発表論文リスト(デバイス工学分野)

(論文題目、発表者、論文誌名、アブストラクト)

Characterization of Deposited Materials Formed by Focused Ion Beam-Induced Chemical Vapor Deposition Using AuSi Alloyed Metal Source

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Jpn. J. Appl. Phys. Vol. 47, pp. 5018-5021 (2008)

Focused ion beam-induced chemical vapor deposition (FIB-CVD) using Au or Si FIBs with phenanthrene gas was performed to obtain Ga-free carbonaceous materials. The characterization of the deposited materials was investigated by atomic force microscopy, Raman scattering spectroscopy, fluorescent X-ray analysis, and Auger electron spectroscopy. The surface of the deposited film using the Au FIBs was found to be very smooth, and the structure of the deposited material was found to be amorphous-like carbon. Although a Ga-free carbonaceous film was formed, it was found that Au or Si atoms were included, instead of Ga, in the deeper region of the deposited materials than the projected range of the ions of such atoms, resulting in the formation of a double-layer structure in the deposited materials, including that the events that occurred in the FIB-CVD using the Au or Si FIBs were similar to those in the same process using the Ga FIBs. However, it was also found that the behavior of the incorporated Au atoms in the deposited films by annealing was different from that of the Ga atoms.

Effect of Annealing on Mechanical Properties of Materials Formed by Focused Au or Si Ion-Beam-Induced Chemical Vapor Deposition Using Phenanthrene

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Jpn. J. Appl. Phys. Vol. 48, 06FB03 (4pp) (2009)

The hardness and Young's modulus of materials deposited by focused Au or Si ion-beam-induced chemical vapor deposition using phenanthrene as a precursor gas were measured by means of nanoindentation. Before annealing, the hardness and Young's modulus of the materials deposited using Au ions were higher than those formed using Si or Ga ions. After annealing at 800 ^{o}C, however, the hardness and Young's modulus of the material formed using Si ions were markedly increased, but those formed using Au or Ga ions were decreased. From the change in Raman spectra, the decrease might be related to a change in the carbonaceous materials from an amorphous phase to graphite and disordered phases upon annealing. On the other hand, from the X-ray photoelectron spectroscopy measurement, it was observed that some of the Si atoms in the deposited material chemically combined with the deposited C atoms and formed Si-C (silicon carbide) bonds upon annealing, resulting in the increase in the hardness and Young's modulus.

Fabrication of Micro-Fluid-Channel Structures by Focused Ion Beam Technique

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Mater. Res. Soc. Symp. Proc. Vol. 1181, 1181-DD03-01 (pp. 61-68) (2009)

One of the new applications of focused Ga ion beam (Ga FIB) techniques in the fabrication of

micro-fluid-channels on plate glass was demonstrated. After discussing the features of the FIB-etched patterns, narrow or Y-shaped channels were fabricated by FIB etching on a patterned plate glass prepared by photolithography and wet etching. Micro-fluid devices were then constructed using a polydimethylsiloxane (PDMS) sheet and silicone rubber tubes, and the water (or ink) flow in the devices was observed under a microscope using a syringe pump. Although no discussion based on fluid mechanics has been carried out at present, the present results indicate the possibility of applying FIB techniques to fabricate micro-fluid devices that can be used in bio- and/or chemical-related fields.

High Sensitivity of Photoluminescence-excitation Spectroscopy for Probing Effects of Plasma-induced Surface Damages on Carrier Transport in $Al_xGa_{1-x}N$ /GaN heterostructures

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Physica Status Solidi (C) Vol. 5, pp.1525-1528 (2008)

We demonstrate that photoluminescence-excitation (PLE) spectroscopy is applicable to probe effects of the surface damages on the carrier transport in $Al_xGa_{1-x}N$/GaN heterostructures by systematically characterizing as-grown and plasma-exposed samples. The characterization of the surface morphology with atomic force microscopy clarifies that the plasma exposure modifies the atomic steps and pits on the $Al_xGa_{1-x}N$ surface. The PLE spectrum of the as-grown sample measured at the energy of the photoluminescence from the GaN layer shows a step rising from the $Al_xGa_{1-x}N$ fundamental transition energy, which reflects the photogenerated-carrier injection from the $Al_xGa_{1-x}N$ layer to the GaN layer, while the rising step disappears in the plasma-exposed sample. In contrast, the reflectance spectra are the same in the two samples; namely, the excitonic transition is hardly changed. Thus, it is concluded that PLE spectroscopy is highly sensitive to probe the carrier-transport characteristics in the $Al_xGa_{1-x}N$/GaN heterostructure.

Enhancement of Terahertz Electromagnetic Wave Emission from an Undoped GaAs/*n*-type GaAs Epitaxial Layer Structure

Hideo Takeuchi, Junichi Yanagisawa, Takayuki Hasegawa, and Masaaki Nakayama

Applied Physics Letters Vol. 93, 081916 1-3 (2008)

We have investigated the emission of the terahertz electromagnetic wave from an undoped GaAs (200 nm)/*n*-type GaAs (3 μm) epitaxial layer structure (*i*-GaAs/*n*-GaAs structure), where the doping concentration of the *n*-GaAs layer is 3×10^{18} cm^{-3}. It is found that the first-burst amplitude of terahertz wave of the *i*-GaAs/*n*-GaAs sample is remarkably larger than that of a *n*-GaAs crystal, which means that the *i*-GaAs layer enhances the terahertz emission intensity. The first-burst amplitude of the *i*-GaAs/*n*-GaAs sample, by tuning the pump-beam energy to the higher energy side, exceeds that of an *i*-InAs crystal that is known as one of the most intense terahertz emitters. We, therefore, conclude that the *i*-GaAs/*n*-GaAs structure is useful to obtain intense terahertz emission.

Effects of Nitrogen Incorporation on a Direction of a Surface Band Bending Investigated by Polarity of Terahertz Electromagnetic Waves in $GaAs_{1-x}N_x$ Epitaxial Layers

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Journal of Applied Physics Vol.105, 093539 1-4 (2009)

We have investigated the polarity of the terahertz electromagnetic wave from $GaAs_{1-x}N_x$ epitaxial layers with $x = 0.43$ % and 1.53 % in order to clarify the effects of nitrogen incorporation on the direction of the surface band bending using an undoped GaAs/*n*-type GaAs(*i*-GaAs/*n*-GaAs) epitaxial layer structure and a semi-insulating GaAs (SI-GaAs) crystal as reference samples. A numerical calculation on the basis of the Boltzmann-Poisson model clarifies that the conduction band of the *i*-GaAs/*n*-GaAs sample bends upward at the surface region, which indicates that photogenerated electrons flow into the inside. In the measurement of the terahertz wave, it is observed that the polarity of the terahertz wave from the SI-GaAs crystal is the same as that of the *i*-GaAs/*n*-GaAs sample; namely, the present SI-GaAs crystal has an upward band bending. In contrast, the terahertz-wave polarity is reversed in the $GaAs_{1-x}N_x$ samples in spite of the relatively small nitrogen mole fraction; namely, the $GaAs_{1-x}N_x$ samples have a downward band bending. The above-mentioned terahertz-wave polarity reversal is attributed to the phenomenon that conduction-band bottom is considerably lowered by the band anticrossing peculiar to $GaAs_{1-x}N_x$, which results in approaching the conduction-band bottom to the surface Fermi level. This modifies the direction of the surface band bending connected with the polarity of the terahertz wave.

Intense Emission of Terahertz Electromagnetic Wave from an Undoped GaAs/*n*-type GaAs Epitaxial Layer Structure

Hideo Takeuchi, Junichi Yanagisawa, Takayuki Hasegawa, and Masaaki Nakayama

Physica Status Solidi (C) Vol. 6, pp.1513-1516 (2009)

We have investigated the emission of the terahertz (THz) electromagnetic wave from an undoped GaAs (200 nm)/*n*-type GaAs (3 μm) epitaxial layer structure (*i*-GaAs/*n*-GaAs structure), where the doping concentration of the *n*-GaAs layer is 3×10^{18} cm^{-3}. It is found that the first-burst amplitude of THz wave of the *i*-GaAs/*n*-GaAs structure is considerably stronger than that of an *n*-GaAs crystal, which means that the *i*-GaAs layer enhances the THz emission intensity. The first-burst amplitude of the *i*-GaAs/*n*-GaAs structure, by tuning the pump-beam energy to the higher energy side, exceeds that of an *i*-InAs crystal known as one of the most intense THz emitters. We, therefore, conclude that the *i*-GaAs/*n*-GaAs structure is useful to obtain intense THz emission. From the pump-beam energy dependence of the first-burst amplitude, the THz-emission mechanism of the *i*-GaAs/*n*-GaAs structure is attributed to the surge current of the photogenerated carriers flowing through the *i*-GaAs layer.

Direction Reversal of the Surface Band Bending in GaAs-based Dilute Nitride Epitaxial Layers Investigated by Polarity of Terahertz Electromagnetic Waves

Hideo Takeuchi, Junichi Yanagisawa, and Masaaki Nakayama

Physics Procedia Vol. 3, pp.1109-1113 (2010)

We have investigated the polarity of terahertz (THz) electromagnetic waves from GaAs-based dilute nitride ($GaAs_{1-x}N_x$ and $In_yGa_{1-y}As_{1-x}N_x$) epitaxial layers to clarify the effects of nitrogen incorporation on the direction of the surface band bending. The THz-wave polarities of the dilute nitride samples are reversed compared with those of an *i*-GaAs/*n*-GaAs sample that has an upward surface band bending; namely, the dilute nitride samples have a downward band bending. The polarity reversal is attributed to the phenomenon that the conduction band bottom is lowered by the band anticrossing due to the nitrogen incorporation, which changes the direction of the

band bending.

Fabrication of Mid-Infrared Tunable Filter with Roughened Silicon Plates

Itsunari Yamada, Mitsunori Saito

Jpn. J. Appl. Phys., Vol. 46, no. 9A, pp. 5829–5833 (2007)

We fabricated infrared Fabry–Perot filters by stacking two wet-etched silicon plates. The silicon plates were etched in a KOH solution to 100 mm thickness to reduce the driving voltage, and were scratched before etching to suppress the interference inside the silicon plates. When a voltage was applied to the filter, the spacing between the plates changed due to an electrostatic force, which caused a shift in the interference peaks. When the voltage was increased from 0 to 50V, an interference peak shifted from an 8.0 wavelength to a 4.1 mm wavelength, corresponding to the decrease in the spacing from 4.1 to 2.1 mm.

Self-Controlled Signal Branch by the Use of a Nonlinear Liquid Crystal Cell

Mitsunori Saito, Ryosuke Takeda, Kazuhiro Yoshimura, Ryota Okamoto, Itsunari Yamada

Appl. Phys. Lett., Vol. 91, 141110 (2007)

A nonlinear input-output characteristic was observed when neodymium doped yttrium aluminum garnet laser passed through a silicon cell containing a twisted-nematic liquid crystal. The laser beam excited free carriers in the silicon plate, which triggered electrical reorientation of the liquid crystal. Consequently, the polarization direction of the laser beam changed, and the output beam passing through a polarizer became weaker as the input power increased. This function was utilized for self-branching of an optical pulse train.

Tunable Infrared Filter Made of Thin Silicon Wedges

Mitsunri Saito, Itsunari Yamada, Takahiro Mizuta, Atsushi Matsuura, Hisakazu Kawashima, Naotake Otsuka, Yasunori Shindo, Takashi Kuwabara

Infrared Phys. Technol., Vol. 51, pp. 236–241 (2008)

An electrostatically-tunable infrared filter was fabricated by constructing a Fabry–Pe´rot interferometer with stacked silicon plates. Driving-voltage, which used to be 100 V with ordinary silicon plates, could be reduced to 30 V by decreasing plate thickness to 100 μm. Both theoretical simulation and bending test confirmed sufficient mechanical durability of these thin plates. Superimposition of a noise spectrum, which was caused by interference inside thin silicon plates, could be suppressed by polishing the plates into wedges. Consequently, pronounced interference peaks appeared at 12.6, 6.3, and 4.2 μm wavelengths, and they shifted to 9.8, 4.9, and 3.3 μm, respectively, by 30-V application.

Mid-Infrared Wire-Grid Polarizer with Silicides

Itsunari Yamada, Kenji Kintaka, Junji Nishii, Satoshi Akioka, Yutaka Yamagishi, Mitsunori Saito

Opt. Lett., Vol. 33, pp. 258–260 (2008)

An infrared (IR) polarizer with tungsten silicide (WSi) wire grid was fabricated by two-beam interference exposure and reactive ion etching. To enhance TM transmittance, silicon monoxide was deposited between the WSi wire grid (400-nm period) and a Si substrate. The transmittance was over 80% in the 4–5 μm wavelength range. The ratio of TM and TE transmittances was over 100 (20 dB) in the 2.5–6 μm wavelength range. The fabricated polarizer has higher durability and

bettter compatibility with microfabrication processes compared with conventional IR polarizers.

Modeling, Fabrication, and Characterization of Tungsten Silicide Wire-Grid Polarizer in Infrared Region

Itsunari Yamada, Junji Nishii, Mitsunori Saito

Appl. Opt., Vol. 47, pp. 4735–4738 (2008)

We designed and fabricated a tungsten silicide wire-grid polarizer. To examine its polarization characteristics, the transmission spectra of the polarizer were simulated using the effective medium theory. The polarizer was fabricated based on the simulation results. The transverse magnetic (TM) polarization transmittance of the fabricated polarizer was greater than 50% over the 5 μm wavelength, and the ratio of TM and transverse electric transmittance was greater than 100 (20 dB) in the infrared range. This fabricated polarizer has higher durability and better compatibility with microfabrication processes than conventional infrared polarizers.

Terahertz Wire-Grid Polarizers with Micrometer-Pitch Al Gratings

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Opt. Lett., Vol. 34, pp. 274–276 (2009)

We fabricated a terahertz wire-grid polarizer consisting of a micrometer-pitch Al grating on a Si substrate by photolithography and wet etching. The ratio of TM and TE transmittances (extinction ratio) was over 35 dB at 0.5 THz. At the Brewster angle of the Si substrate, the polarization transmittance of a TM wave through the fabricated polarizer exceeded 95% and the extinction ratio was over 45 dB at 1 THz. The fabricated polarizer has a higher extinction ratio than conventional free-standing terahertz wire-grid polarizers.

Transmittance Enhancement of a Wire-Grid Polarizer by Antireflection Coating

Itsunari Yamada, Kenji Kintaka, Junji Nishii, Satoshi Akioka, Yutaka Yamagishi, Mitsunori Saito

Appl. Opt., Vol. 48, pp. 316–320 (2009)

We examined the effect of an antireflection (AR) coating to enhance the TM transmittance of the wire-grid polarizer. The polarization transmission spectra were calculated using the rigorous coupled-wave analysis. As a result, we verified that an AR film should be inserted between a wire-grid and a Si substrate as regards the TM transmittance and the polarization function. Based on the simulation results, we fabricated a tungsten silicide (WSi) wire-grid polarizer with SiO films on both sides of the Si substrate. The transmittance exceeded 80% at a 4–5 μm wavelength range, although the theoretical transmittance of Si substrate is 54% and the ratio of the TM and TE transmittances reached 24 dB at a 3 μm wavelength when the WSi grating has a 300nm thickness, a 400nm period, and a fill factor of 0.6. Wire-grid polarizers with higher transmittance and larger extinction ratio can be obtained by adjusting the AR film thickness, the fill factor, and the thickness of the WSi grating.

Nickel Plating on Silicon for Fabricating an Infrared Wire-Grid Polarizer

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Jpn. J. Appl. Phys., Vol. 49, 052503 (2010)

An IR polarizer was fabricated by plating a Ni wire-grid on a Si substrate. The Si surface was

processed by photolithography to create grooves with ~200 nm width, ~200nm spacing, and ~300nm depth. After surface treatment, the Si plate was put in a plating bath for ~5 min to fill the grooves with Ni. The excess Ni film that was deposited outside the grooves was removed by mechanical polishing. The fabricated wire-grid exhibited a polarization function with an extinction ratio of 15–20 dB in the 3–13 mm wavelength range.