Science and Technology of MBE
Room Hall of Ideas E-J - Session ST-MoP

Science and Technology of MBE Poster Session

ST-MoP-1 Shadow Mask Molecular Beam Epitaxy*, Shagorika Mukherjee*, *S. Sitaram, X. Wang,* University of Delaware*; S. Law,* Penn State University

Shadow mask molecular beam epitaxy (SMMBE) is a form of selected area epitaxy (SAE) in which one can pattern vacuum-deposited films using a mechanical mask. If the mask is not a contamination source itself and is near the substrate, epitaxial layers may be deposited on the substrate sequentially through the patterned mask. In this way, a patterned film can be produced without etching. A unique feature of SMMBE is the shadowing effect that arises near the mask edges, which causes the elemental fluxes to change as a function of position. The shadowing effect occurs when the mask edges are not perfectly vertical. This results in a gradient of film thickness and/or composition. The gradient can be controlled by changing the mask thickness and/or the angle of the mask edges. In this presentation, we demonstrate the potential of SMMBE to produce in-plane gradient permittivity materials (GPMs) by taking advantage of the shadowing effect.

GPMs are materials in which the permittivity changes horizontally in the plane of the sample. There are a variety of applications of GPMs, we are focused on the excitation of surface plasmon polaritons (SPPs) which can confine light and enhance its electric field. In a GPM, light of different wavelengths is confined at different positions on the sample. If successful, this type of material could be used to develop an on-chip spectrometer. Since we are interested in working in the infrared, our GPMs consist of heavily silicon-doped InAs, which is known to be a good infrared plasmonic material. By varying the silicon doping density in the plane, we can control the Si:InAs permittivity in the lateral direction. We propose to create such a material using SMMBE with reusable silicon shadow masks. The shadow masks are each 200 µm thick and have a dimension of 1 cmx1 cm. Each mask has an aperture at its center. The aperture has slanted inner walls, which makes its dimension 0.5 cmx0.5 cm at the top and 0.528 cmx0.528 cm at the substrate side. To date, we have studied the effect of several growth parameters in controlling the in-plane permittivity in the GPMs. In comparison to non-SMMBE growth recipe, we have found that increased quantities of Bi surfactant (2.5x higher) and As (1.5x higher) in the growth recipe of the GPM can significantly minimize poor growth regions around the edges of GPM where the permittivity gradients are. Characterization by s-SNOM (scattering-type scanning near-field optical microscopy) using mid-IR light source illustrates that the GPMs we have made confine different wavelengths of light at different in-plane positions in the GPMs, setting the stage for the creation of an on-chip spectrometer.

ST-MoP-2 Strain Relaxation of Graded InGaN and AlGaN*, Reem Alhelais*, *F. Mais de Oliveira, H. Stanchu, M. Sarollahi, Y. Mazur, N. Al-Hosainy, M. Ware,* University of Arkansas

III-nitride semiconductor materials have proved to be ideal materials for high-power, high-frequency, and high-temperature applications because of their tunable direct band gaps, high breakdown voltage, high absorption coefficient, resistance to defects, lattice match, and polarization characteristics. These materials form a continuous alloy system with direct bandgaps from 6.2 eV (AlN) through 3.4 eV (GaN) to 0.7 eV (InN). The compositionally graded Group III-nitride alloy enables access to a large range of energies through varying the bandgap. This change in bandgap is achieved by varying the indium and aluminum composition during growth, which yields excellent compatibility for various optoelectronic applications.

The growth and quality of mismatched heteroepitaxial III-Nitrides layers are generally influenced by strain relaxation mechanisms that release the accumulated strain energy. Plastic relaxation is generally started by the formation of misfit dislocations above the critical thickness. This has been well studied and is generally understood for heteroepitaxial films with a fixed composition. Graded composition films have been investigated recently for potential incorporation into semiconductor devices, however, the issue of plastic relaxation for graded III-Nitride semiconductors has not been thoroughly investigated.

Graded InGaN and AlGaN can be grown pseudomorphically strained to its substrate until some critical amount of strain energy is built up. This can happen either as a result of reaching a maximum composition or a maximum growth thickness. These two parameters are not independent in terms of their contribution to the buildup of strain energy, and the goal of this study is to determine both the range over which these alloy layers can be grown without relaxation and the mechanisms by which they exhibit relaxation.

In the present work, we have grown both graded InGaN and AlGaN layers with 30 % of In and Al composition of increasing thicknesses for 15 min, 30 min, and 60 min on GaN substrates. We investigated their properties through X-ray diffraction reciprocal space mapping (RSM). With increasing the thickness of these graded layers, the InGaN or AlGaN signature in the RSM shifts from a fully strained position. Atomic force microscopy will be also used to characterize the sample surface of interest, including dislocation density, while transmission electron microscopy will be used to understand the nature of relaxing defects that is formed in these layers. How these introduced dislocations impact the electrical and optical properties will be demonstrated through photoluminescence and Raman spectroscopy.

ST-MoP-3 Improved N-Type Doping Activation in AlGaAs:Si Through Digital Alloy Growth*, Xizheng Fang*, *B. Kim, D. Montealegre, Y. Wang, A. Birge, M. Lee,* University of Illinois at Urbana Champaign

Despite its maturity, MBE growth of Si-doped $Al_xGa_{1-x}As$ (n-$Al_xGa_{1-x}As$:Si) with moderately high electron concentration (n_0 >1e17 cm^{-3}) remains challenging due to the formation of DX centers and other traps, particularly near the direct to indirect band transition at x=0.45.[1] $Al_xGa_{1-x}As$ surfaces are also prone to roughening during growth[2], which can negatively impact subsequent growth of active regions. In this work, we show that n-$Al_{0.4}Ga_{0.6}As$:Si grown as a 3 monolayer (ML) GaAs/2 ML AlAs digital alloy at 610°C exhibits ~34x higher activation than in bulk samples, enabling straightforward doping up to n_0 = 2.5e17 cm^{-3} with smooth surface morphology.

All samples were grown on semi-insulating GaAs (001) and consisted of a 200 nm GaAs buffer, a 100 nm undoped $Al_{0.4}Ga_{0.6}As$ layer to prevent charge transfer into the GaAs buffer, and a 500-nm-thick n-$Al_{0.4}Ga_{0.6}As$:Si layer followed by a 9 nm n$^+$-GaAs cap to facilitate ohmic contact formation. In all cases, the growth rate was held at 0.65 µm/hr with V/III of 30 and a target Si concentration [Si] = 1e19 cm^{-3}.

We started with the growth of a bulk n-$Al_{0.4}Ga_{0.6}As$:Si alloy control sample, which gave a root mean square (RMS) roughness of 2.1 nm and n_0 = 7.3e15 cm^{-3} (activation = 0.073%) according to Hall effect measurements. In an attempt to increase the activation, we reduced [Si] to 5e18 cm^{-3} and added 10x Si delta doping spikes[3] at 50 nm intervals to bring the integrated Si concentration to 1e19 cm^{-3}. However, the activation only improved by 40%, while the roughness increased by 2x. Next we grew a 6 ML GaAs/4 ML AlAs digital alloy (6/4 DA), with the rationale that Si atoms residing within layers of pure GaAs or AlAs and away from the GaAs/AlAs interfaces may be less prone to DX-center formation. Hall effect measurements showed that activation increased by 2.6x over the control, while the RMS roughness decreased to 1.0 nm; the position of satellite peaks in 004 ω/2θ x-ray scans agreed with the 10 ML periodicity. Encouraged by the improvement in surface morphology and activation, we next grew 3/2 DAs at 500°C and 610°C, attaining 14x and 34x improvements in activation, respectively, while maintaining roughness similar to the 6/4 DA; the peak n_0 achieved in this work of 2.5e17 cm^{-3} is sufficient for use as the n-cladding layer in GaAs/AlGaAs laser diodes.[4] All samples exhibited photoluminescence at the expected wavelength (~640 nm) and similar reflectance spectra to bulk n-$Al_{0.4}Ga_{0.6}As$:Si, showing that the DAs mimic the optical properties of random alloys. In future, we will further explore the effects of periodicity and composition on n_0 to elucidate the mechanism for n-doping enhancement in DAs.

ST-MoP-4 Metal Contact Etch Process Optimization of Metal Contact Etching in 3D Integration Devices*, Sung Gyu Pyo,* CAU, Republic of Korea

In this paper, we would like to report the metal contact etch, which is different from the existing device contact process, on the film stack side and the supercontact etching characteristics accordingly. General metal contact etch etch is organically related to physical profile and electrical properties, so evaluating only one item does not have much meaning, but 3D Integration. The physical profile characteristics of metal contact etch etch and 3D Integrated supercontact were examined. As a result of the 1st step etch evaluation, the etch target in the wafer left area was approximately 2365A, and the bottom surface was found to be good with a bottom rounded profile.

After the 1st step etch for liner TEOS and nitride removal, the stopping margin was evaluated using 1) metal contact etch etch conditions where the target was reduced by about 22 sec, 2) CMOS image sensor metal contact etch baseline conditions to which an ILD reduction scheme was applied to improve optical characteristics, and 3) the selectivity was improved by increasing the C5F8/O2 ratio and the etch target was reduced. As a result, all three conditions were punch-through of BLC nitride has occurred.

In the 1st and 2nd steps, after proceeding with etch to the appropriate target, in the 3rd step, a good stopping margin was secured as a result of evaluating the 3-step etch recipe that over-etched using high selectivity.

It was confirmed that the stopping margin according to the over etch target split and process window change was also good, and the CD bias also secured good results.

Author Index

Bold page numbers indicate presenter