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## High-Quality AlN by Initial Layer-by-Layer Growth on Surface-Controlled 4H–SiC(0001) Substrate

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(Received March 24, 2003; accepted for publication April 1, 2003)

The initial layer-by-layer growth of AlN was realized on a surface-controlled 4H–SiC(0001) substrate using plasma-assisted molecular-beam epitaxy (PA-MBE). To achieve initial two-dimensional (2D) growth, the control of SiC surface chemistry is very important as well as that of surface flatness. The effect of SiC preparation on the surface structure and chemical composition was investigated by using reflection high-energy electron diffraction (RHEED) and *in situ* X-ray photoelectron spectroscopy (XPS). The initial growth mode of AlN was strongly influenced by the removal of residual oxygen atoms from the SiC surface. Symmetrical and asymmetrical X-ray rocking curve (XRC) measurements revealed that initial 2D growth was essential to obtain the excellent crystalline quality of AlN layer. [DOI:10.1143 / JJAP.42.L445]

**KEYWORDS:** AlN, SiC, MBE, surface control, RHEED intensity oscillation, in-plane misorientation

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## Digital Sorting of Flow-through Droplet Phase Microfluid

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The *in-plane digital sorting* of the multiphase microfluid flow is presented in the laminar flow regime. It is achieved by manipulating the pitch of alternate microfluid flow and delay distance resulting from passing through special microchannels. The theoretical analysis derives delay distance. For experimental evaluation, a characteristic in-plane microchannel is fabricated by using micromachining. The pitch of the alternate microfluid flow is controlled. Digital sorting is demonstrated by using the immiscible droplet phase fluids. Also, the dynamic behavior of the droplet phase microfluids is measured by the particle image velocimetry (micro-PIV) and characterized qualitatively and quantitatively. [DOI:10.1143 / JJAP.42.L448]

**KEYWORDS:** digital sorting, droplet phase, alternate fluid, delay distance, micro-PIV

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## InGaN-Based Single-Chip Multicolor Light-Emitting Diodes

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(Received April 7, 2003; accepted for publication April 14, 2003)

A light-emitting diode (LED) driving technique to realize single-chip multicolor LEDs was proposed. The technique utilizes one of the characteristics of InGaN-based visible LEDs, the current-induced spectral blue-shift. By applying pulsed current, which had two pulses of different amplitude in a cycle, to an InGaN single-quantum-well green LED, the light of two wavelengths corresponding to bluegreen and green was emitted from the same point, and the emission color of the LED was controlled continuously from bluegreen to green by adjusting only the pulse widths. [DOI:10.1143 / JJAP.42.L497]

**KEYWORDS:** InGaN, single chip, multicolor, LED, spectral blueshift, pulsed current

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## Magnetic Tunnel Junction (MTJ) Patterning for Magnetic Random Access Memory (MRAM) Process Applications

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We have developed a top free type magnetic tunnel junction (MTJ) patterning technique that involves tunnel barrier etching with enough time margins for chemical assisted ion etching (CAIE). The approximately 1nm thick tunnel barrier enables stopping the etching process in a shorter time margin. We have found that no aluminum-oxide barrier shorting by re-deposition occurred in chlorine based CAIE, when the etching depth into anti-ferromagnetic IrMn layer was less than 5nm. The magnetoresistance (MR) ratio of the whole MTJ patterns reached 35% on a 6-inch wafer. The time margin of the etching was 120s, which is long enough for an magnetic random access memory (MRAM) process. [DOI:10.1143 / JJAP.42.L499]

**KEYWORDS:** magnetic tunnel junction, reactive ion etching, MRAM, tunnel barrier

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## Highly Efficient Room Temperature Spin Injection in a Metal-Insulator-Semiconductor Light-Emitting Diode

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(Received March 31, 2003; accepted for publication April 8, 2003)

We demonstrate highly efficient spin injection at low and room temperature in an AlGaAs/GaAs semiconductor heterostructure from a CoFe/AIO<sub>x</sub> tunnel spin injector. We use a double-step oxide deposition for the fabrication of a pinhole-free AlO<sub>x</sub> tunnel barrier. The measurements of the circular polarization of the electroluminescence in the Oblique Hanle Effect geometry reveal injected spin polarizations of at least 24% at 80K and 12% at room temperature.

[DOI:10.1143 / JJAP.42.L502]

**KEYWORDS:** spin injection, spintronics, room temperature, tunnel barrier

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## Behavior of Impurity Ion Velocities during the Pulsed Poloidal Current Drive in the Madison Symmetric Torus Reversed-Field Pinch

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(Received March 25, 2003; accepted for publication April 9, 2003)

We report on passive measurements of impurity ion velocities during the pulsed poloidal current drive (PPCD) in the Madison Symmetric Torus reversed-field pinch. During PPCD, the electron temperature increased and a sudden reduction of magnetic fluctuations was observed. For this change, we have studied whether plasma velocity is affected. Plasma rotation is observed to decrease during PPCD. From measurements of line intensities for several impurities at 10 poloidal chords, it is found that the impurity line emission shifts outward. The ion temperature of impurities is reasonably connected to that measured by charge exchange recombination spectroscopy from core to edge. [DOI:10.1143 / JJAP.42.L505]

**KEYWORDS:** plasma velocity, ion temperature, impurity emission, equilibrium reconstruction, pulsed poloidal current drive, reversed field pinch

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## Growth of Bulk GaN Single Crystals Using Li-Na Mixed Flux System

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(Received March 31, 2003; accepted for publication April 21, 2003)

We found the yield of GaN grown in a Li-Na flux system to be much higher than that grown in Na flux. Nitrogen dissolution seemed to increase with Li in solution, which promotes the growth of GaN crystals. In this paper, we report that the yield of GaN and habit modifications greatly depend on the composition of the Li-Na flux system and that GaN can be grown in a pure Li flux at about 50atm.

[DOI:10.1143 / JJAP.42.L565]

**KEYWORDS:** GaN, flux method, single crystal, high pressure, bulk, LPE, nitrogen vacancy, habit modification

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## Self-Tailored One-Dimensional ZnO Nanodot Arrays Formed by Metalorganic Chemical Vapor Deposition

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(Received April 11, 2003; accepted for publication April 18, 2003)

One-dimensional ZnO nanodot arrays have been realized by metal-organic chemical vapor deposition on SiO<sub>2</sub> substrates patterned by focused ion beam (FIB). Especially for the lines with the depth of 5nm and the length of 0.7, 1.3 or 1.7μm, one, two or three nanodots, respectively, of fairly uniform size 6-nm height and 80-nm width are symmetrically accommodated in a line. These phenomena are translated as "self-tailoring" of ZnO nanodots, i.e., where the nanodots will be is predetermined before the growth and is arbitrarily controlled by the nanopatterns. This can be a promising technique to build nanostructure blocks for nanoscale device applications. [DOI:10.1143 / JJAP.42.L568]

**KEYWORDS:** ZnO, one-dimensional, nanodot arrays, self-tailoring, MOCVD, FIB, SiO<sub>2</sub>

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## The Electrical Characteristics of Metal-Oxide-Semiconductor Field Effect Transistors Fabricated on Cubic Silicon Carbide

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(Received April 30, 2003; accepted for publication May 9, 2003)

The n-channel metal-oxide-semiconductor field effect transistors (MOSFETs) were fabricated on cubic silicon carbide (3C-SiC) epitaxial layers grown on 3C-SiC substrates. The gate oxide of the MOSFETs was formed using pyrogenic oxidation at 1100°C. The 3C-SiC MOSFETs showed enhancement type behaviors after annealing at 200°C for 30min in argon atmosphere. The maximum value of the effective channel mobility of the 3C-SiC MOSFETs was 260cm<sup>2</sup>/V·s. The leakage current of gate oxide was of a few tens of nA/cm<sup>2</sup> at an electric field range below 8.5MV/cm, and breakdown began around 8.5MV/cm.

[DOI:10.1143 / JJAP.42.L625]

**KEYWORDS:** cubic-silicon carbide, metal-oxide-semiconductor field effect transistor, channel mobility, gate oxide breakdown

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## Growth of Transparent, Large Size GaN Single Crystal with Low Dislocations Using Ca-Na Flux System

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(Received May 6, 2003; accepted for publication May 23, 2003)

Growth of large and transparent GaN single crystals was carried out by applying the liquid phase epitaxy (LPE) method in a Ca-Na mixed flux system. We have previously reported LPE growth of GaN in a Na flux system, and that GaN crystals grown by LPE have extreme low dislocations and show excellent photoluminescence characteristics. In this study, use of a Ca-Na mixed flux system enabled us to grow transparent GaN crystals under low nitrogen pressure and to further improve the photoluminescence (PL) characteristic. The dislocation density of this crystal is very low ( $2 \times 10^5 \text{ cm}^{-2}$  in highest point). [DOI:10.1143 / JJAP.42.L729]

**KEYWORDS:** GaN, bulk, LPE, photoluminescence, film, flux

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## 292nm AlGaIn Single-Quantum Well Light Emitting Diodes Grown on Transparent AlN Base

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(Received May 8, 2003; accepted for publication May 9, 2003)

We report the use of a novel transparent AlN base layer to achieve sub-300nm electroluminescence from an AlGaIn *p-n* junction single quantum well light emitting diode grown on sapphire by metal organic chemical vapor deposition. For unpackaged devices tested on wafer at a continuous current of 120mA, an optical power of 2.4μW was achieved. Peak emission was 292nm, with very little secondary wavelength emission. [DOI:10.1143 / JJAP.42.L628]

**KEYWORDS:** LED, MOCVD, ultraviolet, UV, AlN, AlGaIn

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## Ultrathin Oxynitride Films Formed by Using Pulse-Time-Modulated Nitrogen Beams

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(Received May 27, 2003; accepted for publication June 9, 2003)

Ultra thin Si oxynitride (SiO<sub>x</sub>N<sub>y</sub>) films have been identified as leading candidates to replace conventional SiO<sub>2</sub> gate dielectrics for present and future ultra large-scale integrated circuits. Remote plasma processes for top surface nitridation of thermally grown oxides have been developed and applied in complementary metal-oxide-silicon (MOS) device applications. However, it is much difficult to control the concentration and position of nitrogen in ultrathin Si oxynitride film by using plasma processing and there are many serious problems, such as plasma radiation damage and increases in interface state density due to N penetrating the SiO<sub>2</sub>-Si interface. To overcome these problems, we propose using pulse-time-modulated N<sub>2</sub> neutral beams. We first found that the concentration and position of nitrogen in ultrathin Si oxynitride film could be controlled by changing the pulse-on time in the pulse-time-modulated N<sub>2</sub> neutral beams without any radiation damage. It is speculated that the injected N<sub>2</sub> was diffused at a time constant of a few tens of μseconds in the thermal SiO<sub>2</sub> film. [DOI:10.1143 / JJAP.42.L795]

**KEYWORDS:** metal-oxide-semiconductor, gate dielectric film, oxynitride, plasma, nitridation, beam

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## Laser Irradiated Growth of Protein Crystal

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We succeeded in the first ever generation of protein crystals by laser irradiation. We call this process Laser Irradiated Growth Technique (LIGHT). Effective crystallization was confirmed by applying an intense femtosecond laser. The crystallization period was dramatically shortened by LIGHT. In addition, protein crystals were obtained by LIGHT from normally uncrystallized conditions. These results indicate that intense femtosecond laser irradiation generates crystal nuclei; protein crystals can then be grown from the nuclei that act as seeds in a supersaturated solution. The nuclei formation is possible primarily due to nonlinear nucleation processes of an intense femtosecond laser with a peak intensity of over a gigawatt (GW). [DOI:10.1143 / JJAP.42.L798]

**KEYWORDS:** protein crystal, nucleation, laser, short-pulse, supersaturated solution

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## Image Pickup from Zinc Phthalocyanine/Bathocuproine Double-Layer Film Using Pickup Tube

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We have demonstrated image pickup from zinc phthalocyanine/bathocuproine double-layer film incorporated into a pickup tube for both standard television systems and high-definition television (HDTV) systems. A limiting resolution of more than 800 television lines was obtained, which is sufficient for HDTV. The peak external quantum efficiency was 14.7% under 620nm irradiation. The results indicate that organic molecules have great potential for use in imaging devices.

[DOI:10.1143 / JJAP.42.L801]

**KEYWORDS:** organic photoconductive film, imaging device, pickup tube, resolution, quantum efficiency

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## Synthesis of Aligned Carbon Nanofibers at 200°C

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Aligned carbon nanofibers (CNFs) were synthesized at a growth temperature as low as 200°C by inductively coupled plasma chemical vapor deposition with hydrogen and methane gas mixtures. The synthesized CNFs were aligned perpendicular to the substrate and capped with a single-crystal Ni nanoparticle. The results indicate that the hydrogen species play a significant role in both the reduction of carbonaceous particles deposits and the formation of catalyst particles by effecting a moderate etching during the inductively coupled chemical vapor deposition.

[DOI:10.1143 / JJAP.42.L804]

**KEYWORDS:** aligned carbon nanofibers, inductively coupled plasma chemical vapor deposition, low-temperature synthesis, hydrogen, etching

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## Novel Liquid Phase Epitaxy (LPE) Growth Method for Growing Large GaN Single Crystals: Introduction of the Flux Film Coated-Liquid Phase Epitaxy (FFC-LPE) Method

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We developed a new liquid phase epitaxy (LPE) growth method for growing large GaN single crystals. In this method, the homo-epitaxial growth of the GaN crystal proceeds by nitrogen dissolution against a Na-Ga solution film coating the GaN thin-film substrate. A growth rate of 4μm/h was achieved though nitrogen pressure was relatively low at 9.5atm. Furthermore, the GaN film grown by this method showed a flat surface. [DOI:10.1143 / JJAP.42.L879]

**KEYWORDS:** GaN, LPE, single crystal, photoluminescence, bulk

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## Ohmic Contact Formation for N-Type Diamond by Selective Doping

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Ohmic contacts with low contact resistivity were formed on phosphorus-doped *n*-type {111} diamond thin films grown by microwave-plasma chemical-vapor deposition. Heavily-doped diamond layers were selectively grown on a diamond substrate by covering a part of substrate surface with a titanium/gold layer. Gold contacts deposited directly on a lightly phosphorus-doped diamond showed a rectification characteristic, while those formed on the selectively grown, heavily doped diamond layers showed an Ohmic characteristic. The Ohmic property of contacts formed with the heavily doped layers was found to be independent of the metals. It is therefore concluded that the tunneling current dominates carrier transport at the interface between the metal and the heavily doped *n*-type diamond. [DOI:10.1143/JJAP.42.L882]

**KEYWORDS:** *n*-type diamond, Ohmic contact, selective growth, heavily doping

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## *T<sub>c</sub>*-Enhanced Codoping Method for GaAs-Based Dilute Magnetic Semiconductors

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(Received June 20, 2003; accepted for publication June 23, 2003)

Based on *ab initio* calculations of Ga<sub>1-x</sub>Mn<sub>x</sub>N<sub>y</sub>As<sub>1-y</sub> and Ga<sub>1-x</sub>Mn<sub>x</sub>C<sub>y</sub>As<sub>1-y</sub>, we propose a new codoping method to enhance the Curie temperature *T<sub>c</sub>* of diluted magnetic semiconductors. The solubility of Mn can be increased up to high concentration by the codoping of N or C to reduce the lattice and volume expansion caused by Mn doping. It is found that the impurity band of the majority spin is strongly broadened and pushed up into the higher energy region due to the strong *p-d* hybridization caused by the codoping, and the *T<sub>c</sub>* becomes higher than the room temperature at *x* > 6%. [DOI:10.1143/JJAP.42.L888]

**KEYWORDS:** *ab initio* calculation, III-V compound semiconductors, transition metal, codoping, dilute magnetic semiconductors, semiconductors spintronics, materials design

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## A UV Light-Emitting Diode Incorporating GaN Quantum Dots

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The fabrication and evaluation of a UV light-emitting diode (LED) incorporating GaN quantum dots as the active layer is demonstrated. The GaN quantum dots were fabricated on an Al<sub>x</sub>Ga<sub>1-x</sub>N (*x* ~ 0.1) surface using Si as an antisurfactant. Exposing the Al<sub>x</sub>Ga<sub>1-x</sub>N surface to the Si antisurfactant prior to GaN growth enabled the formation of quantum dots on a surface where growth by the Stranski-Krastanov mode would not be possible. A fairly high density of dots (10<sup>10</sup>–10<sup>11</sup>cm<sup>-2</sup>) with controllable dot sizes was achieved. Room temperature luminescence at 360nm was clearly observed during current injection (cw) into an LED structure including the GaN quantum dots. The origin of the electroluminescence is discussed by comparing it to photoluminescence measurements.

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**KEYWORDS:** nitride, quantum dot, UV-LED, MOVPE, antisurfactant, compositional fluctuation, electroluminescence, photoluminescence

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## Tight-Binding Calculation of Current Distribution in a Porphin Connected to Two Semi-Infinite Wires

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(Received June 6, 2003; accepted for publication June 13, 2003)

We have calculated current distribution in a porphin molecule connected to two semi-infinite wires using a tight-binding method. We found that loop currents larger than the incident ones, which have been predicted for a few other molecules, also appear in the present case. We also found that the current directions of two paths between electrodes are opposite in certain incident electron energies. These phenomena appear regardless of the electrode positions, though considerable changes by varying the positions are also seen. [DOI:10.1143/JJAP.42.L892]

**KEYWORDS:** porphyrin, single molecule, scattering states, tight-binding, current distribution

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## Structure and Properties of Silicon Thin Films Deposited at Low Substrate Temperatures

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Silicon thin films were grown near the microcrystalline/amorphous boundary at substrate temperatures  $T_s = 35\text{--}200^\circ\text{C}$  and dilutions  $[\text{H}_2]/[\text{SiH}_4] = 25\text{--}167$ . The conductivity percolation threshold occurred at crystallinity  $\sim 60\%$ , above the random composite threshold  $33.3\%$ , due to amorphous tissue coating crystalline grains and limiting the electronic transport. Higher content of hydrogen at lower  $T_s$  facilitates formation of ordered silicon phase even close to room temperature (the sample grown at  $35^\circ\text{C}$  had  $30\text{at}\%$  of hydrogen and crystallinity  $\sim 60\%$ ), providing a technological window for deposition of silicon thin films on cheap polymer substrates with electronic properties suitable for solar cells.

[DOI:10.1143 / JJAP.42.L987]

**KEYWORDS:** a-Si:H,  $\mu$ -Si:H, low temperature growth, plastic substrates, crystallinity, hydrogen, electronic transport

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## Enhanced Water-Window X-Ray Pulse Generation from Femtosecond-Laser-Produced Plasma with a Carbon Nanotube Target

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We adopt a carbon nanotube target to increase the efficiency of water-window X-ray pulse conversion from femtosecond-laser-produced plasma. The target is an array of vertically aligned multiwalled carbon nanotubes, each 30 nm in diameter and about 12- $\mu\text{m}$  long. Center-to-center nanotube distance is around 150nm. The X-ray fluence enhancement in the water-window region is seven-fold compared with a conventional carbon plate target. Further enhancement can be expected by optimizing the size of the carbon nanotubes. X-ray pulse duration is 26 ps. The results show that carbon nanotubes are very attractive as a target for femtosecond laser-produced-plasma X-ray sources in single-shot X-ray microscopy. [DOI:10.1143 / JJAP.42.L990]

**KEYWORDS:** laser plasma, X-ray pulse, water-window, carbon nanotube, X-ray microscopy

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## Ultraviolet Light Emitting Diodes Using Non-Polar *a*-Plane GaN-AlGa<sub>N</sub> Multiple Quantum Wells

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(Received July 14, 2003; accepted for publication July 22, 2003)

We report a pn-junction ultraviolet light-emitting diode (LED) with peak emission at 363 nm using *a*-plane GaN-AlGa<sub>N</sub> multiple quantum wells over *r*-plane sapphire. The peak emission wavelength does not shift with increasing pump currents-therefore establishing the feasibility of high-efficiency non-polar light emitting devices.

[DOI:10.1143 / JJAP.42.L1039]

**KEYWORDS:** *a*-plane GaN; non-polar, pn junction, MQWs, UV LED

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## Highly Adhesive Electroless Cu Layer Formation Using an Ultra Thin Ionized Cluster Beam (ICB)-Pd Catalytic Layer for Sub-100nm Cu Interconnections

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A continuous electroless-plated Cu film of only 10nm in thickness was successfully deposited on a TaN barrier over a 1nm-thick Pd catalytic layer formed by ionized cluster beam deposition. The electrical resistivity of the Cu interconnection was found to decrease as the Pd layer thickness was reduced, to as low as  $2.1\mu\Omega\cdot\text{cm}$  at a Pd thickness of 1nm. Moreover, the deposited film has adhesion strength as high as that of sputtered Cu on TaN, even for the case of the 1nm-thick Pd catalyst layer. A uniform and continuous 10nm-thick Cu seed layer was formed by electroless plating over a 1nm-thick Pd layer, and subsequent Cu electroplating filled all high aspect ratio via-holes without the appearance of voids. [DOI:10.1143 / JJAP.42.L1223]

**KEYWORDS:** electroless copper plating, adhesion, copper interconnections, CMP, damascene

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## Stabilization of the Position of a Solid Body Isolated in Micro-Gravity and Field-Induced Rotational-Oscillation Caused by Diamagnetic Anisotropy

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(Received August 25, 2003; accepted for publication September 4, 2003)

Stabilization was realized on the position of solid body isolated in diffused gas using micro-gravity. The c-planes of graphite single-crystals, stabilized in micro-gravity, showed rotational-oscillations with respect to magnetic field. Periods of oscillation agreed with theoretical values using field intensity, moment of inertia and published diamagnetic anisotropy of graphite. This method is a step to improve sensitivity of measuring magnetic anisotropy considerably. [DOI:10.1143 / JJAP.42.L1226]

**KEYWORDS:** stabilizing the position of solid body isolated in micro-gravity, rotational oscillation of solid body induced by magnetic-field in micro-gravity, graphite, diamagnetic anisotropy, magnetic torque measurement, measurement of magnetic anisotropy

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## A Novel Growth Approach of Ultrasmall Ge and Si Nanoclusters on a Si(100) Substrate without a Wetting Layer

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Growth of ultrasmall Ge and Si nanoclusters has been achieved on a Si(100) substrate in the use of Xe buffer layer. The temporary use of Xe buffer layer, which has the low surface free energy, leads to nanoclusters formation on Si(100) due to the indirect interaction between deposited Ge or Si atoms and a Si(100) substrate. The formation of Ge and Si nanoclusters on Si(100) surface without a wetting layer was confirmed by the scanning tunneling microscope observation. Ge nanoclusters are much smaller and denser than that are grown by the Stranski-Krastanov mode. [DOI:10.1143 / JJAP.42.L1232]

**KEYWORDS:** nanoclusters, growth, Ge islands, silicon, low-temperature synthesis, STM, MBE

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## Room-Temperature Ultraviolet Lasing from Zinc Oxide Microtubes

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Prismatic zinc oxide microtubes have been fabricated by vapor transport. Room-temperature ultraviolet lasing action has been demonstrated in these microtube arrays. The ZnO microtubes, mainly appearing in tapered bell-mouthed shape, form natural laser cavities along the length direction. The hexagon diagonal and length of the microtube vary from 1μm to 20μm and 10μm to a few hundredμm respectively. Under 355nm optical excitation, lasing action is observed at room-temperature around 393nm. Multi-longitudinal modes are also observed with significantly narrowed emission linewidth. [DOI:10.1143 / JJAP.42.L1229]

**KEYWORDS:** ZnO, microtube, UV lasing

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