing leakage current in the high electric field region and in increasing the remanent polarization. In a 3at% Cr-doped 350-nm-thick BFO film, the remanent polarization as large as 100 μC/cm<sup>2</sup> and the coercive field of 260 kV/cm were observed when polarization vs electric field hysteresis loops were drawn at a frequency of 100 kHz with the maximum electric field of 750 kV/cm.

[DOI: 10.1143/JJAP.45.L1087]

**Keywords:** BiFeO<sub>3</sub> film, Cr-doping, chemical solution deposition (CSD), ferroelectric properties

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## 30-nm-Gate AlGa<sub>0.4</sub>N/GaN Heterostructure Field-Effect Transistors with a Current-Gain Cutoff Frequency of 181 GHz

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(Received September 29, 2006; accepted September 30, 2006; published online October 20, 2006)

We fabricated Al<sub>0.4</sub>Ga<sub>0.6</sub>N(8 nm)/GaN heterostructure field-effect transistors (HFETs) with a gate length ( $L_G$ ) of 30 nm on a sapphire substrate. The AlGa<sub>0.4</sub>N/GaN HFETs, which had a 2-nm-thick SiN passivation and gate-insulating layer formed by catalytic chemical vapor deposition, showed a maximum drain current density of 1.49 A/mm, a peak extrinsic transconductance of 402 mS/mm, a current-gain cutoff frequency ( $f_T$ ) of 181 GHz, and a maximum oscillation frequency of 186 GHz. From a delay time analysis of  $f_T$  for the HFETs with  $L_G=30$ –150 nm, the electron velocity overshoot was not observed even when  $L_G$  was decreased to 30 nm.

[DOI: 10.1143/JJAP.45.L1111]

**Keywords:** GaN, heterostructure field-effect transistor (HFET), catalytic chemical vapor deposition (Cat-CVD), current-gain cutoff frequency ( $f_T$ ), maximum oscillation frequency ( $f_{max}$ ), millimeter wave

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## Characterization of Direct Immobilized Probe DNA on Partially Functionalized Diamond Solution-Gate Field-Effect Transistors

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Amino groups were functionalized directly on the diamond surface after treating 0.5 monolayer of oxidation for detection of DNAs. Also, immobilization of probe DNAs was carried out directly on the partially aminated diamond without linker molecules. Specific hybridization with 21-mer DNA at a concentration of 100 nM could be clearly detected by two methods, fluorescence microscopy and diamond solution-gate field-effect transistors (SGFETs). DNA hybridization was confirmed using Cy-5-labeled target DNA on a micropatterned diamond surface. The changes in gate potential by the negative charge of immobilized or hybridized DNA were measured on SGFETs and hybridization efficiency on the functionalized diamond surface was estimated as about 40%.

[DOI: 10.1143/JJAP.45.L1114]

**Keywords:** diamond, functionalization, DNA detection, direct immobilization, SGFETs, micropattern

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## Growth of a Two-Inch GaN Single Crystal Substrate Using the Na Flux Method

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We succeeded in growing a GaN single crystal substrate with diameter of about two inches using the Na flux method. Our success is due to the development of a new apparatus for growing large GaN single crystals. The crystal grown in this study has a low dislocation density of  $2.3 \times 10^5$  cm<sup>-2</sup>. The secondary ion mass spectrometry (SIMS) technique demonstrates that the Na element is difficult to be taken in the crystal in both the "+" and "-" c directions, resulting in a Na concentration of  $4.2 \times 10^{14}$  cm<sup>-3</sup> in the crystal. Our success in growing a two-inch GaN substrate with a low impurity content and low dislocation density should pave the way for the Na flux method to become a practical application.

[DOI: 10.1143/JJAP.45.L1136]

**Keywords:** GaN, single crystal, 2 inch, liquid phase epitaxy, LPE

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## Layer-by-Layer Growth of AlN on ZnO(000 $\bar{1}$ ) Substrates at Room Temperature

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(Received October 5, 2006; accepted October 7, 2006; published online October 27, 2006)

We have grown AlN layers on atomically flat ZnO(000 $\bar{1}$ ) substrates by pulsed laser deposition at room temperature (RT) and investigated their structural properties. The reflection high-energy electron-diffraction (RHEED) intensity monitoring and atomic force microscopy (AFM) observations have revealed that the RT growth of AlN films proceeds by a layer-by-layer mode from the initial stage of the growth, and that the surfaces of the AlN films possess atomically-flat terraces separated by straight steps. We have also found that the AlN/ZnO heterointerfaces are atomically abrupt. [DOI : 10.1143/JJAP.45.L1139]

**Keywords:** AlN, ZnO, epitaxial growth, crystal growth, pulsed laser deposition, molecular-beam epitaxy

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## Enhancement-Mode AlGaIn/GaN High Electron Mobility Transistor with Low On-State Resistance and High Breakdown Voltage

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(Received October 14, 2006; accepted October 16, 2006; published online November 2, 2006)

A low on-resistance and high-breakdown-voltage enhancement-mode (E-mode) AlGaIn/GaN high electron mobility transistor (HEMT) was fabricated without the recessed-gate process. A thin AlGaIn barrier layer (4.5 nm) was used for the normally-off operation. In order to decrease the on-state resistance, two different techniques are used. One is the side-ohmic contact, which has a low contact resistance, due to the direct contact with the two-dimensional electron gas (2DEG). The other is SiO<sub>2</sub> passivation, which induces the sheet carriers and decreases the sheet resistance. As a result, an on-state resistance of 1.9 m $\Omega$ ·cm<sup>2</sup> and an off-state breakdown voltage of 610 V were achieved for the E-mode HEMT within a threshold voltage of approximately -0.1 V.

[DOI : 10.1143/JJAP.45.L1168]

**Keywords:** GaN, thin AlGaIn, high electron mobility transistor (HEMT), normally-off, enhancement-mode, SiO<sub>2</sub> passivation, side ohmic, on-state resistance, off-state breakdown voltage

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## Organic Thin-Film Transistors with Conductive Metal-Oxides as Source-Drain Electrodes

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(Received September 20, 2006; accepted October 17, 2006; published online November 2, 2006)

We demonstrated that bottom contact (BC) configuration organic thin-film transistors (OTFTs) easily get higher performance by using conductive metal oxide (CMO) as source and drain electrodes. Although BC-OTFTs are more advantageous than top contact (TC) configuration in the viewpoint of device fabrications, it is also well-known that BC-OTFTs show poor performance compared with TC-OTFTs with the same active material. We found out that using CMO like indium tin oxide as contact electrodes enhanced performance of BC-OTFTs without any special surface treatments. This manner was truly effective for most organic semiconducting materials, for example, pentacene, polythiophene, and so on. [DOI : 10.1143/JJAP.45.L1171]

**Keywords:** organic transistor, organic TFT, bottom contact, pentacene, ITO

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## Optical Observation of Carrier Accumulation in Single-Walled Carbon Nanotube Transistors

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Electric-field-induced spectral changes in single-walled carbon nanotubes were studied using a thin-film transistor configuration. As a function of electric field, the optical spectra displayed continuous intensity modulations. This is the direct evidence of carrier accumulation, and the amount of accumulated carriers was quantitatively consistent with the carrier density in the nanoscale wire-form field-effect transistor model.

[DOI : 10.1143/JJAP.45.L1190]

**Keywords:** single-walled carbon nanotube, field-effect device, thin film, optical properties

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## CW Operation of the First-Order AlInGaN 405 nm Distributed Feedback Laser Diodes

Shingo Masui, Kazutaka Tsukayama, Tomoya Yanamoto, Tokuya Kozaki, Shin-ichi Nagahama and Takashi Mukai

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The first-order AlInGaN 405 nm distributed feed-back (DFB) laser diodes were grown on the free-standing GaN substrates by a metal organic chemical vapor deposition method. The first-order diffractive grating was formed into an n-type cladding layer. As a result, we succeeded in demonstrating the first-order AlInGaN based 405 nm DFB laser diodes under cw operation. The threshold current and the slope efficiency were 22 mA and 1.44 W/A under cw operation at 25 °C, respectively. The single longitudinal mode emission was maintained up to an output power of 60 mW. The fundamental transverse mode operation with a single longitudinal mode was observed in the temperature range from 15 to 85 °C at an output power of 20 mW.

[DOI : 10.1143/JJAP.45.L1223]

**Keywords:** AlInGaN, laser diode, first-order, DFB, 405 nm, EB

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## Controlling Polarization of 1.55-μm Columnar InAs Quantum Dots with Highly Tensile-Strained InGaAsP Barriers on InP(001)

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The optical polarization properties of columnar InAs quantum dots (QDs) on InP substrate grown by metalorganic vapor-phase epitaxy were investigated. The polarization of photoluminescence was found to strongly depend on the strain in QDs as well as the shape of QDs. We successfully changed the polarization properties from a transverse-electric-dominant to a transverse-magnetic-dominant regime by controlling the height of coupled QDs based on the stacking number and by controlling strain within QDs based on the thickness of 3.7%-tensile-strained barriers. Highly strained side barriers were required to change the polarization of QDs, which is considered to be due to wetting layers acting in maintaining biaxial-compressive strain in QDs. Polarization-insensitive QDs with the 1.55-μm telecom region were obtained, which promises to provide polarization-insensitive semiconductor optical amplifiers. [DOI : 10.1143/JJAP.45.L1244]

**Keywords:** quantum dot, polarization, tensile-strained barrier, stacking

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## Room-Temperature Stimulated Emission from AlN at 214 nm

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We report the first ever room temperature (RT) stimulated emission at 214 nm using high quality AlN layers that were grown over patterned sapphire substrates by pulsed lateral epitaxial overgrowth (PLOG) process. The PLOG process yielded fully coalesced layers with total thicknesses in excess of 10 μm resulting in a reduction in the threading dislocation density by several orders. The stimulated emission was achieved at 214 nm under pulsed optical pumping at RT. The RT threshold optical power density was approximately 9 MW/cm<sup>2</sup> and the stimulated edge-emission signal was strongly polarized with  $E \parallel c$ .

[DOI : 10.1143/JJAP.45.L1286]

**Keywords:** AlN, nitride, stimulated emission, lasing, polarization, MOCVD, lateral overgrowth

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## Domain Nucleation and Annihilation in Uniformly Magnetized State under Current Pulses in Narrow Ferromagnetic Wires

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We investigate the current-driven magnetization dynamics in narrow Permalloy wires by means of Lorentz microscopy and electron holography. Current pulses are found to transform the magnetic structure in the uniformly magnetized state below the Curie temperature. A variety of magnetic states including reversed magnetic domains are randomly obtained in low probability. The dynamics of vortices found in most of observed magnetic states seems to play a key role in triggering the magnetization reversal. [DOI : 10.1143/JJAP.45.L1322]

**Keywords:** current-driven magnetization dynamics, magnetic domain nucleation, annihilation, Lorentz microscopy, electron holography

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## Reversible Resistance Switching of GeTi Thin Film Used for Non-Volatile Memory

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Reversible resistance switching behavior was observed in a simple proto-type non-volatile memory cell using GeTi thin film. The film prepared by magnetic sputtering at room temperature was amorphous. The reversible switching phenomenon appeared when applying a property external bias voltage on the cell. The ratio of the high resistance state (off-state) to the low resistance state (on-state) was  $10\text{--}10^2$ . Because of the electric-pulse-induced resistance switching property of GeTi and its simple binary constitution compatible with the semiconductor industry, the application prospect of GeTi as a storage medium for data recording can be predicted. [DOI : 10.1143/JJAP.46.L1]

**Keywords:** non-volatile memory, GeTi, electric-pulse-induced, reversible resistance switching, new storage medium

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## Electrical Spin Injection from Out-of-Plane Magnetized FePt/MgO Tunneling Junction into GaAs at Room Temperature

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We have succeeded in demonstrating zero-magnetic-field spin injection in metal-insulator-semiconductor (MIS) structure at room temperature using FePt/MgO/GaAs-based light-emitting diode heterojunction with out-of-plane magnetization. The spin polarization was investigated by spin-polarized electroluminescence (EL). The lower estimate injected at remanence was 1.5% and that injected at 1T was reached up to 11.5%. The spin injection efficiency was estimated at least 29%. The bias dependence of the EL circular polarization showed that it decreases with increasing bias voltage for both at 1T and at remanence.

[DOI : 10.1143/JJAP.46.L4]

**Keywords:** spin injection, perpendicular magnetization, tunneling junction, spin-polarized light-emitting diode, FePt, MgO, GaAs

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## Nonlinear Optical Properties of the Lanthanum-Modified Lead Zirconate Titanate Ferroelectric Thin Films Using Z-Scan Technique

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Lanthanum-modified lead zirconate titanate ( $(\text{Pb},\text{La})(\text{Zr},\text{Ti})\text{O}_3$  (PLZT) ferroelectric thin films with perovskite structure were fabricated on quartz substrates by rf magnetron sputtering at  $650^\circ\text{C}$ . Their optical fundamental constants (the band gap, linear refractive index, and absorption coefficient) were obtained through optical transmittance measurements with the envelope method. The nonlinear optical properties of the PLZT films were investigated by the Z-scan technique. The films display strong nonlinear optical effects. A negative nonlinear refractive index  $n_2$  is determined to be  $1.21 \times 10^{-6}$  esu in the films. These results show that the PLZT ferroelectric thin films are promising materials for nonlinear optics. [DOI : 10.1143/JJAP.46.L7]

**Keywords:**  $(\text{Pb},\text{La})(\text{Zr},\text{Ti})\text{O}_3$ , rf magnetron sputtering, nonlinear optical properties, Z-scan technique

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## Ultra High Efficiency Green Organic Light-Emitting Devices

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We developed ultra high efficiency green organic light-emitting devices (OLEDs) using a novel electron transport material containing dipyrrolylphenyl moieties and green phosphorescent emitter, *fac* tris(2-phenylpyridine)iridium,  $\text{Ir}(\text{ppy})_3$ . An OLED with a simple structure of glass/indium-tin oxide/polymer buffer layer/arylamine derivative as a hole transport layer/ $\text{Ir}(\text{ppy})_3$ -doped dicarbazolylbiphenyl as an emitter layer/dipyrrolylphenyl derivative as an electron transport layer/ $\text{LiF}/\text{Al}$  exhibited low drive voltages, which were 2.5V at  $100\text{cd}/\text{m}^2$  and 2.9V at  $1000\text{cd}/\text{m}^2$ . High external quantum efficiencies of 29% at  $100\text{cd}/\text{m}^2$  and 26% at  $1000\text{cd}/\text{m}^2$  were also observed, which lead to the ultra high power efficiencies of  $133\text{lm}/\text{W}$  at  $100\text{cd}/\text{m}^2$  and  $107\text{lm}/\text{W}$  at  $1000\text{cd}/\text{m}^2$ . [DOI : 10.1143/JJAP.46.L10]

**Keywords:** organic light-emitting device, iridium complex, dipyrrolylphenyl, electron transport layer, high efficiency

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## Multilevel Data Storage Characteristics of Phase Change Memory Cell with Doublelayer Chalcogenide Films ( $\text{Ge}_2\text{Sb}_2\text{Te}_5$ and $\text{Sb}_2\text{Te}_3$ )

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(Received December 7, 2006; accepted December 9, 2006; published online January 9, 2007)

Phase change memory (PCM) cells with monolayer chalcogenide film ( $\text{Ge}_2\text{Sb}_2\text{Te}_5$  or  $\text{Sb}_2\text{Te}_3$ ) and doublelayer chalcogenide films ( $\text{Ge}_2\text{Sb}_2\text{Te}_5$  and  $\text{Sb}_2\text{Te}_3$ ) were successfully fabricated. The PCM cell with doublelayer structure like  $\text{W}/\text{Ge}_2\text{Sb}_2\text{Te}_5(30\text{nm})/\text{Sb}_2\text{Te}_3(60\text{nm})/\text{TiN}/\text{Al}$  shows superior performances to monolayer ones, which is mostly referred to the reduction of set voltage value and reset voltage value, and the ability of multi-level data storage. Theoretical simulations of the temperature distribution of the PCM cell with the doublelayer structure were also investigated. [DOI : 10.1143/JJAP.46.L25]

**Keywords:** phase change memory (PCM), multilevel data storage,  $\text{Sb}_2\text{Te}_3$ ,  $\text{Ge}_2\text{Sb}_2\text{Te}_5$

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## Synthesis and Characterization of Pt/Co–O/Pt Trilayer Exhibiting Large Reproducible Resistance Switching

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(Received November 15, 2006; accepted December 5, 2006; published online January 12, 2007)

The resistance switching in Pt/Co–O/Pt trilayers has been successfully demonstrated. The trilayers were prepared by radio-frequency magnetron sputtering. The partial pressure of oxygen during sputtering and the post thermal process for the trilayer are crucial to realize the reproducible resistance switching. By adjusting oxygen partial pressure as well as post-annealing temperature and time, large resistance switching was steadily obtainable in both the as deposited and post-annealed Pt/Co–O/Pt trilayers. The resistance switching ratio exceeds  $10^3$ , being sufficiently large for the resistance random access memory (RRAM). Co–O is regarded as a very promising oxide for RRAM having compatibilities with the conventional complementary metal–oxide semiconductor process. [DOI : 10.1143/JJAP.46.L57]

**Keywords:** ReRAM, Co oxide, magnetron sputtering, non-volatile memory, CMOS compatibility, Pt electrode, oxide thin film

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## Continuous Wave Laser Oscillation of Stoichiometric YbAG Crystal

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Continuous wave laser oscillation of the stoichiometric microchip YbAG crystal was realized at 1076nm wavelength. The 200- $\mu\text{m}$ -thick YbAG crystal was pumped by the Ti:sapphire laser at 937nm. Maximum output power of 100mW was obtained at room temperature with slope efficiency of 38% and maximum optical-to-optical efficiency of 29% for the incident pump power. [DOI : 10.1143/JJAP.46.L61]

**Keywords:** stoichiometric Yb material, YbAG crystal, quasi-three-level, cw laser oscillation, room temperature

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## Surface Reaction Enhancement by UV irradiation during Si Etching Process with Chlorine Atom Beam

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(Received December 12, 2006; accepted December 18, 2006; published online January 12, 2007)

We investigated the dependence of etching rate on irradiation of photons with a UV lamp during Si etching processes with chlorine atom beam to understand the influence of UV photon irradiation in the plasma etching process. We found that UV from 220 to 380nm drastically enhanced Si surface reactions with a chlorine atom beam at lamp power densities over  $20\text{mW}/\text{cm}^2$ . Additionally, we were able to control the Si etching rate by changing the photon irradiation power density. These results led us to speculate that the irradiation of UV photons from 220 to 380nm generates crystal defects on the Si surface and enhances chemical reactions between Si and chlorine during  $\text{Cl}_2$  plasma etching processes. [DOI : 10.1143/JJAP.46.L64]

**Keywords:** etching reaction, UV photon assisted reaction, neutral beam etching, plasma etching, defect generation

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## **In-Situ Observation of the Fabrication Process of a Single Shell Carbon Fullerene Nano-Contact Using Transmission Electron Microscope–Scanning Tunneling Microscope**

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(Received December 1, 2006; accepted December 20, 2006; published online January 12, 2007)

A single shell carbon fullerene (SSF) was fabricated from an amorphous carbon agglomerate (a-C agglomerate) suspended between two gold electrodes. As the applied bias voltage to the a-C agglomerate was increased using a transmission electron microscope–scanning tunneling microscope (TEM–STM) system, the transformation into the SSF via a glassy carbon was observed. It was found that the SSF transformation occurred above the bias voltage of 0.6V without a prominent loss of the number of carbon atoms. The size of the SSFs ranged from C<sub>60</sub> to C<sub>620</sub> having *I<sub>h</sub>* or *I* symmetry. [DOI : 10.1143/JJAP.46.L67]

**Keywords:** single shell carbon fullerene, amorphous carbon agglomerate, bias voltage, glassy carbon, size reduction, TEM–STM

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## **Acceptor Doped BiFeO<sub>3</sub> Ceramics: A New Material for Oxygen Permeation Membranes**

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(Received December 13, 2006; accepted December 23, 2006; published online January 19, 2007)

A new intermediate temperature mixed conducting material has been fabricated based on acceptor doping of bismuth ferrite (BiFeO<sub>3</sub>). Acceptor doping at levels of 5 mol% with either Ca or Sr was found to increase the maximum operating temperature of ceramics by more than 100°C as well as eliminate secondary phase formation often reported in the pure BiFeO<sub>3</sub> system. Mixed ionic and electronic conductivity was confirmed by measuring the oxygen permeation properties of doped ceramics which exhibited flux's on the order of 0.018 μmol/(cm<sup>2</sup>s) at 800°C over the oxygen partial pressure range 0.21 atm (air) to 10<sup>-6</sup> atm (He). Ceramic membranes showed an increase in oxygen flux with decreasing sample thickness indicating good surface catalysis properties of the system. [DOI : 10.1143/JJAP.46.L93]

**Keywords:** ionic conduction, oxygen separation membrane, point defects, ceramics

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## **Lead-Free Piezoelectric Ceramics with Large Dielectric and Piezoelectric Constants Manufactured from BaTiO<sub>3</sub> Nano-Powder**

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(Received December 26, 2006; accepted December 27, 2006; published online January 19, 2007)

Barium titanate (BaTiO<sub>3</sub>) ceramics with a density of more than 98% of the theoretical value were fabricated by two-step sintering method from hydrothermally synthesized BaTiO<sub>3</sub> nano-particles of 100 nm. The average grain size was around 1.6 μm and the biggest one was controlled less than 3 μm. Dielectric constant  $\epsilon_{r33}^T$  of the poled samples was 5000 and electromechanical coupling factor  $k_p$  was 42%. Large piezoelectric constants  $d_{33} = 460$  pC/N and  $d_{31} = -185$  pC/N were measured by a  $d_{33}$ -meter and the resonance–antiresonance method, respectively. A high Poisson's ratio  $\sigma = 0.38$  was determined from the ratio of overtone frequency and resonant frequency in the planar mode. The high Poisson's ratio and the large dielectric constants are most likely the origin of the high  $d_{33}$  of the ceramics. The discovery of high  $d_{33}$  in non-lead-based BaTiO<sub>3</sub> ceramics with low cost process has important practical consequences in addition to scientific interest.

[DOI : 10.1143/JJAP.46.L97]

**Keywords:** lead-free, piezoelectric ceramics, barium titanate, piezoelectric constant, nano-particle, two-step sintering

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## **Highly Manufacturable 90 nm NOR Flash Multi-Level Cell Technology with WSi<sub>x</sub> Gate**

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(Received November 27, 2006; accepted January 18, 2007; published online February 2, 2007)

The multi-level cell (MLC) technology in flash memory has been focused as one of solution for the enhancement of memory capacity and cost reduction. Recently, we had developed highly manufacturable 90 nm NOR flash MLC technology with WSi<sub>x</sub> gate. This technology presents the control of several critical parameters such as low resistance of word-line, high transistor performance, narrow erase cell threshold voltage distribution, and high reliability characteristics. Here, tungsten silicide (WSi<sub>x</sub>) using dichlorosilane (DCS) gas chemistry is used as gate material in order to reduce word-line resistance. Furthermore, the gate edge profile is carefully controlled by optimizing a gate oxidation condition for narrow cell threshold voltage distribution. Finally, MLC reliability characteristic was obtained by the advanced tunnel oxidation method.

[DOI : 10.1143/JJAP.46.L120]

**Keywords:** NOR flash, MLC, word-line resistance, DCS WSi<sub>x</sub>, reliability

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## High Power and High External Efficiency *m*-Plane InGaN Light Emitting Diodes

Mathew C. Schmidt, Kwang-Choong Kim, Hitoshi Sato, Natalie Fellows, Hisashi Masui, Shuji Nakamura, Steven P. DenBaars, and James S. Speck

(Received December 17, 2006; accepted January 25, 2007; published online February 9, 2007)

High power and high efficiency nonpolar *m*-plane (1 $\bar{1}00$ ) nitride light emitting diodes (LEDs) have been fabricated on low extended defect bulk *m*-plane GaN substrates. The LEDs were grown by metal organic chemical vapor deposition (MOCVD) using conditions similar to that of *c*-plane device growth. The output power and external quantum efficiency (EQE) of the packaged 300×300μm<sup>2</sup> was 23.7mW and 38.9%, respectively, at 20mA. The peak wavelength was 407nm and <1nm redshift was observed with change in drive current from 1–20mA. The EQE shows a minimal drop off at higher currents. [DOI : 10.1143/JJAP.46.L126]

**Keywords:** GaN, nonpolar, *m*-plane, LED, high power, high efficiency

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## High Brightness Violet InGaN/GaN Light Emitting Diodes on Semipolar (10 $\bar{1}\bar{1}$ ) Bulk GaN Substrates

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(Received December 16, 2006; accepted January 23, 2007; published online February 9, 2007)

We report the fabrication of violet InGaN/GaN light-emitting diodes (LEDs) on semipolar (10 $\bar{1}\bar{1}$ ) GaN bulk substrates. The LEDs have a dimension of 300×300μm<sup>2</sup> and are packaged in an epoxy resin. The output power and external quantum efficiency (EQE) at a driving current of 20mA were 20.58mW and 33.91% respectively, with peak electroluminescence (EL) emission wavelength at 411nm. The LEDs show minimal shift in peak EL wavelength with increasing drive current along with a high EQE. [DOI : 10.1143/JJAP.46.L129]

**Keywords:** semipolar, (10 $\bar{1}\bar{1}$ ) plane, InGaN, light-emitting diode, GaN bulk substrate

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## Highly Efficient Continuous-Wave Laser Oscillation in Microchip Yb:YAG Laser at Room Temperature

Shinichi Matsubara\*, Tsutomu Ueda, Sakae Kawato, and Takao Kobayashi

(Received November 2, 2006; accepted November 23, 2006; published online February 9, 2007)

Highly efficient continuous-wave laser oscillation in Yb:YAG microchip crystal has been realized at room temperature by high intensity Ti:sapphire laser pumping. The maximum output power of 810mW was obtained at 1048nm wavelength oscillation. The optical-to-optical efficiency was 81% for the incident pump power and 85% for the absorbed pump power. These optical-to-optical efficiencies are close to the quantum-defect-limit of 90%. [DOI : 10.1143/JJAP.46.L132]

**Keywords:** Yb:YAG, quasi-three-level, high-efficiency oscillation, high intensity pumping, room temperature

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## Readout Durability Improvement of Super-Resolution Near-Field Structure Discs with PtO<sub>x</sub>-SiO<sub>2</sub> Recording and GeN<sub>y</sub> Interfacial Layers

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(Received November 15, 2006; accepted January 23, 2007; published online February 9, 2007)

Two dielectric materials were added to a super-resolution near-field optical disc structure (super-RENS) to improve the readout durability. PtO<sub>x</sub>-SiO<sub>2</sub> (Pt<sub>8.4</sub>Si<sub>21.1</sub>O<sub>70.5</sub>) layers showed O<sub>2</sub> desorption for temperatures above 200°C and were usable as write-once recording layers. The GeN<sub>y</sub> interfacial layers located between the Sb<sub>75</sub>Te<sub>25</sub> and (ZnS)<sub>85</sub>(SiO<sub>2</sub>)<sub>15</sub> layers suppressed degradation in the reflected light intensity from the disc, i.e., maintained the recorded structure as is, to at least 5×10<sup>4</sup> readout cycles using a recorded pattern designed to accelerate disc deterioration. The carrier-to-noise ratio (CNR) obtained for 100-nm marks (laser wavelength: 405nm, numerical aperture: 0.65) was about 43dB. It was possible to readout 2.6×10<sup>5</sup> cycles before the CNR decreased by 3dB. This represents an improvement of a factor of 70 over the readout durability of a conventional super-RENS structure. [DOI : 10.1143/JJAP.46.L135]

**Keywords:** super-RENS, readout durability, platinum oxide, germanium nitride, interfacial layer

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## Injection and Population Inversion in Electrically Induced p–n Junction in Graphene with Split Gates

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We study electron and hole injection processes in a forward biased p–n junction electrically induced in a graphene heterostructure with split gates and calculate the ac conductivity associated with the interband and intraband transitions under the conditions of population inversion. It is shown that the net conductivity can be negative in the terahertz range of frequencies, so that the electrically induced p–n junctions in graphene heterostructures might be used in sources of coherent terahertz radiation. [DOI : 10.1143/JJAP.46.L151]

**Keywords:** graphene, split gates, two-dimensional electron–hole system, p–n junction, injection, population inversion, ac interband and intraband conductivity, terahertz radiation

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## Active Magnetic Regeneration Behavior of Spherical Hydrogenated $\text{La}(\text{Fe}_{0.86}\text{Si}_{0.14})_{13}$ Fabricated by Rotating Electrode Process

Asaya Fujita, Sadayoshi Koizumi<sup>1</sup>, Shun Fujieda, Kazuaki Fukamichi<sup>2</sup>, Tadahiko Kobayashi<sup>3</sup>, Hideyuki Tsuji<sup>3</sup>, Shiori Kaji<sup>3</sup>, and Akiko Takahashi Saito<sup>3</sup>

(Received December 26, 2006; accepted January 30, 2007; published online February 16, 2007)

To verify effectiveness for a magnetic refrigerant, we have fabricated spheres of  $\text{La}(\text{Fe}_{0.86}\text{Si}_{0.14})_{13}$  by a rotating electrode process (REP). The Curie temperature of the spheres was increased up to around room temperature by hydrogen absorption. Putting these spheres into an active magnetic regenerator (AMR) test module, the temperature span of 16K in the vicinity of room temperature was obtained in a steady state. Consequently, it has been confirmed for the first time that the  $\text{La}(\text{Fe}_{0.86}\text{Si}_{0.14})_{13}$  spheres perform as an excellent material for the AMR. [DOI : 10.1143/JJAP.46.L154]

**Keywords:** magnetocaloric effect, itinerant-electron metamagnetic transition, active magnetic regenerator (AMR), rotating electrode process

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## Ultrafast All-Optical Refractive Index Modulation in Intersubband Transition Switch Using InGaAs/AlAs/AlAsSb Quantum Well

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Large, very fast phase modulation was observed in transverse electric (TE) probe light when an intersubband transition (ISBT) switch module using an InGaAs/AlAs/AlAsSb quantum well was pumped by transverse magnetic (TM) light. The phase shift amounted to 1.88rad for a pump pulse energy of 4pJ (fiber input), with very fast response. This phenomenon is explained by the change in plasma dispersion caused by the redistribution of electrons among subbands having different effective masses. This phase modulation will enable us to realize various novel ultrafast all-optical devices for signal processing. [DOI : 10.1143/JJAP.46.L157]

**Keywords:** intersubband transition, quantum well, phase modulation, refractive index, band nonparabolicity, effective mass

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## Direct Observation of Molecular Orbital at Carbon Nanotube End

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(Received January 23, 2007; accepted January 29, 2007; published online February 16, 2007)

We report the appearance of superstructures in the topological images of scanning tunneling microscopy of single wall carbon nanotubes in the regions near the cap. These structures are localized with 6–7nm from nanotubes ends and provide wavy pattern parallel to the armchair direction. Our molecular orbital calculation indicates that the superstructure shows a good agreement with calculated lowest unoccupied molecular orbital state. We consider the observed structures are the appearance of real (or imaginary) part of the Bloch state, which occurs as the result of the quantum interference between forward and backward waves. This suggests that the scattering of wave vector from  $k$  to  $-k$  occurs in two-dimensional manner at the end of the tube. [DOI : 10.1143/JJAP.46.L161]

**Keywords:** carbon nanotube, scanning tunneling microscopy, superlattice, molecular orbital

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## Continuous-Wave Operation of *m*-Plane InGaN Multiple Quantum Well Laser Diodes

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(Received February 4, 2007; accepted February 6, 2007; published online February 23, 2007)

Continuous-wave (CW) operation of nonpolar *m*-plane InGaN/GaN laser diodes (LDs) with the lasing wavelengths approximately 400 nm was demonstrated. The threshold current was 36 mA (4.0 kA/cm<sup>2</sup>) for the CW operation [28 mA (3.1 kA/cm<sup>2</sup>) for pulsed mode], being comparable to that of conventional *c*-plane violet LDs. Both the LDs with the stripes parallel to *a*- and *c*-axes showed TE mode operation, according to the polarization selection rules of the transitions in strained InGaN. The *c*-axis stripe LDs exhibited lower threshold current density, since the lowest energy transition is allowed. As is the case with the *m*-plane light emitting diodes fabricated on the free-standing *m*-plane GaN bulk crystals [Okamoto *et al.*: Jpn. J. Appl. Phys. **45** (2006) L1197], the LDs shown in this paper did not have distinct dislocations, stacking faults, or macroscopic cracks. Nonpolar *m*-plane GaN-based materials are coming into general use. [DOI : 10.1143/JJAP.46.L187]

**Keywords:** nonpolar, *m*-plane, InGaN, laser diode, GaN bulk substrate, polarized light

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## Demonstration of Nonpolar *m*-Plane InGaN/GaN Laser Diodes

Mathew C. Schmidt, Kwang-Choong Kim, Robert M. Farrell, Daniel F. Feezell, Daniel A. Cohen, Makoto Saito, Kenji Fujito<sup>1</sup>, James S. Speck, Steven P. DenBaars, and Shuji Nakamura

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The first nonpolar *m*-plane (1-100) nitride laser diodes (LDs) have been realized on low extended defect bulk *m*-plane GaN substrates. The LDs were grown by metal organic chemical vapor deposition (MOCVD) using conditions similar to that of *c*-plane device growth. Broad area lasers were fabricated and tested under pulsed conditions. Lasing was observed at duty cycles as high as 10%. These laser diodes had threshold current densities ( $J_{th}$ ) as low as 7.5 kA/cm<sup>2</sup>. Stimulated emission was observed at 405.5 nm, with a spectral line-width of 1 nm.

[DOI : 10.1143/JJAP.46.L190]

**Keywords:** GaN, nonpolar, *m*-plane, laser diode

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## X-ray Induced Effects on Photocurrents in Amorphous Se Films

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Amorphous selenium (a-Se) is one of the X-ray photoconductors that is available for use in recently developed direct conversion flat panel X-ray image detectors for medical imaging. To obtain a better understanding of trapping and recombination effects in a-Se, we have studied light and X-ray induced photocurrents in a-Se films. The residual photocurrent, after X-ray exposure, decreases in sandwich cells whereas it increases in coplanar cells. These effects are recovered over a time scale of hours. We show that the results can be interpreted by using valence alternation pair (VAP) type charged defects. [DOI : 10.1143/JJAP.46.L192]

**Keywords:** amorphous selenium, X-ray image detector, X-ray induced carriers, X-ray induced photocurrent, direct conversion of X-ray image, ghosting image

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## Electric Field Breakdown of Lateral Schottky Diodes of Diamond

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Current-voltage characteristics of Al lateral Schottky diodes fabricated on homoepitaxial diamond (100) films were analyzed. The currents in reverse-bias voltages smaller and larger than 3 V were well explained by the image-force lowering mechanism modified by localized-field enhancement and the thermionic-field emission mechanism, respectively. An electric field breakdown was observed when the maximum electric field was in the range 1.08–1.46 MV/cm. The breakdown electric field became large with increasing the Schottky barrier height. These features suggest that the electric field breakdown occurred at the electrode fringe due to the field enhancement. [DOI : 10.1143/JJAP.46.L196]

**Keywords:** diamond, Schottky, breakdown, field enhancement

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## Narrow-Bandwidth High-Brightness External-Cavity Laser Diode Bar

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The spectral bandwidth and beam divergence of a high-power laser diode bar were simultaneously suppressed with an external-cavity configuration consisting of a micro-cylindrical lens and an off-axis volume Bragg grating. We reduced the bandwidth from 1.7 to 0.32 nm and the divergence angle from 7.5 to 2.7° under operation at a peak current of 55 A. The external-cavity laser diode bar achieved a peak power output of 36.6 W, or as much as 80% of the power radiated by a free-running laser diode bar without an external cavity. [DOI: 10.1143/JJAP.46.L218]

**Keywords:** laser diode bar, volume Bragg grating, external cavity, bandwidth, divergence angle, output efficiency

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## Sinusoidal Voltage-Controlled Oscillator Based on a Liquid Crystal Cell as Variable Capacitance

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(Received December 27, 2006; accepted February 8, 2007; published online March 2, 2007)

A voltage-controlled oscillator (VCO) in Colpitts circuit configuration is demonstrated using a twisted-nematic (TN) liquid crystal (LC) cell as a capacitance that can be varied as a function of applied voltage. Oscillation frequencies in the range of kHz have been obtained for the combination of inductance and capacitances used in the circuit. A theoretical study for the whole circuit is proposed and experimentally validated. Applications of this circuit include, among others, modulation and demodulation frequency signal, phase locked-loops, and function generators. [DOI: 10.1143/JJAP.46.L221]

**Keywords:** liquid crystal cell, variable capacitance, feedback, voltage-controlled oscillator, communication systems

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## Electro-Optic Properties of Lanthanum-Modified Lead Zirconate Titanate Thin Films Epitaxially Grown by the Advanced Sol-Gel Method

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Epitaxially grown lanthanum-modified lead zirconate titanate (PLZT) thin films were deposited on *r*-cut sapphire substrates using an advanced sol-gel method. The methanol addition into sol-gel solutions brought high quality epitaxial growth of PLZT thin films. This film showed high electro-optic (EO) coefficients that were almost comparable to those of bulk PLZTs. We believe this PLZT deposition technique will open the door for the future data communication systems with integrated EO devices.

[DOI: 10.1143/JJAP.46.L244]

**Keywords:** lanthanum-modified lead zirconate titanate, PLZT, electro-optic coefficients, epitaxial growth, thin films

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## 247 nm Ultra-Violet Light Emitting Diodes

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We report on AlGaIn-based ultraviolet light emitting diodes with emission at the wavelengths as short as 247 nm. Migration-enhanced metal organic chemical vapor deposition technique allowed us to improve the material quality. The phonon energy gap engineering approach was used to optimize these UV sources and achieve continuous-wave regime at turn-on voltages lower than 8 V at 20 mA current. Power levels of 0.3 mW were achieved for the packaged devices driven at 90 mA DC current. In the pulse operation 9 mW output power was measured at 1.4 A current. The peak to noise emission ratio was close to 400 at cw current in excess of 20 mA. [DOI: 10.1143/JJAP.46.L263]

**Keywords:** AlGaIn, deep ultra-violet, light emitting diode, sub-250 nm, MEMOCVD

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## Photoinduced Phenomena in $\text{GeO}_2$ - $\text{GeS}_2$ Glasses

Nobuaki Terakado and Keiji Tanaka

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Composition dependences of glass-transition temperature, optical gap, photodarkening, and photoinduced volume change in  $x\text{GeO}_2$ -(100- $x$ )  $\text{GeS}_2$  oxy-chalcogenide glasses have been studied comparatively. The transition temperature and optical gap are nearly constant at  $0 \leq x < \sim 80$  mol %, while the photodarkening and volume expansion appear only at  $x > \sim 60$ . Implications of these results are discussed.

[DOI : 10.1143/JJAP.46.L265]

**Keywords:** photoinduced phenomena, photodarkening, volume expansion, percolation, oxide, chalcogenide, oxy-chalcogenide,  $\text{GeO}_2$ ,  $\text{GeS}_2$

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## Photon Antibunching in the Emission from a Single Organic Dye Nanocrystal

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We demonstrated that the emission from a single organic nanocrystal consisting of organic dye molecules shows photon antibunching. That is, an assembling structure consisting of many chromophores can also be made to behave as a single-photon source by controlling the size. We found that most of single nanocrystals within a size range from 35 to 85 nm show photon antibunching even when more than one exciton in a crystal is generated by an intense single excitation pulse. On the other hand, single micrometer-sized crystals showed no antibunching. The present results indicate that molecular assemblies can also be considered as candidates for new single-photon sources.

[DOI : 10.1143/JJAP.46.L268]

**Keywords:** nanocrystal, single-photon source, photon antibunching, quantum cryptography, photon correlation measurement, coincidence measurement, emission, perylenebisimide, molecular assembly

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## Strong Intersubband Absorption in $\text{EuTe}/\text{PbTe}$ Double-Well Superlattices at Normal Incidence

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$\text{EuTe}/\text{PbTe}$  double-well superlattices with two kinds of  $\text{PbTe}$  quantum wells separated by monolayer  $\text{EuTe}$  were prepared on  $\text{KCl}(100)$  substrates by hot wall epitaxy. Strong intersubband absorptions as high as  $2000\text{ cm}^{-1}$  in absorption coefficient were observed for  $n$ -type samples with a carrier concentration as high as  $3 \times 10^{18}\text{ cm}^{-3}$  at normal incidence. The absorption was caused through the modulation of quantum-well potential along superlattice direction at  $L$ -point of the Brillouin zone. Temperature dependence of the optical transmission properties was also measured and the absorption peak showed a large tunability of  $0.9\text{ cm}^{-1}\text{ K}^{-1}$  caused by large temperature dependence of effective masses in  $\text{PbTe}$ .

[DOI : 10.1143/JJAP.46.L281]

**Keywords:** intersubband absorption, IV-VI semiconductor, superlattice, quantum well, optical property

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## $\text{AlGaIn}$ -Cladding-Free Nonpolar $\text{InGaIn}/\text{GaIn}$ Laser Diodes

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We demonstrate highly manufacturable nonpolar ( $m$ -plane)  $\text{InGaIn}/\text{GaIn}$  laser diodes without any  $\text{Al}$ -containing waveguide cladding layers. These devices utilize thick  $\text{InGaIn}$  quantum wells to generate transverse optical mode confinement and can be grown and fabricated in a manner analogous to  $\text{InGaIn}/\text{GaIn}$  light emitting diodes. Pulsed lasing operation was demonstrated, with threshold voltages and current densities of 6.7 V and  $3.7\text{ kA/cm}^2$ , respectively. [DOI : 10.1143/JJAP.46.L284]

**Keywords:**  $\text{GaIn}$ , nonpolar,  $m$ -plane, laser diode

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