1998 Electronic Materials Conference

TECHNICAL PROGRAM

University of Virginia · Charlottesville, Virginia · June 24 - 26, 1998

*** Indicates *Invited** **+ Indicates Student Paper**

Wednesday, June 24, 1998

EMC PLENARY LECTURE/STUDENT AWARDS

Ceremony: 8:30 AM

Room: 402, Chemistry Building

Session Chairman: Thomas Kuech, University of Wisconsin, Dept. of Chemical Engineering, Madison, WI 53706

Plenary Speaker: Laurence Eaves, University of Nottingham, Dept. of Physics, Nottingham, NG7 2RD UK

Topic: "Superlattices and Resonant Tunnelling: A Quarter-Century Overview"

BREAK: 9:30 AM - 10:00 AM

WEDNESDAY AM

June 24, 1998

Session A. Novel Contacts and Low Temperature - Grown Materials

Room: E303
Location: Thornton Hall

Session Chairs: Len Brillson, The Ohio State University, 205 Dreese Lab, Columbus, OH 43210-1272 USA; Suzanne Mohney, Penn State, University Park, PA 16802

10:00 AM, A1+

Studies of Schottky Barrier Height of $Ga_xIn_{1-x}P$ ($0 \le x \le 1$) For HFET Applications: H. C. KUO[1]; H. Hsia[1]; D. Caruth[1]; B. G. Moser[1]; Z. Tang[1]; S. Thomas[1]; M. Feng[1]; G. E. Stillman[1]; C. H. Lin[2]; H. Chen[2]; [1]University of Illinois at Urbana-Champaign, Electrical and Computer Engineering, Microelectronics Laboratory, Urbana, IL 61801 USA; [2]University of Ilinois at Urbana-Champaign, Materials Research Laboratory, Urbana, IL 61801 USA

The incorporation of an InGaP Schottky barrier enhancement layer (SBEL) is very attractive for the InP based MESFET and HFET applications since $Ga_xIn_{1-x}P$ ($0 \le x \le 1$) have energy gaps covering the range from 1.35 to 2.24eV at room temperature and a conduction band discontinuity of GaInP/InP ($\Delta Ec = 0.8 \Delta Eg$ for GaP on InP) is favorable for SBEL. Also there are no DX centers in GaInP. The performance of InP FETs strongly depends on the optimization of the gate contact. Knowledge about the dependence of the Schottky barrier heights on the material composition of GaInP is very important. However, to the best of our knowledge, a systematic study of the Schottky barrier heights of GaInP on InP for varying gallium composition has not been reported in the literature. In this talk, we presents a study of Schottky barrier heights for GaInP ($0 \le x \le 1$) on InP using both I-V, I-V-T and C-V measurements. The device performance of InGaAs/InP HFETs utilizing GaInP SBEL will also be discussed. All layers structure were grown by GSMBE on InP substrates using In and Ga as group III sources and AsH_3 and PH_3 as group V sources. For C-V measurements, 0.5 μm thick Si-doped (4-6X10^{17} cm^{-3}) GaInP samples with various Ga composition (0, 0.2, 0.3, 0.4, 0.5) were grown. Metamorphic buffer layers were grown on the InP substrate to reduce threading dislocations and improve the measurement reliability, even though C-V technique is not very sensitive to defects. The barrier heights were determined from the intercept voltages of the $(A/C)^2$-V plots. The compositional variation of the barrier heights for Au/GaInP/InP obtained from C-V measurements is nearly identical to that of the conduction-band offsets for InGaP/InP heterointerfaces. This result is consistent with the metal-induced gap states (MIGS) model of the Schottky barrier formation. Another series of samples of undoped $Ga_xIn_{1-x}P$ (x=0.2, 0.3, 0.4, 0.5,1) were grown on InP substrates for I-V measurement. The thickness of all GaInP SBELs was below critical layer thickness to prevent dislocation induced leakage current (no dislocations were observed by TEM). Using the thermionic-emission current equation and these characteristics, the effective barrier height was estimated to be in the range from 0.65 to 0.81 eV (ideality factors 1.01~ 1.3). This values are much lower than the data obtain from C-V measurements because the tunneling current increases as the thickness of the GaInP layer is decreased. We have designed and fabricated 0.25 μm gate-length InGaAs/P doped channel HIFETs utilizing 150 A $Ga_{0.2}In_{0.8}P$ SBEL. These devices show very good DC and RF performance. The extrinsic transcondance is 665 mS/mm. The f_{max} was 168 GHz and the f_T was 117 GHz. These results are comparable with InAlAs/InGaAs HEMTs which indicate the GaInP is a promising material for replacing InAlAs as gate SBEL material for InP based HFET applications.

10:20 AM, A2+

Reliability Studies on InAs/GaP and Au/Ti/GaP Schottky Diodes: J. JEON[1]; E. H. Chen[1]; V. Gopal[1]; E. P. Kvam[1]; J. M. Woodall[1]; [1]Purdue University, School of Engineering and NSF-MRSEC for Technology-Enabling Heterostructure Materials, West Lafayette, IN 47907-1289 USA

Schottky rectifiers have been widely utilized in semiconductor industry. Typically, these diodes consist of a metal in contact with a semiconductor material. However, thermal stability has been an important issue on these metal-semiconductor devices because of the metallurgical changes that can occur at the interface during any kind of intentional or unavoidable heat treatments. Recently, Chen et al reported that direct growth of InAs on GaP has shown promise as a Schottky diode. The resulting I-V characteristics showed low leakage currents and high breakdown voltages in reverse bias region and nearly ideal, Schottky-barrier like, forward bias characteristics with ideality factors of 1.1 or less. Since InAs/GaP junction has a large lattice mismatch (~11%), we expect that this mismatch could suppress the atomic inter-diffusion across the interface between InAs and Gap and hence reduce the mutual solubility of InAs and Gap. In this paper we discuss device reliability under thermal stress. Samples were prepared by Molecular Beam Epitaxy. After growth of a lightly doped (n=1E17) GaP layer, a thin heavily-doped (n=1E19) InAs layer (300 A) was deposited directly on GaP buffer. A thick heavily doped $In_{0.8}Ga_{0.2}As$ layer was grownon top for the purpose of making ohmic contact by AuTi evaporation. The device active region is at the InAs/GaP heterojunction. For comparison, metal-semiconductor Schottky diodes were fabricated by evaporating Au/Ti metal films on MBE grown GaP (1E17) materials. Both InAs/GaP and Au/Ti/GaP devices were annealed under a nitrogen ambient at various

have the appropriate bandgaps for blue-green laser applications. We also perform MBE growth of ZnSe-based layers and quantum well (QW) structures and investigate their properties. We have grown hexagonal (Zn,Mg)(S,Se) bulk crystals with 12%Mg and 8% S by the zone melting technique. Powder diffraction was used to confirm the structure, which has a lattice constant a_o of 4.0128 Angstrom and c_o/a_o ratio of 1.6335. Cleavage surfaces having (11-20) orientation were identified using single crystal x-ray scans. The high crystalline quality of the substrates was also confirmed by the x-ray measurements. The 77K photoluminescence (PL) shows a dominant bandedge emission and a near absence of deep levels. We have grown single layers of ZnSe on these (11-20) surfaces by MBE. The cleaved surfaces were degreased prior to introduction into the chamber. Thermal treatment before growth was made by heating the sample under a Se flux to 450 °C, to remove a native oxide layer. The single crystal x-ray scans of the layers were indistinguishable from those of the substrate, suggesting a similar crystalline structure. 77K PL measurements show a near bandedge peak at 2.8 eV and a dominant peak at 2.6 eV, assumed to be the so-called Y-line, which suggests the presence of defects. A second sample was used to grow a quantum well structure, consisting of a ZnSe barrier layer ~2 mm thick, a $Zn_{0.8}Cd_{0.2}$Sewell, nominally 10 nm thick, and a top ZnSe barrier layer ~100 nm thick. A more thorough heating of the substrate (510 °C) was performed on this sample to ensure a higher quality substrate/epi interface. No change in the RHEED pattern occurred upon growth initiation. The room temperature and 77K PL spectra for this structure are dominated by a strong sharp peak corresponding to the QW emission. No deep level emission is observed. Double crystal x-ray rocking curves present only one peak from the layer structure ~100 arcsec from the substrate peak. Although no unequivocal identification of the crystal structure of the epitaxial layers has been obtained, the similarity to the substrate characteristics and the high quality of the layer properties suggest that it is also hexagonal. Other measurements such as TEM and Raman spectroscopy are being pursued to establish the crystal structure.

9:40 AM, EE5+

Chalcopyrite Structure $ZnSnP_2$ Grown by Sas Source Molecular Beam Epitaxy: GEORGIY A. SERYOGIN[1]; Sergey A. Nikishin[1]; Sebastien Francoeur[1]; Henryk Temkin[1]; Toni D. Sauncy[3]; Nikolai Nikolaevich Faleev[4]; Alexander Mintairov[4]; Bruce Parkinson[2]; [1]Texas Tech University, Department of Electrical Engineering, Lubbock, TX 79409 USA; [2]Colorado State University, Department of Chemistry, Fort Collins, CO 80523 USA; [3]Texas Tech University, Department of Physics, Lubbock, TX 79409 USA; [4]A. F. Ioffe Physico-Technical Institute, 26 Polytechnicheskaya St., St.Petersburg 194021 Russia

The II-IV-V_2 compound $ZnSnP_2$ is isoelectronic with a III-V alloy $In_{0.5}Ga_{0.5}P$. It can be prepared, depending on growth conditions, in two different crystalline structures - chalcopyrite and sphalerite. The two structural modifications have different band gaps of 1.24 eV and 1.66 eV, respectively. The existence of such a difference gives rise to a possibility of forming heterostructures and makes $ZnSnP_2$ a very interesting material for photovoltaic and nonlinear optics applications. However, the possibility of two crystalline modifications and a high probability of forming interfacial compounds such as Zn_3P_2 and Zn_3P_4 at low substrate temperatures, makes it difficult to obtain single phase epitaxial layers. Having a bulk lattice constant of 5.651 angstrom, very similar to that of GaAs, lattice matched layers of $ZnSnP_2$ can, in principle, be grown on GaAs substrates. Single layers of $ZnSnP_2$ were grown by gas source molecular beam epitaxy on GaAs(100) using PH_3 as phosphorus source. We used a custom designed MBE apparatus that allows for excellent control of the growth temperature and the group II/IV flux ratio. Samples were evaluated by high resolution X-ray diffraction, Raman spectroscopy, secondary ion mass spectroscopy (SIMS), photoluminescence and atomic force microscopy. Growth conditions were investigated as a function of substrate temperature, from 300°C to 360°C, and the Sn/Zn flux ratio. The sticking coefficient of zinc is one of the factors limiting the growth rate at higher substrate temperatures. We were able to supply a Zn flux sufficient to maintain the growth rate of at least 0.25 um/hr at substrate temperatures of 360°C. The stoichiometry of epitaxial layers was confirmed, to within ~1%, using SIMS. The growth rate was found to be linearly dependent on the Sn flux, under a constant Sn/Zn flux ratio. With increasing Sn/Zn flux ratio, by 5% to 10%, we observe a transition between two epitaxial phases. The initial phase has a negative lattice mismatch with respect to GaAs, on the order of 0.4 %. With increasing Sn/Zn flux the growth switches to a second phase which has a small positive lattice mismatch, varying from 0 to 0.01 %. The presence of thickness oscillations in high resolution X-ray patterns demonstrates the planar structure and high structural quality of epitaxial layers. Photoluminescence measurements were performed on both types of samples. Only samples with a positive mismatch produce room temperature luminescence. Its peak position, indicative of the bandgap, is at 1.36 eV. Raman measurements show the presence of a strong A1 chalcopyrite mode in samples with a positive mismatch. In samples with a negative mismatch the A1 mode is weak and shifted to low energies. Microscopic structure of these layers is being determined.

10:00 AM Break

Friday AM, June 26, 1998

Session FF. Novel Light Emitters

Room: E303
Location: Thornton Hall

Session Chairs: Hong Q. Hou, EMCORE West, Albuquerque, NM; Phil W. Yi, Kwangju Institute of Science and Technology, Kwangju 506-303 Korea

10:20 AM, FF1+

Erbium-Doped Polysilicon and Dielectric Stack Microcavity for Light Emitting Applications: THOMAS D. CHEN[1]; Anuradha M. Agarwal[1]; Jurgen Michel[1]; Lionel C. Kimerling[1]; [1]MIT, Materials Science and Engineering, 77 Massachusetts Avenue 13-4153, Cambridge, MA 02139 USA

Erbium-doped silicon (Si:Er) has been widely studied as a possible light emitter (λ=1.537 μm) for integrated silicon microphotonics technology. Although single crystal Si:Er has been the focus of many studies in recent times, erbium-doped polysilicon (poly-Si:Er) allows higher concentrations of erbium incorporation and the ability to use a stack dielectric microcavity to increase the luminescence intensity through spontaneous emission enhancement. The microcavity enhancement will especially allow higher light emission at room temperature. This microcavity consists of two dielectric stack mirrors, separated by a light emitting active layer. The mirrors are comprised of alternating layers of amorphous silicon and silicon dioxide, which are compatible with standard CMOS technology. Because crystalline silicon cannot be deposited on such a structure, poly-Si:Er must be used as the light emitting active layer. Combined with polysilicon waveguide technology, poly-Si:Er microcavity emitters allow the possibility for multiple levels of optical interconnection in a silicon microphotonic system. We have studied erbium/oxygen-implanted (10^{20} cm^{-3} and $5x10^{20}$ cm^{-3} respectively) silicon films that were amorphously deposited on 1 μm of oxide and subsequently recrystallized by a series of thermal treatments. Photoluminescence (PL) and glancing angle x-ray diffraction (XRD) were used to characterize the poly-Si:Er. Isochronal anneals for 30 minutes and isothermal anneals at 600ºC showed that the erbium luminescence intensity was directly related to the degree of recrystallization during the anneal. Hydrogen passivation of dangling bonds further increased the luminescence intensity to about one half of the intensity found in some single crystal material. A Si/SiO_2 stack dielectric microcavity tuned to the Er emission wavelength was fabricated by electron-beam deposition and annealed under conditions that yielded the best poly-Si:Er luminescence. After the recrystallization anneal, the microcavity was found to have a resonance at 1.539 μm and a cavity quality factor of ~300. The microcavity was used to enhance the Er spontaneous emission rate in order to increase the luminescence intensity. The enhancement factor is directly related to the quality factor of the microcavity and thus depends on the number of dielectric layers that comprise the microcavity mirrors. Electroluminescence from poly-Si:Er diodes in forward and reverse bias will be presented to demonstrate functionality as resonant cavity LEDs.

10:40 AM, FF2+

Epitaxial Er-Doped $BaTiO_3$ and Its Luminescent Properties: ANDREW TEREN[1]; Gregory M. Ford[1]; BRUCE W. WESSELS[1]; [1]Northwestern University, Materials Science and Engineering, 2225 N. Campus Dr., Evanston, IL 60208 USA

There is considerable interest in the development of epitaxial $BaTiO_3$ ferroelectric thin films for integrated optic and micro-photonic applications. Recently we have shown that Er-doped $BaTiO_3$ waveguides exhibited stimulated emission upon optical pumping. Further increases, however, in the luminescence efficiency are required if it is to be used as an optical gain medium. The luminescent properties of Er-doped $BaTiO_3$ thin films prepared by MOCVD were investigated. It was noted that the characteristic Er-related luminescence intensity at 1.54 microns depended upon both deposition conditions and post-deposition processing. To determine the factors influencing the intensity, the Er-doped films were annealed at high temperatures in oxygen. The characteristic luminescence intensity increased as much as twenty-fold upon annealing. The increase in intensity is tentatively attributed to the activation of the Er centers. The influence of annealing on the lifetime of the optically excited Er center was also studied using transient photoluminescence. Radiative lifetimes of 8 ms were measured. A model for the luminescence efficiency was developed and will be described.

11:00 AM, FF3+

Single-Layer Polymer Blend Organic Light Emitting Diodes with Electron Transport Polymers: K. A. Killeen[2]; T. R. Hebner[1]; F. Pschenitzka[1]; M. H. Lu[1]; M. E. Thompson[2]; J. A. STURM[1]; [1]Princeton University, Dept. of Electrical Engineering, Engineering Quadrangle, Princeton, NJ 08544-5263 USA; [2]University of Southern California, Department of Chemistry, Los Angeles, CA 90089 USA

One structure for the wet processing of organic light emitting diodes (OLEDS) which has exhibited great promise are polymer blends, in which emissive, and carrier transport agents are blended into a host polymer. Most previous work focused on blends of the hole transport polymer poly-vinylcarbazole (PVK) with electron transport small molecule of 2-(4-Biphynlyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole (PBD)[1]. However, concerns about the recrystallization of PBD and other small molecule electron transport materials make it desirable to develop an electron transport polymer (ETP) for use in polymer blends. Previous work in this direction has focused on multi layer devices [2,3] but to our knowledge, no single-layer polymer blend devices using ETP have been made. In this work we describe the preparation and use of an electron transport polymer in such single-layer devices. In this work we focus on polymers with pendant oxadiazole groups similar to PBD. A 2,5-diaryl oxadiazole pendant polymer (POXD) was prepared by the substitution of the chloride groups in poly(vinylbenzyl chloride) (Aldrich; 60/40 mixture of 3- and 4- isomers; Mw ca. ~55,000) with 2-(hydroxyphenyl)-5-phenyl-1,3,4-oxadiazole in basic DMF. ^{1}H NMR spectroscopy of the oxadiazole pendant polymer shows complete substitution of the benzyl chloride groups and we observe no chlorine in the elemental analyses of the polymer. Single-layer devices were successfully fabricated on indium tin oxide (ITO) coated glass using Mg:Ag/Ag electrodes. The single organic layer was deposited via spin coating with the hole transport material PVK, the electron transport material POXD and the emissive dye coumarin 6 (C6) along with PVK/PBD/C6 control devices. Devices had turn-on voltages of ~10-13V, emission spectra matching that of C6 dye (peak = 493 nm), and a quantum efficiency of ~0. 18%. The optimum ratio of hole transport (PVK) to electron transport (POXD) was found to be ~5:2, which is surprisingly similar to the optimal ratio of PVK:PBD in the related molecularly doped devices. Work in progress includes, the continuing optimization of the PVK/POXD/C6 blend devices and examination of new devices with molecular hole transport materials doped into the polymeric electron transport materials. In addition, we will report on the phase segregation in the polymer blend layers utilizing techniques in atomic force microscopy and transmission electron microscopy. This work was supported by NSF and DARPA (1464-967). 1 . C.C. Wu, J.C. Sturm, R. A. Register, J. Tian, E.P. Dana, and M.E. Thompson IEEE, Transactions on Electron Devices 1997, 44, 1269-1280. 2. E. Buchwaid, M. Meier, S. Karg, P. Posch, H. Schmidt, P. Strohriegl, W. Reiß, and M. Schwoerer Adv. Mater. 1995, 7, 839-842. 3. M. Greczmiel, P. Strohriegl, M. Meier, and W. Brutting Macromolecules 1997, 30, 60426046.

11:20 AM, FF4+

Carrier Transport Mechanisms in Organic Electroluminescent Devices: JUN SHEN[1]; Jie Yang[1]; Ji-Hai Xu[2]; Franky So[2]; H.-C. Lee[2]; [1]Arizona State University, Dept. of Electrical Engineering and Center for Solid State Electronic Research, P.O. Box 875706, Tempe, AZ 85287 USA; [2]Motorola, Inc., Phoenix Applied Research Center, 2100 E. Elliot Rd., Tempe, AZ 85284 USA

We will review the current status of the theoretical understanding of carrier transport mechanisms in organic electroluminescent devices (OEDs). Existing theories are critically compared with available experimental data from various laboratories. The applicability of contact-limited (thermionic emission, Fowler-Nordheim tunneling, etc.) and bulk-limited (trap-charge limited (TCL), field-mobility dependence, etc.) to various conditions is discussed. Then we present our theoretical results on the double-carrier injection devices (OEDs) under trap-charge limited conditions. Our theoretical work consists of two parts: analytical and numerical studies. In our analytical study, we extended previous single-carrier TCL theories to double-carrier case. Several new pieces of physics, which have been puzzling researchers in the field, are revealed and explained using the formula. A new region in the experimental current-voltage characteristics is identified and postulated to be the internal photo de-trapping (IPD) region. Recently, we also developed a numerical model taking into account the main ingredients in the OED TCL transport. Current-voltage characteristics, detailed energy and charge profiles are generated, and some physical insights are gained. For example, we developed clear pictures on the mechanisms that determine the location of the recombination zone, the double v.s. single carrier injection current enhancement, the temperature dependence, etc. Interesting doping effects and contact effects are also studied. In the talk, we will present these results and discuss their relevance with the experimental data.

11:40 AM, FF5

Late News