Conference Report

UK Semiconductors conference 2022, July 6-7th

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Introduction:

This year's conference was held in association with the UK Nitrides Consortium and the TMD-UK meeting on 2D materials at Sheffield Hallam University. Topics covered a wide-range of semiconductors and their applications, including novel III-V semiconductor materials grown by metal-organic vapor phase epitaxy, quantum dot-based devices for telecom wavelength quantum networks, growth of high quality $\alpha - Ga_2O_3$ epilayers and the challenges and opportunities presented by semiconductors with non-ideal properties. This conference is divided into eight symposiums, which are Physics in Semiconductors, Optical Devices, Electronic Devices, Semiconductor Materials and Nanostructures, Mid-IR and THz Materials and Devices, Organic, Organic/Inorganic Hybrid Semiconductors and Perovskites, Wide-bandgap Semiconductors and 2D Materials.

The summary of talks I am particularly interested in are given below.

Selected Presentations:

Band Structure Engineering and the Quest for Ideal Semiconductor Materials and Devices, *Eoin P. O'Reilly*, *Tyndall National Institute* (Plenary talk)

In this plenary talk, the speaker presented and reflected the evolution an some of the key achievements in semiconductor physics, materials and engineering over the last 40 years, including the 1. The transformative impact of condensed matter physics overall and semiconductor physics in particular over that time (band engineering through strain management); 2. The ideal semiconductor materials behave outstandingly in their "comfort zone", however, their performance degrade dramatically outside this zone.

The speaker first discussed how we learnt to engineer the band structure through control of the dimensionality and strain in ideal semiconductor materials. Then, a number of non-ideal materials (e.g, III-nitides) and their applications such as avalanche photodetector, laser and LEDs were outlined. Finally, it was concluded that the close interaction between physics, materials science and engineering is required to mitigate against and overcome these limitations, not just for optical devices, but also for wider possible applications and opportunities.

Toward Temperature Stable Near-Infrared Emitters: GaAs-based "W"-Lasers, *Dominic A. Duffy, University of Surrey* (Optical Device, Oral Presentation)

The development of cooler-free semiconductors lasers in the near-infrared (NIR) is particularly important for the future of low-energy data communications. Though the type-I quantum well (QW) and quantum dot structure have been widely applied, devices remain limited by the fundamental non-radiative recombination processes such as Auger recombination, carrier leakage or defect-related recombination. Type-II heterostructures, where the electrons and holes are spatially confined in separate QWs, offer an opportunity to control non-radiative processes as well as temperature sensitivity of the output power and operating wavelength. In this talk, the speaker reported the device performance of (GaIn)As/Ga(AsSb)-based lasers operating at 1225 nm as a function of temperature and current, compared and contrasted this behavior with type-I lasers emitting at similar wavelengths. Based upon segmented contact measurements, observe strong modal gain characteristics up to G ≈ 23 cm^{-1} and relatively low optical losses of α_i = 8 ± 3 cm^{-1} at room temperature. Broad area lasers processed from the wafer exhibit relatively low pulsed room temperature threshold current densities of ≈ 200–300 A cm^{-2} and peak output powers exceeding 1 W. These are strong figures of merit for devices emitting in this wavelength range. In the end, the speaker discussed the development of "W"-structure as a platform for integrating dilute bismide and nitride alloys to further extend the accessible wavelength range of these structures and work towards reducing the effect of unfavourable Auger losses on device performance.

Radiation Damage in Ultra-Thin GaAs Solar Cells, *Armin Barthel, University of Cambridge* (Optical Device, Oral Presentation)

Solar cells for space applications require high tolerance to radiation, particularly high energy protons and electrons, as radiation damage degrades device performance. Depending on the orbit and the accompanying radiation environment, this performance degradation can limit the lifetime of a mission. In this talk, the speakers describe a novel device structure that can be used to mitigate such degradation, which is the ultra-thin solar cells (UTSCs). By incorporating an absorber layer (80 nm GaAs homojunction) that is significantly thinner than the diffusion of minority carriers in the material, the short circuit current can be preserved up to high fluences even after extensive irradiation. The speaker discussed the variations of the absorber layer carrier lifetime and reverse saturation with radiation damage determined by the time-resolved cathodoluminescence (TRCL) and dark current-voltage (DIV) measurements. It was found that the lifetime decreased and dark spots in the panchromatic maps with the radiation fluence that can be attribute to the introduction of non-radiative defects through radiation. The linear fitting of reverse current reveals that Shockley-Read-Hall recombination is able to describe the performance degradation of homojunction UTSCs.

Metallic nano-rings for broadband extraction of quantum light, *Luca Sapienza, University of Glasgow* (Semiconductor Materials and Nanostructures, Invited oral Presentation)

Extracting light into free space is one of the challenges to face when dealing with solid-state emitters embedded within high-index materials. In particular, improving the extraction efficiency has been the object of intensive research when intrinsically dim light sources, like single-photon emitters, are implemented for fundamental science and quantum information technology application. The speaker discussed the metallic nano-rings deposited on the surface of the sample and centred around the single InAs/GaAs quantum dots, which are formed by strain-induced self-assembly. It was shown that such nano-ring structure provides a lensing effect that concentrates the excitation light and focuses the emission out of the chip. The brightness was found to increase by up to factor of 20 and the collected photon rates are as high as 7 million photons per second when combined with metallic back reflector. Compared with optical cavities, metallic rings are intrinsically broadband, and they do not rely on specifically prepared substrate, which enables it to be applied to any emitter/substrate combination.

Investigating the Carrier Dynamics in InGaN/GaN Core-Shell Nanorods, *Kagiso Loeto, University of Cambridge* (Wide-bandgap semiconductors, Oral Presentation)

Charge carrier dynamics describe the motion and activity of excess electrons and holes in a semiconductor from the point they are generated to when they recombine. Understanding the charge carrier dynamics is crucial in unravelling a multitude of phenomena related to the behaviour and properties of GaN-based semiconductor materials and their devices. The speaker discussed the application of time-resolved cathodoluminescence (TRCL) in investigating the fundamental differences in the low temperature carrier dynamics of different crystal facets present in GaN nanorods with an overgrown InGaN layer. The nanorod used in their study was fabricated by top-down etching, which contains six non-polar {10-10} sidewalls, six semi-polar {1-101} facets and one polar c-plane facet at the apex. The TRCL measurements reveal that the carrier lifetime reduced from apex polar, to semi-polar to non-polar plane, which might be related to the increased electron-hole wavefunction separation caused by the inherent polarization field. Furthermore, their study suggests that localization potential barrier may present in apex polar facet, which were not found in their semi-polar and non-polar counterparts. These findings suggests that the interplay between exciton localization at potential minima and the different strength of the inherent polarization filed are crucial to the understanding of the observed differences in decay times.

Carrier localization-enhanced Auger recombination and efficiency droop in InGaN/GaN quantum wells, *R. M. Barrett, University of Manchester* (Wide-bandgap semiconductors, Oral Presentation)

Though the internal quantum efficiency (IQE) of InGaN/GaN quantum wells (QWs) can be as high as 95% at moderate drive current, the decrease of efficiency for higher rates of excitation, i.e., droop, limiting their high brightness application. The debate over the most important causes of droop due to the challenges in reconciling experimental data and previous modelling. In this talk, the speaker talked the effect of alloy fluctuation induced localization of carriers on the Auger recombination rates based on atomistic modelling. The sample used in the simulation has 15% indium content in QW with carrier densities ranging from $10^{17}cm^{-3}$ to $10^{20}cm^{-3}$. Besides, three experimental samples were grown by MOCVD under different temperatures with different point defect densities. According to the speaker, theory and experiment agree well. The model demonstrates that whilst non-radiative recombination affects the peak IQE and the carrier densities $> \sim 10^{19} cm^{-3}$ it becomes insignificant and IQE then depends on the competition between radiative and carrier localization enhanced Auger recombination, without any defect assistance.

Efficiency droop in cubic InGaN/GaN Quantum Wells, *D. Dyer, University of Manchester* (Wide-bandgap semiconductors, Oral Presentation)

The efficiency of InGaN/GaN LEDs decreases significantly at high carrier densities, an effect known as "droop", and restricts their use in applications that require high brightness. Regardless of the mechanisms of the droop, it can be mitigated by reducing the carrier recombination lifetime. This can be achieved by adopting the cubic GaN structure, where spontaneous polarization field doesn't exist. The speaker reported the droop of InGaN/GaN grown in cubic zincblende phase, which are free of polarization fields and have nanosecond recombination lifetime. It was found that the emission from cubic QWs can be significantly polarized as well. The degree of linear polarization was found to increase by ~5% for each sample over 3 decades in carrier density. They studied the emission properties for 2.5 nm single QW (SQW) and multiple QWs (MQWs) with QW thickness of 2.5, 5.0 and 7.5 nm. In each case, the efficiency reaches a peak as the carrier density is increased, before declining as the excitation increase further. The carrier density per QW at which peak efficiency occurs increases with the QW thickness. However, for the same QW width, it was less for the MQW than for the SQW, which indicates an uneven distribution of carriers between QWs. The decline of efficiency from its peak for greater carrier densities is steeper for the SQW than the MQWs, suggesting that carrier leakage and recapture is important.

Strongly Enhanced Light Collection From III-Nitride Quantum Emitters, *S. G. Bishop, Cardiff University* (Wide-bandgap semiconductors, Oral Presentation)

Solid state quantum emitters have become an important source of quantized light states, and it has been demonstrated that wurtzite III-nitride materials can also host a wide variety of color centres, with emission energies spanning the visible wavelengths and into the near-infrared. However, as these dipole-like emitters are embedded in high refractive index materials, the photon collection efficiency is limited to few percent by refraction and reflection at the upper surface. The speaker described a way to enhance the photon collection efficiency by using the hemispherical solid immersion lens (SIL) in AlN. Through analytical and numerical methods, they predict a broadband enhancement of the light collected into a high numerical aperture imaging system of up to x8 because of the refractive index match between the AlN and ZrO_2 SIL. Besides, as the speaker said, the collection efficiency has an exponential dependence on the polymer thickness, which is due to the coupling the evanescent field through the polymer at thin film thickness. This exponential dependence was later proved experimentally by photon counting time-resolved measurement. The speaker finally concluded that a MHz single photon detection rate can be achieved due to the inherent wide-field collection efficiency enhancement over a broad spectral range of SIL. At those high rates, one will be able to perform multiphoton correlation spectroscopy, revealing the presence of internal energy levels within single color centres.

Concluding remarks:

I am very grateful to UKNC for providing such an opportunity to attend this year's UK semiconductor conference and present my work there. It was an eye-opening experience and the first conference I attended in person since the pandemic. I've learned a lot from talks spanning from different backgrounds and discussions with others.