NEWLED Newsletter

Number 1, April 2013

Welcome

Hello, and welcome to the 1st newsletter of the NEWLED Project, an European Commission Framework 7 Programme funded project that aims to revolutionise the way the world is lit by developing novel solutions for white light-emitting LED lights.

It is estimated that efficient white-light LEDs, if successfully developed and widely implemented, could have a massive effect on reducing global energy consumption and $C0_2$ emissions since this form of lighting is much more efficient than existing light bulbs.

NEWLED brings together 7 academic and 7 industrial partners from all over Europe, and their efforts to produce highly efficient white LEDs will see the project partners examine every stage of the LED fabrication process, from developing new knowledge on the control of semiconductor properties on a near-atomistic level to light extraction, light mixing and heat management merging the efficiency gap in the orange-green spectral range by shifting the boundaries in each of the two materials systems InGaN/GaN and AlInGaP/AlGaAs.

By examining the entire process, NEWLED aims to ensure that the new LEDs will be well adjusted to avoid compromising the achievements of the overall process and to ensure significant system and operating cost reduction.

The success of NEWLED will bring us all a step closer to a bright and sustainable future.

Edik Rafailov
NEWLED Project Coordinator
University of Dundee, UK

About us:

NEWLED will develop high efficiency and high brightness monolithic and hybrid all-semiconductor white light-emitting GaN-based diodes (LEDs). Power losses due to phosphor conversion and the problem of different ageing rates of the GaN LED pump will be eliminated by the development of phosphor free structures with increased brightness (power emitted per surface per angle). *NEWLED* will enhance the efficiency of yellow InGaAlP/AlGaAs LEDs by bandgap engineered superlattices. Novel light extraction approaches will target advanced directionality and colour adjustment. Values of 50 to 60% overall efficiency with a conversion of greater than 200 lm/W in the exploited warm white LEDs are targeted as well as the realisation of a colour rendering index (CRI) of greater than 95. Advanced packaging will enable effective heat dissipation and light management. The devices will have immediate applications in automotive, industrial lighting and displays industries. Widespread implementation would reduce global energy consumption by approximately 10% and reduce CO2 emissions by 3 billion tonnes with consequent economic and environmental benefits.

Project partners:

- *University of Dundee (Coordinator)*
- *OSRAM Opto Semiconductors GmbH*
- *Technical University of Berlin*
- *A.F. Ioffe Physico-Technical Institute*
- *Centre National de la Recherche Scientific*
- *VI Systems GmbH*
- *TopGaN SP zoo*
- *Compound Semiconductor Technologies Global Ltd.*
- *University of Rome "Tor Vergata"*
- *M-Squared Lasers Ltd.*
- *Tampere University of Technology*
- *STR Group Soft-Impact Ltd.*
- *LUX-TSI Ltd.*
- *Vilnius University*

Project Partners

University of Dundee

The University of Dundee is one of the UK's leading universities. The Division of Electronics Engineering and Physics (EEP) has more recently specialised in photonics and nano-materials with emphasis on the development of semiconductor laser devices, and it is well known for advanced studies of optoelectronic devices including gain chips, lasers, external cavity lasers, mode-locked lasers, quantum dot devices and fundamental properties of quantum dots.

OSRAM Opto Semiconductors GmbH

As the world's second largest manufacturer of optoelectronic semiconductors for the illumination, sensing and visualisation sectors, OSRAM's semiconductor product portfolio includes high-power LEDs in the visible range, high-performance infrared LEDs, high-quality optoelectronic detectors and sensors, organic LEDs (OLEDs) and high-power semiconductor lasers. The entire production chain of devices from III-V epitaxy through photolithography, metal deposition, passivation, plasma etching, chip singulation, optical and electrical chip characterisation up to device packaging including phosphor technology is available.

Technical University of Berlin

The Optics group of the Institute of Solid State Physics at TUB hosts a large number of advanced experimental equipment to investigate optical, electrical and structural properties of nanostructures. The experiments are accompanied and guided by comprehensive electronic structure modelling based on advanced 3D algorithms using own high-performance computing environments. Micro- and nano-Raman spectroscopy, time-resolved and time-integrated micro-photoluminescence and micro-photoluminescence excitation spectroscopy have been developed to perform studies on nanostructures based on nitrides, oxides and arsenides.

A.F. Ioffe Physico-Technical Institute

The Ioffe Institute is the biggest institute of the Russian Academy of Sciences. It pioneered double heterostructures (HS) including the proposal and the first realisation of double HS lasers, LEDs, HS solar cells, bipolar transistors and other HS devices, and it is among the first pioneers of QD growth in Russia. It made pioneering work on photopumped surface stimulated emission and lasing in GaN QD vertical structures and to the observation of non-equilibrium carrier distribution in deep QDs up to elevated temperatures, and it contributed to size and shape engineering of InGaN QDs as well.

Centre National de la Recherche Scientific

CRHEA-CNRS is involved in the growth of wide-bandgap semiconductors (GaN, ZnO and SiC) by several techniques: MBE, CVD, MOVPE and HVPE. Facilities for GaN growth include 5 MBE, 3 MOVPE and 1 HVPE reactors. The main growth activity is supported by structural (high resolution X-ray Diffraction, scanning and transmission electron microscopy, atomic force microscopy and scanning tunneling microscopy), optical (photoluminescence, reflectivity, electro-optic measurements) and electrical characterisation (C-V, Hall, resistivity) techniques.

The CEMES-CNRS covers a wide range of scientific activities aimed at manufacturing, understanding, modelling and manipulation of matter at the atomic scale. Physicists and chemists invent and manufacture materials, nano-materials and molecules with specific desired properties, and integrate them in demonstration devices. CEMES-CNRS as world pioneer in Electron microscopy is a leader in advanced structural characterisation of materials with techniques sensitive to chemical and strain variations in heterostructures.

VI Systems GmbH

VI Systems involves pioneers of QD laser discovery and research, pioneers of 1300 nm GaAs vertical cavity surface emitting lasers (VCSELs), orange InGaAlP VCSELs. The team developed original approaches to modelling of excitonic properties and properties of multi-section short period superlattices and developed the related electrooptic EO materials useful for both positive and negative electrooptic effect under reverse bias without noticeable change in the absorption coefficient.

TopGaN SP zoo

Founded as a spin-off from the Institute of High Pressure Physics belonging to the Polish Academy of Sciences. The company is using 800 m^2 clean-room facility equipped with a number of high-pressure GaN growth chambers, 3 HVPE, 4 MOVPE and 2 MBE systems. The processing include all steps of laser diode fabrication. The analytical lab is equipped with TEM, SEM, CL, 2 HR XRD, microPL, 2 AFM and some other techniques. The company possesses unique technologies as high pressure GaN growth, PA MBE laser diodes, lateral patterning to obtain local off-orientation. The main product of TopGaN are laser diode arrays operating in watt range at wavelengths 390-420 nm.

Compound Semiconductor Technologies Global Ltd.

CSTG is a semiconductor foundry specialising in the design, development, and manufacture of discrete and integrated III-V opto-electronic devices since 1999. CSTG has provided specialist foundry services to clients in Telecommunication, Defence, Medical and Instrumentation markets, and offers full product support from design to manufacturing, levered off a comprehensive library of qualified fabrication processes and a suite of high performance device platforms.

University of Rome "Tor Vergata"

The Opto&Nanoelectronics group of the Department of Electronic Engineering has been involved for long time in research activities on microscopic theory of electronic and optical properties of nanostructure, both organic and inorganic. The tools developed to perform these studies range from ab-initio / semi-empirical atomistic calculations of electronic and optical properties to Monte Carlo simulations of charge transport in bulk, nanostrucures and devices. Large effort has been given to the development of a multiscale-multiphysics simulator, TiberCAD, able to describe from macroscopic down to atomistic details the electronic and optical properties of nanostructured devices.

M-Squared Lasers Ltd.

M Squared Lasers designs and manufactures next-generation, advanced photonic instruments, with wide experience in project and business management, electronics and lasers and commercializing novel photonic instruments for both scientific and industrial use. M Squared Lasers' expertise covers a diverse range of applications as biophotonics, advanced imaging/display, laser spectroscopy, atomic cooling and manipulation, ultrafast laser applications, multi-photon imaging and microscopy, semiconductor inspection and metrology, and optical data storage. M Squared has considerable experience in the development of quantum dot based photonic solutions.

Tampere University of Technology

ORC is a subsidiary unit operating under the Council of Tampere University of Technology (TUT). ORC promotes co-operation between enterprises and universities, fosters the establishment of new business, participates in national and international projects, and facilitates undergraduate and postgraduate studies. The major technologies run at ORC are the Molecular Beam Epitaxy of compound semiconductors (5 MBE reactors are located at ORC), complete device processing and characterisation facilities, ultra-fast and high-power lasers laboratories and other related optical systems. Its core business is the compound semiconductor technology, novel optoelectronic components, and ultra-fast optics.

STR Group Soft-Impact Ltd.

Soft-Impact Ltd. was founded by a group of researchers from Ioffe Institute. Its main activities include scientific researche, equipment design, optimisation of crystal growth techniques and device engineering for semiconductor materials technology. There are four groups of researchers and programmers specialised in the following fields: Crystal growth from melt by Czochralski, Liquid Encapsulated Czochralski, and Bridgman techniques; Sublimation growth of bulk bandgap semiconductors (SiC, AlN, GaN); Chemical Vapor Deposition of Si-based (Si, SiC, SiGe), A3B5 and III-Group Nitrides; Nitride semiconductor based devices manufacturing: light emitting diodes (LEDs), laser diodes (LDs), transistors and others.

LUX-TSI Ltd.

LUX-TSI was formed to focus on providing independent testing services through accredited laboratories and quality management systems conforming to ISO IEC 17025. Support provided to companies includes basic research such as LED module performance through pre-compliance testing and, in conjunction with UL (www.ul.com) for fully accredited testing to international standards and performance schemes such as Energy Star, Lighting Facts, ErP Directives, EN-EC and UL marks. The company has a suite of characterisation facilities and has recently been awarded UKAS accreditation, so their measuring and testing services are internationally recognised. The company is accredited for LM79 (photometric performance) and LM80 (lumen maintenance) standards to test LED modules

Vilnius University

Main research focus of the Institute of Applied Research are the growth of gallium nitride and related alloys by MOCVD technology, the development and characterisation of lighting devices based on nitrides, the design of photometrical and electronic devices, the investigation of non-equilibrium phenomena in semiconductor crystals and quantum structures, the electronic, ionic and optical spectroscopy, and the non-linear optical phenomena in condensed matter. Scientific activities include also investigation of organic materials and development of optoelectronic devices, research of information processes in the visual systems and the design of neural net principle processors, applied software development, Laser surgery problems and the development of tissue diagnostic methods.

Highlights

Formation of Three-Dimensional Islands in Subcritical Layer Deposition in Stranski-Krastanow Growth

VI Systems and Ioffe Physical Institute in collaboration with University of Notre Dame (USA) proposed a new method for the formation of three-dimensional (3D) strained islands in a lattice-mismatched heteroepitaxy by altering the Stranski-Krastanow growth mode. Assume that a material B is grown on a substrate of material A, where B is lattice-mismatched with respect to A. Once B has formed a thin wetting layer (WL) below its critical thickness, i.e. before 3D Stranski-Krastanow growth mode sets in, a third material C is deposited, which is lattice-matched to A and does not wet B. Then B and C phase separate and form local B-rich and C-rich domains on the surface. The thickness of the B-rich domains thus exceeds locally that of the initial film of B, and 3D islands may form. Such form of growth can be obtained e.g. by growth of a subcritical InAs/GaAs(100) film followed by the deposition of AlAs, which has been confirmed experimentally by chemically-sensitive scanning transmission electron microscopy (STEM) and by photoluminescence measurements. Fig. 1 shows an STEM image of a 4-fold stack AlAs/InAs/GaAs structure and two vertical scans of In and Al concentration, showing clearly the presence of In and Al rich domains.

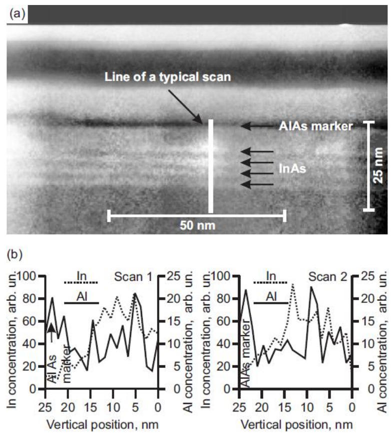

Figure 1: (a) STEM image of a 4-fold stack AlAs/InAs/GaAs structure. (b) vertical scans of In and Al concentration at different horizontal positions.

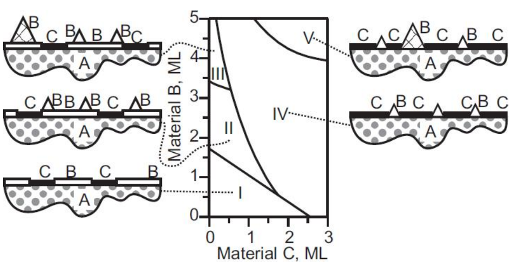

Figure 2: Possible equilibrium phase diagram for the proposed growth mechanism.

The proposed growth mechanism can be described by means of equilibrium phase diagrams, as shown in Fig. 2 for a certain set of material parameters. Different growth regimes can be distinguished, depending on the number of deposited monolayers (MLs) of the B and C materials. The boundary between regions I and II in this case represents the conditions for the onset of 3D growth. In regions I-III B- and C-wetting layers coexist, whereas in IV and V it is exclusively formed by material B. For the shown particular case, the systems allows for growth of finite-size coherent islands of B, with the formation of ripened islands for increasing number of deposited MLs of B.

Growth of Different Spatial Profile InGaN MQW Structures by MOCVD

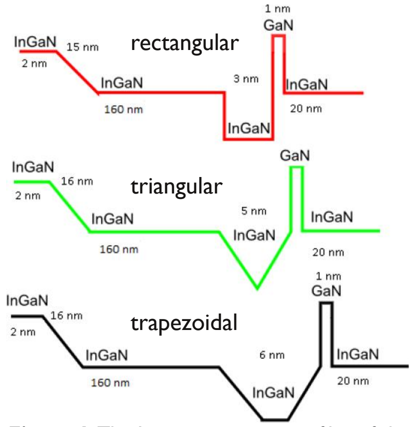

Figure 1: The In concentration profiles of the different samples grown.

The band gap of InGaN can be adjusted to make emission and absorption covering the entire visible spectrum by changing the ratio of indium to gallium in the active layer. This makes the InGaN material attractive for use in optoelectronics and photovoltaics. However, attempts to manufacture LEDs emitting light at long wavelengths encounter problems due to increased defect density, high influence of internal electric field and carrier localization. The group of Vilnius University has therefore performed growth experiments aimed at the improvement of the electrical and optical quality of the active InGaN/GaN multi quantum well (MQW) layers. Several structures with different InGaN composition profiles in the quantum wells and with additional low In concentration InGaN interlayer have been grown on GaN templates on (0001) sapphire substrate by metalorganic chemical vapor deposition (MOCVD), as shown in Fig. 1. The quality of the samples was characterized by photoluminescence (PL) and femtosecond pump-probe measurements. The best results have been obtained with triangular-shaped MQWs grown on 160 nm thick intermediate InGaN layer combined with indium gradient layer (Fig. 1b), as shown by the PL spectra in Fig. 2.

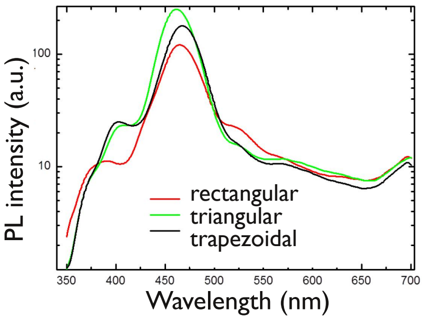

Figure 2: Measured PL spectra.

Simulation of Random Alloy Effects in InGaN/GaN LEDs

The group of University of Rome "Tor Vergata" has studied the influence of random spatial fluctuations of the distribution of the In atoms in an InGaN alloy by means of atomistic simulation approaches. First, the atomistic structures of InGaN/GaN quantum dots (QD) and quantum wells (QW) have been created. Then, Ga atoms of the InGaN region have been exchanged randomly by In atoms, maintaining a given mean In concentration between 10% and 30%. A valence force field (VFF) model has been used to calculate the elastic strain and the equilibrium atomic positions in these disordered structures. Based on the relaxed structures, atomistic empirical tight binding (ETB) simulations have been performed to find the electron and hole ground state energies, including the strong piezoelectric and spontaneous polarization fields. These calculations have been done on hundreds of samples with randomly distributed In atoms. As a result, a statistical distribution of the ground state transition energy has been obtained. It has been found that the emission spectrum of the statistical ensemble, given by the sum of the single sample emission spectra, undergoes a broadening due to the random disposition of In atoms as shown in Fig. 1. For the QD a broadening of 10 to 20 meV has been obtained for In concentrations between 10% and 30%. It was also found that the transition energies are correlated with the effective mean In concentration, given by the mean concentration weighted by the electrons' ground state spatial probability density (SPD). The fluctuations of the latter are shown in Fig. 2 for four random QW samples.

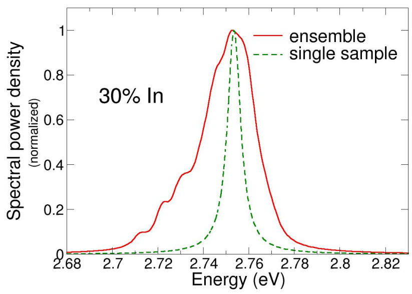

Figure 1: Ensemble and single sample QD emission spectra.

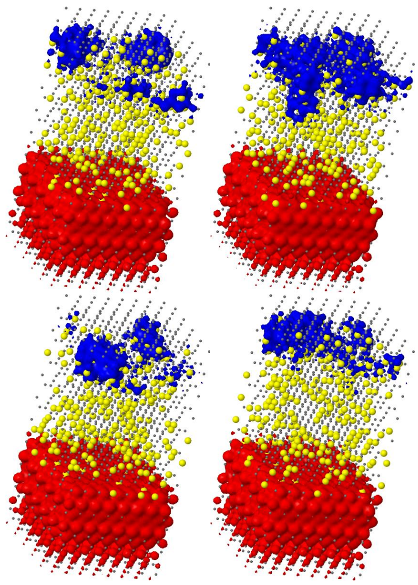

Figure 2: Ground state SPDs for four different random QW samples (blue: electron SPD, red: hole SPD, yellow dots: In atoms, gray dots: Ga atoms).

Publications & Conferences

NEWLED will be present at the following conferences:

- *13th International Conference on Numerical Simulation of Optoelectronic Devices* (NUSOD), 19–22 August, Vancouver, Canada
- *15th European Workshop on Metalorganic Vapour Phase Epitaxy* (EWMOVPE XV), 2–5 June, Aachen, Germany

The following article has been accepted for publication in Physical Review Letters:

- V. Shchukin et. al, *Formation of Three-Dimensional Islands in Subcritical Layer Deposition in Stranski-Krastanow Growth*

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