School of Informatics
University of Wales, Bangor

RESEARCH AWARD – ADVANCED NANOSCALE AND NONLINEAR OPTOELECTRONICS

1 Executive Summary

Prof. K.A.Shore is pleased to announce the award of "Platform" grant from the Engineering and Physical Sciences Research Council (EPSRC) of the United Kingdom to his optoelectronics research team at the School of Informatics, University of Wales, Bangor. The award, which is worth over £400,000, will be used to maintain and enhance nanoscale and nonlinear optical design and measurement expertise within the School of Informatics. In particular the award will underpin an expansion of research activities into bio-photonics and micro-system optics.

2 Introduction and Background

The Optoelectronics Group was established at Bangor in September 1995 with the appointment of K.A.Shore to the Chair of Electronic Engineering and subsequent appointment of five academics - Professor Sam Braunstein, Dr Paul Rees, Dr Paul Spencer, Dr Iestyn Pierce and Dr Koenraad Audenaert. The group currently hosts 8 post-doctoral research associates and 8 PhD students. Bangor has key capabilities in three inter-related areas of leading edge activities:

- Nanoscale Optical Measurements
- Nonlinear Optoelectronics
- Nanoscale Nonlinear Optical Processing.

The co-location of these capabilities in one laboratory offers a unique opportunity for achieving substantial progress ranging from basic science through to technological exploitation. Over the past six years the group has generated a research output in the form of more than 400 publications with over 150 journal papers being published mainly in Science, Nature, PRL, Phys Rev., AIP and IEEE journals.

The output of the group is distinguished by seminal contributions in such diverse areas as quantum computing; quantum lithography and semiconductor laser design including organic and intersubband lasers. Bangor is a world player in experimental and theoretical investigations of chaotic laser diodes and nonlinear optics of laser diodes. The group is also amongst the most productive in the world for theoretical and experimental investigations of VCSEL dynamics.

The rapid expansion of optoelectronics and quantum optics research at Bangor has been facilitated by a number of substantial EPSRC and European Union grants. These grants together with Funding Council Infrastructure awards and notable support from the Royal Society of the UK constitute an active project portfolio whose total value currently exceeds £2.5 million.

This award further supports the ground-breaking research in optoelectronics devices, bio-photonics and microsystem optics.

3 Research Themes

Nano-optoelectronics will be the principal focus of the work performed directly within this project. The aim is to utilize the powerful combination of theoretical expertise and experimental capability at Bangor in order to make significant advances in nano-scale science and engineering. Nanoscale science and engineering is a key driver for broad technological innovation encompassing: optoelectronics, biotechnology, medicine and pharmaceutics, food safety, anti-terrorism, automotive and aeronautical engineering.

This award will further support the deployment of the unique combination of experimental and theoretical capabilities at Bangor to make significant advances in the following areas:

- Nanoscale dynamics in optoelectronic devices
- Intersubband nonlinear optoelectronics
- Semiconductor quantum computer interconnects
- Organic optoelectronics and biochip optical interconnects
- Nanoscale material processing & optical micromachine fabrication.

Taking each in turn.

3.1 Nanoscale Dynamics in Optoelectronic Devices

Bangor has a strong record of achievement in nonlinear optical processes in laser diode devices including substantial experimental work on multiwave mixing phenomena in laser diode devices, the dynamics of external cavity laser diodes for applications in chaotic optical data encryption and VCSEL dynamics.

The Near-field Scanning Optical Microscope (NSOM) together with the Hurricane picosecond laser will allow fundamental investigations of pulse multiwave mixing in Semiconductor Optical Amplifiers (SOA) and will, in particular, allow attention will be given to enhancements of multiwave mixing efficiency arising due to pump/probe detuning. The NSOM will also allow simultaneous observation of spatial and dynamical behaviour in, for example, VCSELs undergoing optical switching of polarization and transverse modes and hence enable a clear demonstration of the mechanism underpinning the observed switching. The facility will also be used to examine spatio-temporal effects arising in external cavity VCSELs and multi-transverse modes in VCSELs subject to optical injection where rich dynamical behaviour is known to arise. These observations will significantly enhance understanding of the processes occurring in such VCSEL configurations and will thus provide crucial information for their application in sensor and monitoring functions.

3.2 Intersubband Nonlinear Optoelectronics

Bangor has been active in the design and theoretical investigation of intersubband ‘quantum cascade ‘ lasers for a number of years. A strong motivation for this work is the promise of high-speed optical response arising from characteristic picosecond carrier lifetimes in intersubband semiconductor lasers. Such lifetimes imply TeraHertz direct current modulation of intersubband lasers.

Intersubband transitions are characterised by a very low linewidth enhancement factor, which suggest opportunities for chirp free amplification of picosecond pulses in intersubband optical amplifiers. However, the response may be compromised by the relatively narrow optical gain spectrum of the lasers where gain dispersion effects become important. Theoretical work at Bangor has recently highlighted the opportunities for designing multi-functional devices where application of a suitable bias allows the achievement of, for example, both efficient multiwave mixing and high-harmonic generation. This award will support work to probe the dynamical response of both Near Infra-red intersubband lasers emerging from the collaboration with UMIST in Manchester, UK and also to explore properties of a commercial Quantum Cascade Laser which will be available at Bangor within the Quantum Computer Interconnect project which is discussed next.

3.3 Semiconductor Quantum Computer Interconnects

Experimental work on interconnects for quantum computers is underway at Bangor and is directed at demonstrating capabilities for interrogating quantum dot-based qubits. This award will enable the scope of the work to be extended to the in situ examination of dynamical switching of quantum dot qubits. Suitable quantum well structures will be examined as analogues of the qubits. The work will enable the extraction of key time constants of the system, which will allow comparison with theoretical requirements for effective quantum processing.

3.4 Organic Optoelectronics & Biochip Optical Interconnects

The award will be used to significantly augment the development of organic semiconductor lasers, which is being pursued in collaboration with the University of St Andrews in Scotland. The specific focus of effort will be a detailed calibration to be performed of the dynamical behaviour of optically pumped circular grating DFB organic semiconductor lasers.

The second area that will be enhanced by the award relates to the examination of processes occurring in optical waveguides incorporated in biofactory-on-a-chip (BFC) structures. The goal of BFC research undertaken at Bangor has been to develop miniaturised devices - biochips – with the capability to identify and manipulate biological particles and materials such as bacteria and cancerous cells whose size is typically of order a few microns. There are significant advantages in terms of higher-speeds, greater throughput and lower costs for bio-particle processing using BFC technology. The microfabrication and particle electrokinetic technologies incorporated in the BFC concept are the outcome of basic research undertaken over a 15 year period at Bangor and leading to the spin-out of Aura Biosystems Inc., Palo Alto, California.

Recently, attention has been directed at incorporating optical waveguides in BFC and more general lab-on-a-chip devices as a further means for bio-particle identification. Thus, for example, chemical detection can be undertaken by optical absorbance and emission measurements using relatively simple waveguide structures where light travels in a straight line to the sensor device. BFC devices, however, typically contain large arrays of microelectrodes and hence there can be significant constraints on the location of optical detectors. The practical requirement is for the development of waveguide arrays that enable linear "image" data to be extracted from a biochip device. For cell identification there is also a need for measuring particle velocity and size in order to determine a range of physiological parameters. Work in the present project will be directed at undertaking detailed NSOM measurements of prototype biochip optical interconnect waveguides including tracking of dynamical response.

3.5 Nanoscale material processing & optical micromachine fabrication.

The development of micromachines has become a major research and development activity, which is primarily motivated by the expectation of realizing low-cost highly functional elements. Much attention has been given to micro-electro-mechanical systems (MEMS) technology for powering micro-machines. Attention has also been given to alternative driving mechanisms such as a motor based on micro-fluidic convection. The use of optical processes for powering micro-machines has also been the subject of some recent exploration with effort has been given to the use of "photon wind pressure" and the derivation of optical angular momentum from a focussed laser beam to drive microengines. Work will be undertaken with this award to explore microfabrication technologies for the production of optical micromachines. Such work will allow consideration of fabricating key functional elements with identified applications in micro-mechanics, micro-fluidics and the biosciences.

4 Exploitation

Within the School of Informatics at Bangor, a specific framework for exploiting Intellectual Property (IP) arising from the optoelectronics research is provided by the Centre of Excellence for Industrial and Commercial Optoelectronics (ICON), which is directed by Prof. K A Shore. ICON has a particular mission to promote the utilization of optoelectronics technology by SMEs. The ICON Commercial Manager (Dr M W Holmes) is responsible for the identification; protection and exploitation of IP including seeking opportunities for spinouts, joint ventures and licensing agreements. In particular ICON works closely with the Welsh Development Agency to exploit IP in association with the OpTIC business incubation and technology centre that is in the process of being built on the St Asaph Business Park, north Wales and which will open in September 2003.

5 Further Information

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