SPIE Photonics West ‘15

Conference report for the UKNC by Ionut Girgel, EE Engineering, University of Bath

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Introduction

Photonics West is an annual international conference on Laser, Photonics and Biomedical Optics organised by the International Society for Optics and Photonics (SPIE) and held this year (2015) 7-12 February in San Francisco, US. The conference prides itself with a wide variety of topics determined by recent developments in Photonics, bringing in 4700 papers and 20000 attendees. There were excellent plenary sessions in each day and I had the good fortune to attend 4 presentations from recent Nobel Prize laureates, including Prof Nakamura. There were workshops on technical writing and presentations, student centred events, a photonics business start-up challenge held its final stage and there was a job fair. It is also a big event for the Photonics industry to showcase their products and over 1250 companies from all over the world were present.

The talks were spread over a breadth of symposia, beside the Gallium Nitride Materials and Devices which grouped a lot of talks in my area of interest of core-shell LED and during which I had my presentation, I learned about new topics in semiconductor LEDs, lasers and vertical cavity surface emitting lasers (VCSELs), solar cells, oxide materials, photonics materials. Over the 60-70 talks I joined some very close to my research have made me think about new topics worth looking into, and the following is a technical summary of the topics and presentations I found most interesting.

Highlights

Vertical thinking in blue light emitting diodes: GaN-on-graphene technology

Can Bayram, Univ. of Illinois at Urbana-Champaign

GaN high quality layers can be obtained by release from a substrate using mechanical stress. The initial GaN layer is grown on epitaxial graphene by MOCVD with high temperature two step growth. With Van der Waals epitaxy (vdWE) there is no requirement to satisfy lattice mismatch between the underlying 2D material (graphene) and the growing GaN crystal. The GaN obtained and released from the graphene is 5 Å rms smooth, with no traces of graphene and can be directly bonded onto a Si (100) substrate covered with a 90 nm SiO_2 layer.

Releasing the GaN from graphene requires using mechanical stress from a Ni stressor layer grown on top of the GaN. It has been used to release an entire substrate (4inch Ge/InGaAs/InGaP solar cell or LED 2 inch). Strain energy can be induced in GaN by high-internal stress of Ni on top the GaN. The initial crack and propagation of the lateral fracture is used to peel off a controlled thickness from the GaN surface. The release can be initiated either at the GaN/graphene or graphene/SiC interface if the strain energy of the GaN film reaches the Van der Waals-bonding energy of the GaN/graphene or graphene/SiC interface. A 2.5 µm thick GaN film was released from the substrate by a 2 µm thick Ni stressor. Fully functional LED stacks are grown on epitaxial graphene/SiC and transferred from the substrate using tape.

Top-down and bottom-up fabrication of GaN core/shell micropillar arrays on Si

Albert V. Davydov, National Institute of Standards and Technology

NIST is using GaN to integrate GaN NWs on Si for photodetectors to take advantage of the high aspect ratio of NWs. The NWs are plasma etched at high temperature (350) ºC to obtain very slim rods. A further step of chemical etching with H_3PO_4 is used to produce an undercut to promote growth from the bottom of the rod, rather than the top. Regrowth is performed in an HVPE system at a low V/III ratio and 950 -1000 ºC. Electrical contacts on p-side are realised by filling with SOG, followed by back-etch to expose only the top of the rods for a 5nm Ni-Au transparent electrode.

Characterization by Raman shows planar GaN film is under tensile strain due to thermal mismatch, however once the footprint of the GaN is reduced, the GaN becomes relaxed and with the growth of further shells, it is still relaxed. CL at 6K showed strong emission from the top facet and sidewalls, but poor emission from the centre. This can be explained by TDs present in the core, but not on the high quality sidewalls. Only at the bottom there are BSF caused by the GaN/Si interface. Furthermore the CL showed the yellow band luminescence was eliminated by the growth on the p-GaN shell. The magnesium species for doping the p-type shell was determined by SIMS to be around 10^{20} cm^{-2}. As Hall measurements were impossible on NWs, a planar sample was grown at the same time and showed the density of holes to be ~10^{17} -10^{18} cm^{-2}.

Some further work by this group is on UV LEDs, crack free GaN and BN photodetectors.

Regularly-patterned non-polar InGaN/GaN quantum-well nanorod light-emitting diode array

Chih-Chung Yang, National Taiwan Univ.

Yang used pulsed growth technique in MBE to promote self-catalytic growth of GaN nanowires with no metal particles by switching on/off the TMGa and NH_3 sources alternatively. The Ga droplet accumulated at the top of a NR will serve as a catalyst. When NH_3 is supplied in the next cycle, the NW will grow vertically. N-type GaN, sidewall InGaN QWs and ultimately a p-type layer was achieved. Sources cycle is typically 30 sec NH_3 and 20 sec TMGa source.

The cross section size can be controlled, or tapered, by alternating the amount of time and flow of the TMGa source. A large number (10) of long 20sec TMGa cycles build the main body of the wire, and just 3 cycles at 15/10/5 sec make up the transition area. Each thinner section uses a progressively smaller flow of TMGa, while keeping the NH_3 supply constant. The wires have 2/3/4 diameter sections, the widest diameter is ~400 nm. A long cycle at the end can eliminate the remaining c-plane facet. The different section NWs should have different strain relaxation, and different indium integration and emission, to obtain white light emission without phosphorus. The QW width and separation become narrower, going from the thinner section at the top to the wider rod diameter at the bottom. The tapering angle in the transition area is changing from 62 deg to 42 deg. The InGaN QW was grown after the entire GaN nanorod was obtained. A p-type GaN shell was grown conformably and tends to be thicker at the top of the nanorod, perhaps due to the close proximity of neighbours. The transparent GaZnO (highly doped ZnO with Ga) covers the nanorod down to the SiO mask opening. The layer is 250nm thick which still permits 90% transmission. Ni/Au can make up contacts, the device IQE is 21%.

In comparison with a high quality c-plane planar LED with resistance of 15 Ω, the resistance of the nanowire LED is high at 360 Ω, however the emission area of the devices is quite different. The turn on voltage is about the same as the planar LED, and comparing the areas the equivalent resistance, the NW LED is actually lower than for planar. Another interesting aspect for electroluminescence was that although the QW was on the non-polar plane, the device showed a shift in emission with increasing current. The spectrum is blued shifted – near the bottom of the nanorod, while at the top it shows redshift. This was linked with better current spread at higher injection current, therefore the wavelengths are longer at the top (530nm) and shorter at the bottom (482nm), and eventually there is a saturation and the device is stabilized .

Direct imaging of nitride-based microrod LED structures using nano-scale scanning transmission electron microscope cathodoluminescence

Marcus Müller, Univ. Magdeburg

Core-shell micro-led structures etched from a GaN film had a height of (6 µm) and diameter (2 -2.5 µm at the widest point of the structure). The density of the micro-rods was $5x10^6$ cm^{-2} and with a structure of GaN core(1 µm) , AlGaN layer , GaN/InGaN SQW, GaN . An electron blocking layer of AlGaN was used and the structure was capped with a 200 nm thick p-GaN shell.

Cathodoluminescence (CL) characterization at low temperature showed the highest emission intensity was from non-polar planes of the microrod with weak luminesce from the GaN core, as the core has a higher density of point defects . Emission from the InGaN QW was at 440 nm , and showed a redshift at the tip of the microrod due to different growing conditions at the tip. Luminescence contribution from the first AlGaN layer, was at 340 nm on both sides of the structure. A blue band emission around 400 nm is considered to originate from the Mg p-doped GaN.

An interesting technique uses line scans on the InGaN layer to observe the change in emission spreading of a bright point with different intensity CL on a the micro rod. The slope of the CL intensity can be used to estimate the diffusion lengths of the free carriers, and they were quantified at 66nm from n-doped GaN and 35 nm for p-doped GaN.

A theoretical study of III-nitride nanowire arrays for emission and detection

Bernd Witzigmann, Univ. Kassel

Theoretical aspects of NW light propagation, PV, LED design were presented. Advantages such as high aspect ratio, single photon sources, efficient carrier injection and strain engineering were approached by modelling.

Within a nanowire the modes closer to the surface of the wire do most of the work, they absorb 95% of optical power within the wires, thus the wires are good broadband absorbers or can make good light concentrators. Strain engineering proposed a model for GaN/InGaN/GaN NWs in which close to the surface the NW experiences tensile strain, which compensates for compressive strain in the InGaN well, so there is much less strain close to the surface. Heterostructures with very thick InGaN layer can be achieved that normally wouldn't be possible on planar. For bulk InGaN growth of 30% InN, normally there is 4-5% strain, but in a NW there is practically no strain in the InGaN layer.

Core-shell model showed non-polar QWs may be subject to stronger photon recycling, depending on wire diameter, compared to the c-plane wells. Photon recycling happens when a green-emitting region absorbs part of the blue light, yellow-emitting region absorbs part of the green and blue, and red-emitting region absorbs photons from all. It is thus better to work in the bandgap to supress the horizontal radiation and take advantage of the directionality of the NWs. For PV cells at the bandgap of GaN, the efficiency of such a cell is 3%. InGaN which expands over the visible spectra, can make a good light absorber, but thick structures are needed to absorb most of the light. Efficiency can be up to 18% if light is captured by a thick InGaN layer (90% absorption up to the bandgap of GaN).

Status and future of GaN-based vertical-cavity surface-emitting lasers

Daniel F. Feezell , The Univ. of New Mexico

Dr. Feezell presented state of the art work on VCSELs based on GaN for projectors, optical data storage, head up displays, chip scale atomic clocks, biosensors. Compared to edge emitting lasers VCSELs have advantages such as small device footprint, lower power consumption, circular low divergence output beam, single longitudinal mode operation due to the short cavity and can be densely packed in 2D arrays. VCSELS have random polarization on c-plane GaN, the cavity is symmetric and the gain is isotropic within the plane of the QW. For non-polar plane the gain becomes anisotropic, so there is a preferential emission direction E perpendicular to c-plane.

Some of the challenges for the design of fabrication of VCSELs are: achieving high reflectance distributed Bragg reflector mirrors, optical mode confinement and optical aperture to maximise the overlap of the carriers, polarization, carrier transport, a highly resistive p-GaN and losses caused by variation in p-GaN thickness. A big challenge is cavity length control, which were approached by using an AlGaN stop etch layer to achieve a cavity length of 1.5 µm. Photo electrochemical etching technique was used to fabricate the GaN based VCSEL.

Room temperature non polar VCSELs were obtained pulse lasing at 409nm for 30 ns pulse, 7 µm diameter aperture, and 24.5 µW output power. Polarization was pinned with E perpendicular to <0001> direction, along the <1120> direction.

Future and present technologies of solid state lighting

Shuji Nakamura, Univ. California Santa Barbara

Started growing LEDs in 1989 when ZnSe was thought to be the material of choice for blue LED. Prof Nakamura candidly said his first work in GaN began driven by his purpose of publishing for a PhD degree in the incipient domain of GaN which offered the possibility to publish a large number of articles. For 18 months the MOCVD reactor available suffered daily mechanical changes to obtain GaN layers on sapphire, eventually leading to the two gas flow used today for GaN. Another important step was obtaining p–type GaN. Prof. Akasaki and Amano using electron beam irradiation activation to reduce resistivity of the p-doped GaN, while Prof. Nakamura figured out the atomic hydrogen in the reactor had a passivation effect on the Mg, which could be removed by thermal annealing above 600 ºC.

Homojunction blue LEDs were very dim, so next efforts were directed towards obtaining a heterojunction GaN/InGaN. Initially at room temperature InGaN showed no band –to-band emission at room temperature, however the two flow MOCVD reactor allowed for to obtain InGaN for QWs.

Currently at UCSB, Prof Nakamura is focusing on laser based white light. For laser diodes there is no Auger recombination and no droop. Current density in LED can be ~ 1000 larger than LED, the equivalent 60W white light source would need to be 28mm^2. Laser lighting allows for much smaller area like 0.3mm^2, and similar to current LED, phosphorus can be used to produce white light.

Single-molecule spectroscopy, imaging, and photocontrol

William E. Moerner, Stanford Univ.

Single molecule spectroscopy uses flurophores diluted enough to allow observing single florescent proteins. The molecules could be observed (switched) on or off to a 'dark state' by switching the molecules with laser light.

By spreading the image of a single molecule over multiple pixels of the detector, the detector records different number of photons according to the Airy function, which can be approximated to a Gaussian. The width is diffraction limited, but the centre has a narrower error, sigma distribution. So the 'super-localization' idea provides high accuracy of position of centres of a single molecule over multiple pixels of the detector. Another big step was done in 2006 by actively keep the molecules to emit all at the same time. Photo activation for a few molecules, photo bleach them and redo will a map at super high resolution, going beyond the optical diffraction limit. Further challenges for the method are working with more fluorophores and 3D imaging.

Poster sessions

There were two poster sessions with numerous topics in GaN/InGaN from which I picked a few to summarize.

"Strain relaxation and indium incorporation kinetics, in high indium content InGaN layers synthetized by PAMBE" (S.Valdueza Felip, Univ. Grenoble), showed a planar solar cell with 4 InGaN junctions, achieved 30% indium at temperature slightly under 640 ºC cells, and covered the full spectra with InN between 15-45%. The high indium was possible with increasing the InN layer thickness to relieve strain.

"Monolithically integrated RGB surface emitting laser chip" (Chu-Hsiang Teng, Univ. Michigan, Ann Arbor). Used InGaN/GaN nanowires with disk QWs on AlInN/GaN superlattice to make photonic crystal surface emitting lasers on a single chip. Varying the nanowire diameter allows tuning of emission wavelength 40-160nm on a patterned obtained by electron beam lithography and plasma etching. Nanowire diameters below 100 nm allow for colour tuning.

"Impact of stripe geometry on the relaxation behaviour of InGaN/GaN MQW nanostripe arrays" (Cory Lund, UCSB). Study of the effect of regrowth on the strain state of etched nanostripes. Considering width/height ratio, samples with ratio 0.5 show plastic relaxation after regrowth leading to cracking and misfit dislocations, while stripes with for ratio 1, there is elastic relaxation.

My presentation on “Investigation of facet dependent InGaN growth for core-shell LEDs” went very well, answered a couple of questions and I was happy to share the results we had at Bath and Strathclyde with such a high level international audience. The next paragraph is a summary of those results.

In this work we used vertically aligned GaN nanowires with well-defined crystal facets, i.e. the {11-20} a-plane, {10-10} m-plane, (0001) c-plane and {1-101} semi-polar planes, to investigate the impact of MOVPE reactor parameters on the characteristics of an InGaN layer. The morphology and optical characteristics of the InGaN layers grown of each facet were investigated by cathodoluminescence (CL) hyperspectral imaging and scanning electron microscopy (SEM). The influence of reactor parameters on growth rate and alloy fraction were determined and compared. The study revealed that pressure can have an important impact on the incorporation of InN on the {10-10} m-plane facets. The growth performed at 750°C and 100mbar led to a homogeneous high InN fraction of 25% on the {10-10} facets of the nanowires.

Conclusions

Overall the SPIE Photonics West ’15 was a great experience for me and I’d like to thank the UKNC for contributing towards my participation. I was able to evaluate the level of research done by other groups other than the UK in the III-nitrides area, and do some networking with some very impressive people, from group leaders to PhD students like myself. Talking with people about their work at the poster session was quite informal yet people were wonderfully knowledgeable and I found it easy to learn from each other. The next Photonics West will be in 13-18 Feb ’16, I definitely recommend attending for networking with some of the group leaders in Photonics, for the wide breadth of topics, as well as for the view over the Golden Gate Bridge. This conference gave me fresh motivation and made me plan new designs for future work.

Lower down there is a link for videos of some of plenary sessions and more.

(http://spie.org/app/spietv/)

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