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An InAs-Based Intersubband Quantum Cascade Laser

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Quantum cascade laser structures using InAs quantum wells are designed, grown by molecular beam epitaxy, and processed into lasers. The intersubband transition is chosen to be bound-to-continuum and the double plasmon waveguide is employed as a cladding structure. Lasing at $10.1\mu\text{m}$ has been observed at 4K with a threshold current density of 5.2 kA/cm^2 . [DOI: 10.1143/JJAP.41.L1279]

KEYWORDS: quantum cascade laser, type-II quantum well, intersubband transition, molecular beam epitaxy

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Nitrogen-Doped p-Type ZnO Layers Prepared with H_2O Vapor-Assisted Metalorganic Molecular-Beam Epitaxy

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Nitrogen (N) doping in ZnO is studied to realize reproducible p-type conductivity. Undoped ZnO layers prepared on a-face of sapphire substrates with H_2O vapor-assisted growth showed n-type conductivity. However, N-doped ZnO (ZnO:N) layers grown in the similar manner showed the type conversion to p-type conductivity. As-grown p-type ZnO:N layers showed low net acceptor concentrations ($N_A - N_D$) of $\sim 10^{14}\text{ cm}^{-3}$, but thermal annealing of the N-doped ZnO samples as well as the optimization of growth parameters increased the $N_A - N_D$ up to $\sim 5 \times 10^{16}\text{ cm}^{-3}$. Photoluminescence measurements showed consistent spectra with the electrical properties by a clear conversion from neutral donor-bound exciton emission in n-ZnO to neutral acceptor-bound exciton emission in the p-ZnO layers. [DOI: 10.1143/JJAP.41.L1281]

KEYWORDS: H_2O vapor, undoped ZnO, N doped p-ZnO, H passivation, neutral acceptor-bound exciton

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Observation of Stark Spectra of Argon High Rydberg States in Well-Defined Electric Fields by Laser-Induced Fluorescence-Dip Spectroscopy

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We detected high Rydberg states of Ar which had energies close to the $^2P_{3/2}^0$ first ionization potential by laser-induced fluorescence-dip spectroscopy, and observed the Stark spectra of the high Rydberg states in well-defined electric fields. The detection was carried out by a two-step laser excitation technique ($4s[3/2]_2^0 \rightarrow 4p[3/2]_2 \rightarrow$ high Rydberg states). In the presence of electric fields, the Stark mixing made the $4p[3/2]_2 \rightarrow np$ forbidden transitions observable. It has been shown that the Stark shift of the np state is a good measure for the determination of the electric field strength. A detection limit of 6 V/cm has been demonstrated, which is the most sensitive detection limit when the Stark effect of an inert gas useful for applications is used for the electric field measurement. [DOI: 10.1143/JJAP.41.L1285]

KEYWORDS: Stark effect, Ar, Rydberg state, electric field measurement, LIF-dip spectroscopy

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Photo-Rubbing: A General Method to Induce Durable Liquid-Crystal Pretilt Angle on Photo-Alignment Films

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A normal-incidence single-exposure scheme to obtain a stable pretilted alignment of nematic liquid crystals on photo-alignment polymer layers is proposed. The new scheme consists in periodically modulating the intensity of the normally incident linearly polarized near-ultraviolet light and unidirectionally scanning it on the photosensitive alignment layer. By properly choosing the relative directions of scan and polarization, this scheme works for any types of photo-alignment materials regardless of the resultant alignment direction relative to the polarization direction of the UV light. The pretilt appears in such a way that the nematic director is lifted up in the scan direction, similar to the case of the conventional cloth rubbing. This "photo-rubbing" method allows a fairly accurate control of the pretilt angle by way of the scan speed. [DOI: 10.1143/JJAP.41.L1345]

KEYWORDS: photo-alignment, surface alignment, pretilt angle, liquid crystal, scanning, rubbing

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A Metastable Precursor in the Oxidation of Si(111)-(7 × 7)

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We have studied the initial adsorption of O₂ on Si(111) at 78K using scanning tunneling microscope (STM). The dominant products at 78K appear darker than the unreacted Si adatoms, in contrast to the adsorption at room temperature where the dominant products appear bright. The dark site is found to be a precursor to the bright site. The reaction of the precursor is very slow at 78K ($\tau > 64$ h, τ : lifetime of the precursor), but can be readily induced by the STM tip. We briefly discuss the chemical configurations of the reaction products. [DOI: 10.1143/JJAP.41.L1419]

KEYWORDS: scanning tunneling microscope, silicon, oxygen, precursor, manipulation

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Preparation of Freestanding GaN Wafers by Hydride Vapor Phase Epitaxy with Void-Assisted Separation

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(Received November 11, 2002; accepted for publication December 3, 2002)

We have developed a novel technique for preparing large-scale free-standing GaN wafers. Hydride vapor phase epitaxy (HVPE) growth of thick GaN layer was performed on a GaN template with a thin TiN film on the top. After the cooling process of the HVPE growth, the thick GaN layer was easily separated from the template by the assistance of many voids generated around the TiN film. As a result, a freestanding GaN wafer was obtained. The wafer obtained had a diameter of 45 mm, and a mirror-like surface. The full-width-at-half-maximum (FWHM) of (0002) and (10 $\bar{1}0$) peaks in the X-ray rocking curve profile were 60 and 92 arc-sec, respectively. The dislocation density was evaluated at 5×10^6 cm⁻³ by etch pit density measurement. [DOI: 10.1143/JJAP.42.L1]

KEYWORDS: freestanding GaN, HVPE, TiN, X-ray diffraction, etch pit, TEM

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Sign Inversion of Photocarrier in Poly(3-octadecylthiophene) Associated with Solid-Liquid Phase Transition

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(Received October 30, 2002; accepted for publication November 8, 2002)

In this paper, we have shown that the sign inversion of photocarrier in a fusible conjugated polymer, regiorandom poly(3-octadecylthiophene) associated with the solid-liquid phase transition. The transient photocurrent by hole is clearly observed in the solid state, while it weakens to be below the noise level in the liquid state. On the other hand, the transient photocurrent by a negative carrier can be clearly observed not in the solid state but in the liquid state. The mobility has been found in a narrow range from 10^{-6} to 10^{-5} cm²/V-s for both positive and negative carriers, except for the temperature near the melting point. This indicates not only that the photocarrier in the liquid state is not ionic but electronic one, but also that the same mechanism, i.e. interchain hopping of carrier, dominantly limits their transport. The drastic conformational change of polymer backbone induced by the thermal activation of side chain vibration, which is responsible for the thermochromism in poly(3-alkylthiophene)s, may play a key role for this unique phenomenon. [DOI: 10.1143/JJAP.41.L1422]

KEYWORDS: conjugated polymers, photocarrier, mobility, sign inversion, time-of-flight method, poly(3-alkylthiophene), phase transition, liquid state

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Growth of a Large GaN Single Crystal Using the Liquid Phase Epitaxy (LPE) Technique

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(Received November 28, 2002; accepted for publication December 4, 2002)

We grew a $12 \times 5 \times 0.8$ mm GaN single crystal using the liquid phase epitaxy (LPE) method with Na flux. This GaN single crystal was grown on a 3 μ m-thick GaN thin film synthesized on sapphire using the metal organic chemical vapor deposition (MOCVD) method. It grew in a polyhedral form larger than the MOCVD-GaN substrate. Results indicate that a MOCVD-GaN thin film on a sapphire substrate functions as a seed crystal in Na flux. The use of mixed nitrogen gas containing 40% ammonia instead of pure N₂ gas also enabled the growth of a 10 μ m-thick GaN homo-epitaxial film on an MOCVD-GaN film under 5 atm, the lowest reported pressure for growing GaN in Na flux. In this paper, we describe the liquid phase epitaxy (LPE) technique for growing bulk GaN single crystals, as well as the results of photoluminescence (PL) measurements. We also compare the PL intensity of the bulk GaN obtained in this study and the MOCVD-GaN. PL measurements revealed that the peak intensity of GaN single crystal grown by LPE indicates 40 times larger than MOCVD-GaN film. Also, dislocation density of bulk GaN crystals could be drastically reduced by the LPE growth technique. [DOI: 10.1143/JJAP.42.L4]

KEYWORDS: GaN, LPE, single crystal, high pressure, bulk, high quality, photoluminescence

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Free-Standing InAs/InGaAs Microtubes and Microspirals on InAs (100)

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(Received December 11, 2002; accepted for publication December 12, 2002)

A new material system for creating InAs-based free-standing micro- and nanoobjects is proposed. For the first time, InAs/InGaAs microtubes and microspirals were obtained, including tubes containing two-dimensional electron gas, ordered arrays of tubes, and tubes protruding over the substrate edge. First measurements of the electrical conductivity of InAs/InGaAs microtubes were performed. [DOI: 10.1143/JJAP.42.L7]

KEYWORDS: InAs, free-standing microobjects, semiconductor microtubes, AlSb, selective etching

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Spin-Polarized Electron Injection through an Fe/InAs Junction

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(Received December 17, 2002; accepted for publication January 6, 2003)

We report on the spin-polarized electron injection through an Fe(100)/InAs(100) junction. The circularly polarized electroluminescence of injected electrons from epitaxially grown Fe thin film into InAs(100) in an external magnetic field is measured to investigate the spin injection efficiency. The obtained polarization of the electroluminescence is seen to increase up to about – 12% at the temperature of 6.5K and the external magnetic field of 10 T. This result suggests that the efficient spin injection is possible through the ferromagnetic metal/semiconductor (FM/SC) interface without a tunneling barrier despite the contradictory arguments based on conductivity mismatch at the FM/SC interface. [DOI: 10.1143/JJAP.42.L87]

KEYWORDS: Fe/InAs junction, spin injection, spintronics, indium arsenide, epitaxial growth, Zeeman splitting

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Efficient Second-Harmonic Generation of 340-nm Light in a 1.4- μ m Periodically Poled Bulk MgO:LiNbO₃

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(Received December 6, 2002; accepted for publication December 20, 2002)

Ultra-violet second-harmonic generation in a 1.4 μ m periodically poled MgO:LiNbO₃ is presented. Using a high-voltage multi-pulse application method, a first-order nonlinear grating with a period of 1.4 μ m was fabricated over 10-mm interaction length in a 2-mm thick MgO:LiNbO₃ substrate. In a single pass configuration, cw 1.2mW of ultraviolet light at 341.5 nm was successfully obtained for a fundamental power of 141 mW, corresponding to a normalized conversion efficiency of 5.4%/ W. [DOI: 10.1143/JJAP.42.L90]

KEYWORDS: second-harmonic generation, quasi-phase matching, periodically poled MgO:LiNbO₃, ultraviolet, nonlinear, bulk

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Nanoelectrode Lithography

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A new lithographic method is proposed and demonstrated that has the potential to make nano-fabrication a more widely available technique. Nanoelectrode lithography works by transferring the pattern on a nanoelectrode to a target via an electrochemical reaction. This technique may provide a better throughput and flexibility than conventional lithographic techniques. This describes and proves the concept of nanoelectrode lithography. [DOI: 10.1143/JJAP.42.L92]

KEYWORDS: lithography, nanoelectrode, anodic oxidation, atomic force microscope, nanoprint

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Avalanche-Type High Sensitive Image Pickup Tube Using an a-Se Photoconductive Target

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The avalanche-type high sensitive image pickup tube using 8 μm thick a-Se layer was fabricated. The avalanche multiplication factor of photogenerated carriers was increased with increasing a target voltage. The quantum efficiency in an avalanche mode (target voltage: 880V) was higher than that in a non-avalanche mode (target voltage: 500V). Also the relative sensitivity in an avalanche mode at long wavelength was increased up to 620nm by the increase of the photodetection efficiency. The dark current was suppressed under 0.3 nA at a target voltage of 820 V, and decay lag at the third field was 1.2%. [DOI: 10.1143/JJAP.42.L209]

KEYWORDS: image pickup tube, photoconductive target, avalanche multiplication, quantum efficiency, relative sensitivity, amorphous selenium

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Electrical Properties of Poly(dA)-Poly(dT) and Poly(dG)-Poly(dC) DNA Doped with Iodine Molecules

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Electrical resistivity of Poly(dA)-Poly(dT) and Poly(dG)-Poly(dC) DNA were measured in a vacuum on nano-gap electrodes separated by 30–50 nm. The DNAs showed very low conductivity of less than 0.1 pA at 1V. On the other hand, I₂-doped Poly(dA)-Poly(dT) and Poly(dG)-Poly(dC) DNA form conducting DNAs, the current of which increased with an increase in the doping time. Doped Poly(dG)-Poly(dC) DNA shows higher current than doped Poly(dA)-Poly(dT) DNA. Time dependence of resistivity of Poly(dG)-Poly(dC) DNA doped with iodine molecules exhibited that the total current composes of both hole current and ion current. [DOI: 10.1143/JJAP.42.L215]

KEYWORDS: Poly(dA)-Poly(dT) DNA, Poly(dG)-Poly(dC) DNA, chemical doping, dc measurement, electron transport, ionic conduction

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Plasma Induced Subsurface Reactions for Anisotropic Etching of Organic Low Dielectric Film Employing N₂ and H₂ Gas Chemistry

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Subsurface reactions of organic low dielectric (low k) film exposed to plasmas with low ion bombardment energy were investigated by a real time analysis of Fourier transform infrared attenuated total reflection (FT-IR ATR). The exposure of N₂ plasma resulted in the formation of a CN layer composed of C(sp²)=N and C(sp³)–N bonds. After the N₂ plasma exposure, the surface was exposed to H₂ plasma. C(sp¹)=N and C(sp²)=N bonds were removed by the H radicals, while the C(sp³)–N bond remained. It was found that the C(sp³)–N bond was the key chemical bond against H₂ plasma exposure. Based on the analyses, a reaction model for anisotropic profile in organic low k film etching employing N–H plasmas is proposed. [DOI: 10.1143/JJAP.42.L212]

KEYWORDS: low k , etching, FT-IR ATR, CN layer, N₂/H₂ plasma, VU-VAS

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Quantitative Detection of Small Amount of Nitrogen in Czochralski-Grown Silicon Crystals

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We successfully detected small amounts of nitrogen with a concentration of $3 \times 10^{13} \text{cm}^{-3}$ in a nitrogen-doped Czochralski-grown Si crystal. O–N–O complexes (or shallow thermal donors) were observed through infrared spectroscopy of electronic transition between hydrogen-like levels of the complexes. This method is very sensitive and shows promise as a means of quantitatively detecting nitrogen in Si wafers of 10^{12} – 10^{14}cm^{-3} . We found that almost all the N was in the form of O–N–O complexes when the N concentration is less than $1 \times 10^{14} \text{cm}^{-3}$. Therefore, conventional methods that measure localized vibrational modes due to N–N and N–N–O complexes cannot detect nitrogen of less than $1 \times 10^{14} \text{cm}^{-3}$, not only because of the detection limit but also the lack of such vibrational centers. [DOI: 10.1143/JJAP.42.L261]

KEYWORDS: nitrogen, Czochralski-grown, silicon, infrared absorption, electronic transition, concentration

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In-Plane Orientation and Polarity of ZnO Epitaxial Films on As-Polished Sapphire (α - Al_2O_3) (0001) Substrates Grown by Metal Organic Chemical Vapor Deposition

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We report the control of the in-plane orientation of ZnO epitaxial films grown on as-polished sapphire (α - Al_2O_3) (0001) substrates by metal organic chemical vapor deposition (MOCVD). When passing certain flows of Zn-precursor over the substrate before introducing oxygen-precursor at certain substrate temperatures, unit cells of the ZnO film show the same inplane orientation as the substrate. Otherwise, 30° rotation is observed between unit cells of ZnO and the substrate. In case of using diethylzinc (DEZn) and oxygen gas as precursors, the substrate temperature and the flow rate of DEZn, under which notwist ZnO films can be obtained, are determined experimentally. Measurements by coaxial impact collision ion scattering spectroscopy (CAICISS), however, demonstrate that the ZnO films all have +c polarity, regardless of their in-plane orientation. This is different from the results obtained by laser-molecular beam epitaxy by which +c polarity on as-polished sapphire (0001) substrates are hardly obtained. Since the +c polarity film is preferable in applications of wurtzite semiconductors, our results reveal that MOCVD technique is particularly important in future applications of ZnO-related oxides. [DOI: 10.1143/JJAP.42.L264]

KEYWORDS: ZnO, MOCVD, polarity, epitaxy, thin film, wide gap semiconductor, X-ray diffraction, sapphire, CAICISS

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Significant Enhancement of $\text{Bi}_{3.45}\text{La}_{0.75}\text{Ti}_3\text{O}_{12}$ Ferroelectricity Derived by Sol-Gel Method

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The ferroelectricity of sol-gel derived 80-nm $\text{Bi}_{3.45}\text{La}_{0.75}\text{Ti}_3\text{O}_{12}$ (BLT) films was significantly enhanced by low-pressure baking during the sol-gel process. The ferroelectricity enhancement was caused by the low-pressure baking after the drying process in air and before the crystallization of the dried gel. The maximum remanent polarization (P_r) was 27.2 $\mu\text{C}/\text{cm}^2$, which was achieved after baking at 1.3 kPa oxygen pressure. The coercive field of 54.3 kV/cm was also achieved at the same time. This P_r value is 2.3 times larger than the value attainable with the usual 1-atm baking process. The saturation property of the same capacitor proved that $\pm 2\text{V}$ operation is possible. It was also found that the enhanced polarization is fatigue-free up to 10^{10} switching cycles. [DOI: 10.1143/JJAP.42.L267]

KEYWORDS: BLT, remanent polarization, sol-gel, low pressure, bake

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High Mobility Thin Film Transistors with Transparent ZnO Channels

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We have fabricated high performance ZnO thin film transistors (TFTs) using CaHfO_x buffer layer between ZnO channel and amorphous silicon–nitride gate insulator. The TFT structure, dimensions, and materials set are identical to those of the commercial amorphous silicon (a-Si) TFTs in active matrix liquid crystal display, except for the channel and buffer layers replacing a-Si. The field effect mobility can be as high as 7 $\text{cm}^2/\text{V} \cdot \text{s}$ for devices with maximum process temperature of 300°C. The process temperature can be reduced to 150°C without much degrading the performance, showing the possibility of the use of polymer substrate. [DOI: 10.1143/JJAP.42.L347]

KEYWORDS: ZnO, CaHfO_x , TFT, pulsed laser deposition, field effect mobility

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Direct Synthesis of fct-FePt Nanoparticles by Chemical Route

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Direct synthesis of fct-FePt nanoparticles was achieved by reducing platinum and iron acetylacetonates in tetraethylene glycol (TEG) at 300°C. The particle diameter was between 5 and 10 nm. The X-ray diffraction profile of the as-prepared FePt particles exhibited the superlattice reflections (001) and (110), which signified the tetragonality. The H_k of 31 kOe measured at room temperature (RT) from hysteresis loss analysis confirmed the presence of FePt particles with fractionally ordered fct structure which possesses substantially high anisotropy. However, the RT coercivity was only 370 Oe due to strong magnetostatic interaction of the particles. [DOI: 10.1143/JJAP.42.L350]

KEYWORDS: FePt, nanoparticles, fct-FePt, L1₀ phase, super lattice reflections, polyol process, direct synthesis, coercive field, hysteresis loss analysis

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Molecular Beam Epitaxy of High Magnesium Content Single-Phase Wurzite Mg_xZn_{1-x}O Alloys ($x \approx 0.5$) and Their Application to Solar-Blind Region Photodetectors

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A series of single-phase wurzite Mg_xZn_{1-x}O alloys from $x = 0$ to 0.5 were successfully obtained by molecular beam epitaxial growth on sapphire substrates, resulting in artificial tuning of band gap energy E_g from 3.3 to 4.5 eV which covers UV-A, UV-B, and solar-blind spectral regions. The problem of phase separation ever reported in the growth of Mg_xZn_{1-x}O with higher Mg content, e.g., $x > 0.4$ and $E_g > 3.9$ eV, has been overcome by using a ZnO buffer layer. The Mg_{0.5}Zn_{0.5}O layers have been applied to a planar geometry Schottky type metal-semiconductor-metal photodetector, exhibiting the photoresponse for the wavelength shorter than 270 nm which correspond to the solar-blind region. [DOI: 10.1143/JJAP.42.L401]

KEYWORDS: MgZnO, MBE, ZnO buffer layer, solar-blind spectral region, UV photodetector

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Preparation of Ferroelectric Thin films Using Sol-Gel Solutions Dissolved in Supercritical Carbon Dioxide

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A novel method to form ferroelectric thin films is presented, in which sol-gel solutions such as Bi₂SiO₅-added Bi₄Ti₃O₁₂ (BIT) and Bi₂SiO₅-added SrBi₂Ta₂O₉ (SBT) were dissolved in supercritical CO₂ and ejected onto Pt-coated Si substrates in the atmosphere. The surface morphology of the deposited films was excellent even after crystallization annealing at 700°C for 30 min, and the remnant polarization values were 10 $\mu\text{C}/\text{cm}^2$ and 7 $\mu\text{C}/\text{cm}^2$ for BIT- and SBT-based films with 70 nm in thickness, respectively. It was also found that the leakage current depended on the post-annealing conditions; with increase of oxygen pressure during the annealing, the leakage current density was decreased to about $1.0 \times 10^{-7} \text{ A}/\text{cm}^2$. [DOI: 10.1143/JJAP.42.L404]

KEYWORDS: ferroelectric film, supercritical carbon dioxide, sol-gel solution, Bi₄Ti₃O₁₂, SrBi₂Ta₂O₉

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Ferroelectric Nematic Monolayer

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Ferroelectricity is desirable for realizing fast-response liquid crystal devices. Existing ferroelectric liquid crystals are improper with the spontaneous polarization P_s being indirectly induced by the broken centrosymmetry of molecular arrangement. We found that Langmuir monolayers of certain dialkylated nematic compound exhibit a laterally polarized two-dimensional ferroelectric nematic. The P_s is comparable to that of chiral smectic liquid crystals, and shows a fast linear electro-optic switching with a microsecond response. Estimates of electrostatic energy suggest that the ferroelectricity may be driven by the direct dipolar interactions. [DOI: 10.1143/JJAP.42.L406]

KEYWORDS: intrinsic ferroelectricity, nematic liquid crystal, achiral molecule, spontaneous polarization, Langmuir monolayer, dipolar interaction, two-dimensionality

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