Semiconductors
Room 312 - Session SC2+EL+SS-MoM
Dissimilar Materials

Moderator: H.A. Atwater, California Institute of Technology

8:20am **SC2+EL+SS-MoM1 Integration of Epitaxial Oxide and Nitride Heterostructures with Dissimilar Substrates by Pd-In Wafer Bonding and Laser Lift-off***, **T. Sands**, W.S. Wong, L Tsakalakos, N.W. Cheung,* University of California, Berkeley **INVITED**

The functionality of integrated microsystems can be enhanced through intimate integration of disparate classes of materials. Combining the best materials for their respective functions (e.g., information processing, light emission/detection, and piezoelectric actuation) without sacrificing materials properties is often only possible if the materials are synthesized and processed separately, and subsequently combined. In this talk, a fast, simple and robust "paste-and-cut" method for accomplishing this integration step is described. The process combines low-temperature transient-liquid-phase (TLP) metal bonding with excimer laser lift-off (LLO) to integrate epitaxial group-III nitride (e.g., AlN and InGaN) and perovskite oxide (e.g., PZT and PMN-PT) heterostructures with virtually any substrate, including polymers, stainless steel, and CMOS silicon. Both the TLP and LLO steps are characterized by minimal heating of the receptor substrate, thus maximizing the range of materials classes that may be intimately combined. In our TLP metal bonding process, donor and receptor substrates are coated with Pd/In bilayers and pressure-bonded at 200°C to achieve a high-contact-area PdIn@sub 3@ intermetallic bond with a melting point above 600°C. The L LO process uses a single pulse from a uv laser (e.g., KrF excimer at 248 nm with a pulse length of 38 nsec), irradiating the film/substrate interface through the transparent substrate (sapphire or MgO), to decompose the film at the interface with the substrate. The short pulse duration enables thermal decomposition of the film interface without significant heating of the receptor substrate. Examples of TLP/LLO paste-and-cut integration, including vertical (In,Ga)N light-emitting diodes on Si, and epitaxial ferroelectric (PZT) films on stainless steel, will illustrate the potential of this integration method for the functional enhancement of microsystems. @FootnoteText@ W.S. Wong is now at Xerox PARC, Palo Alto, CA.

9:00am **SC2+EL+SS-MoM3 Growth of SiGe Alloys on Strain-Engineered Si on Insulator (SOI) Substrates***, **P. Rugheimer**, C.H. Lee, D.E. Savage,* University of Wisconsin, Madison*; E. Mateeva,* Colorado School of Mines*; P. Moran, A. Lal, T.F. Kuech, M.G. Lagally,* University of Wisconsin, Madison

Self-organized 3D islands and misfit dislocations form in order to relieve strain during heteroepitaxial growth of SiGe on Si(001). In this work, we use patterned SOI substrates to mediate strain and influence film morphology. Films are grown, using both MBE and CVD, on lithographically defined mesas with lateral dimensions ranging from 2 to 20 microns patterned onto both 10nm Si on SiO2 bonded-wafer substrates and Si(001) control substrates. We have also grown epitaxial films on SOI substrates with MEMs type cantilevers etched on the surface. These cantilevers create regions of either tensile or compressive stress where epitaxial film growth takes place. Film morphology for the samples is followed in-situ during growth with RHEED and ex-situ post growth with X-ray diffraction, Atomic Force Microscopy (AFM) and Cross-sectional Transmission Electron Microscopy (CTEM). We find that growth on patterned mesas as well as cantilevers results in some elastic strain relaxation. Possible mechanisms, such as short-range viscous compliance, anisotropic strain relief, or mediation of dislocations, will be discussed. Supported by NSF-MRSEC and by ONR.

9:20am **SC2+EL+SS-MoM4 Techniques and Interface Effects in Creating Alternative Substrates using GaAs Wafer Bonding***, **A.M. Cain**, P.J. Hesse, D.R. Thomas, K.G. Eyink, D.H. Tomich, M. Ruddell, T.W. Haas, M.L. Seaford,* Air Force Research Laboratory

Compliant substrate technology offers the promise of allowing epitaxial growth of lattice mismatched semiconductors suitable for use in heterogeneous integration. An essential step in realizing a compliant technology is the adequate bonding of the compliant layer to a suitable handle wafer. This work will describe a new wafer bonding facility that allows for precise control of the bonding parameters such as temperature, pressure, atmosphere, and bond processing conditions. The equipment is built around a vacuum furnace fitted with a controllable piston to apply pressure to the bonding wafers. Bonding can be carried out in vacuum or in a variety of inert or reducing atmospheres. The bond furnace is enclosed in a dry box to reduce particle contamination and to reduce atmospheric interactions with bonding surfaces. The equipment is fully computerized to allow for complex bond processing steps. This equipment has been utilized to investigate the effects of various surface chemical treatments of GaAs wafers prior to the bonding process. The technique of arsenic capping of MBE grown buffer layers has been utilized to bond wafers at temperatures as low as 250 °C. Bonding did not occur at 200 °C in agreement with line of sight RGA data that was used to determine the temperatures at which the arsenic was desorbed from the interfaces of the bonding wafers. The conditions used for bonding will be described and characterizations of the interface quality using transmission infrared microscopy and acoustic wave microscopy will be given. Except for occasional particles in the bond interfaces it is possible with this approach to obtain consistently bonded wafers. Comparisons with other surface treatments such as use of epitaxial ready wafers and wafers prepared using conventional etching techniques known to have approximately 2.5nm of oxide present will also be given.

9:40am **SC2+EL+SS-MoM5 Relaxation of SiGe Films on Silicon-on-Insulator Substrates Utilizing Borosilicate Glass***, **E.M. Rehder**, D.E. Savage, P. Moran,* University of Wisconsin, Madison*; T.S. Kuan,* SUNY at Albany*; M.G. Lagally, T.F. Kuech,* University of Wisconsin, Madison

We have grown epitaxial silicon germanium (SiGe) alloy films and studied the relaxation effects of thin silicon-on-insulator (SOI) substrates. Bond and etchback SOI (BESOI) wafers having a top Si layer of 15nm were fabricated. The insulators in these structures were either SiO@sub 2@, using commercial wafers, or chemical vapor deposited borosilicate glass as the insulator. Si@sub 0.82@Ge@sub 0.18@ films were grown on these substrates by ultra high vacuum chemical vapor deposition at temperatures of 550, 630, and 670°C. Films were grown up to 175nm in thickness, which is beyond the equilibrium critical thickness. The low growth temperatures nonetheless result in metastable strained films. Any observed relaxation during growth was then enabled by the SOI. The relaxation following growth was studied by high-resolution double and triple crystal x-ray diffraction and cross sectional transmission electron microscopy. The growth layers on substrates using the SiO@sub 2@ insulator as well as those grown directly on Si substrates are identical and fully strained. However, SOI substrates utilizing a borosilicate glass with 50% B@sub 2@O@sub 3@ content yielded films in which the film strain was reduced by 30%. Post-growth annealing at temperatures from 700 to 1050°C were employed to promote relaxation. When annealed at 950°C the film on the Si substrate remained largely unrelaxed, while the film on the SiO@sub 2@-SOI substrate relaxed to 50%. Lower temperatures resulted in no relaxation, while annealing at 1050°C allows interdiffusion to occur resulting in additional relaxation. Cross-sectional TEM images of these samples reveal a complex dislocation structure in both the film and substrate. The relationship between the oxide viscosities at these temperatures and the image forces affecting dislocation formation and motion will be discussed.

10:00am **SC2+EL+SS-MoM6 Growth of Single Crystalline AlN on Si(111) using Surface Reconstruction Induced Epitaxy***, **M. Jenkins**, A. Faik,* University of North Carolina*; M.R. Sardela Jr,* University of Illinois*; M.-A. Hasan,* University of North Carolina

AlN is a direct wide bandgap (6.2 eV) material suitable for applications in UV emission and detection. In addition, it has a close lattice constant to GaInN, which provides a tunable band gap for emission in the blue to red region. Moreover, integration of group III-nitrides with Si would enable optical interconnects and high power device fabrication on Si. In this work, we have demonstrated growth of hexagonal single crystalline AlN(001) on Si(111) using surface reconstruction induced epitaxy. The Si(111)7x7 surface was first passivated by deposition of ~0.3 monolayer (ML) of Al at 650-700 °C. Each Al atom bonds to 3 Si atoms on the surface, which give rise to the well-known Si(111)@sr@3x@sr@3 surface. The well ordered, Al-passivated Si(111)@sr@3x@sr@3 surface was then used as a template to initiate epitaxial growth of AlN on Si. Without Al passivation, N would react with the clean Si surface forming amorphous Si@sub 3@N@sub 4@, which provides a disordered template and prevents epitaxial growth of AlN. The growth was conducted by using an atomic N flux from a RF atomic source and thermal deposition of Al from an effusion cell. Reflection of high-energy electron diffraction (RHEED), high-resolution X-ray diffraction and transmission electron microscopy results confirmed the formation of single crystalline AlN. The results showed that epitaxial growth of AlN depends strongly on the Al/N flux ratio, growth temperature, and the RF power.

10:20am **SC2+EL+SS-MoM7 Enhanced Thermal Stability of Au Film on GaN by Thin Cr Interfacial Layer***, J.H. Kim, H.J. Kang,* Chungbuk National University, Korea*; C.Y. Kim,* LG CIT, Korea*; J.M. Seo,* Chonbuk National University, Korea

In order to enhance the thermal stability of Au film on GaN, 4 ML of thin Cr layer had been deposited prior to Au evaporation. The AFM image shows that, upon postannealing at 650C, Au overlayer with Cr interlayer still keeps its uniformity without forming either pits or islands, while the same amount of Au without Cr interlayer is agglomerated. The corresponding results of scanning Auger microscopy combined with the high resolution x-ray photoelectron spectroscopy indicate that the interfacial Cr partially mixes with GaN and partially mixes with Au overlayer, and reduces the Schottky barrier height of p-type GaN by 0.4 eV. The core level analyses of Cr 2p, Au 4f and Ga 2p indicate a small portion of Ga species also segregates to the top side of this AuCr alloy overlayer. It has been concluded that the role of Cr interlayer for enhancing thermal stability of Au overlayer is in the gradual relaxation of the strain originating from thermal-expansion-coefficient-difference through diffusing into both sides without losing N species.

10:40am **SC2+EL+SS-MoM8 Effects of Hydrogen on the Properties of Cu(TMVS)(hfac) Sourced CVD Copper Films***, **J. Hong**, D. Yang, S. Shetty, T.S. Cale,* Rensselaer Polytechnic Institute

We describe a study of the effects of hydrogen pre- and post-treatment on films grown by Cu(TMVS)(hfac) sourced Cu CVD on TaN substrates using an LPCVD system. Our previous work@footnote 1,2@ showed that the use of water vapor as a co-reactant during Cu CVD can improve the adhesion between the copper film and the substrate. However, the resistivity and surface roughness of the deposited film were degraded when too much water vapor was introduced, probably due to the formation of Cu oxide. The hydrogen pretreatment is an attempt to reduce the native oxide layer on the TaN barrier layer. Films deposited on pretreated substrates have lower resistivity than those on untreated substrates. We have also studied the effects of hydrogen post-treatment on films grown with various amounts of water vapor as a co-reactant. Film properties depend on the duration of the water vapor flow, and the hydrogen post-treatment baking time and temperature. In all cases, resistivity was decreased after treatment compared to untreated films--an effect that we attribute to the reduction of Cu oxides formed in the film. The effect of hydrogen on the surface roughness depends on the amount of water vapor present during deposition and the length of the hydrogen treatment. We conclude that the resistivity of the Cu films is improved and surface roughness is changed with the use of hydrogen as pre- and post-treatment in Cu CVD process protocols. @FootnoteText@ @footnote 1@ D. Yang, J. Hong and T. S. Cale, in Proceedings of the Advanced Metallization Conference in 1999 (AMC 1999), "Effects of Process Variables on Cu(TMVS)(hfac) Sourced copper CVD films". @footnote 2@ D. Yang, J. Hong, and T. S. Cale, in MRS Symposium Proceedings of the MRS Spring 2000 Meeting, "Evolution of Surface Morphology During Cu(TMVS)(hfac) Sourced copper CVD films".

Author Index

Bold page numbers indicate presenter