Micro-Photoluminescence Excitation of Ordered $GaIn_xP_{1-x}$

An application using Oxford Instruments Superconductivity's MicrostatHiRes, high resolution microstat cryostat

At the National Renewable Energy Laboratory (NREL) in Golden, Colorado, Brian Fluegel, Steve Smith and Angelo Mascarenhas in the Solid State spectroscopy laboratory have been able to use the high-spatial resolution of micro-photoluminescence (micro-PL) spectroscopy to examine the optoelectronic properties of ordered-Gallium Indium Phosphide ($GaIn_xP_{1-x}$) alloys (x=0.48) on a sub-micron length-scale.

While most of the macroscopic ordering related properties of this alloy are thought to be well understood, micro-PL results have been more difficult to explain. As $GaIn_xP_{1-x}$ alloys are an important component in high efficiency solar cells, visible semiconductor lasers and LEDs, and high-speed, high-power, hetero-junction bipolar transistors used in telecommunications devices, a fundamental understanding of this alloy is especially important.

Under certain growth conditions $GaIn_xP_{1-x}$ spontaneously orders, forming a monolayer superlattice of alternating Ga (In)-rich atomic planes (Figure 1). This ordering reduces the crystal symmetry and leads to, among other effects, a large band-gap reduction, which can be continuously tuned by varying growth conditions and thus the degree of ordering. This atomic-scale ordering is continuous only on a micron length-scale, forming a domain structure.

Samples were patterned with opaque masks that created arrays of 200 nm apertures (Figure 2), and mounted in an Oxford Instruments Superconductivity MicrostatHiRes microscope cryostat. This, in turn, was mounted on a computer-controlled XY-stage, enabling individual apertures to be addressed in a repeatable fashion. A 2 μm excitation spot was placed over single apertures. The mechanical stability of the Microstat allowed integration times of up to 15 minutes with a lateral and vertical drift of less than one micron.

Both energy- and time-resolved PL and photoluminescence-excitation (PLE) spectra were collected. By comparing the macro- and micro-PL in Figure 2, one can see that within the envelope of the conventional macro-PL spectra lie many energetically-narrow, quantum dot-like transitions that are hidden in the macro-PL spectra by the effects of spatial averaging.

These narrow lines have been termed "intrinsic quantum dots" because they naturally occur in bulk ordered-$GaIn_xP_{1-x}$ [1,2]. While signatures of a zero dimensional state have been observed in this system, the quantum mechanical nature of these

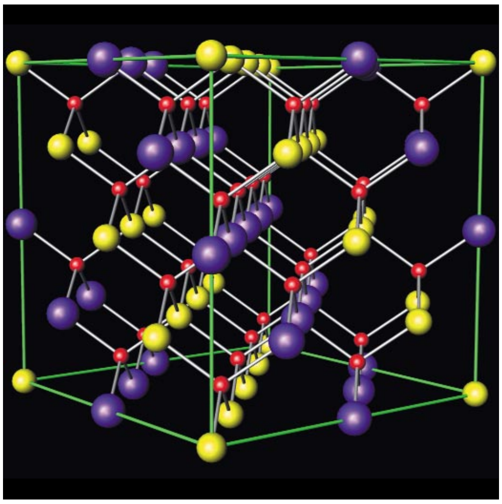

Figure 1: Atomic model of a perfectly ordered GaInP, showing alternating Ga (yellow) and In (purple) monolayers.

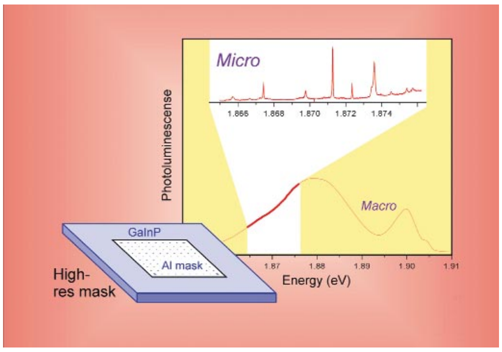

Figure 2: Illustration of GaInP sample with opaque mask (left). An "expanded" view of the macro-PL spectra at 5K (collected using an Oxford Instruments Superconductivity Optistat Bath) shows many quantum-dot like transitions, revealed by the micro-PL spectra (using the MicrostatHiRes).

References:

[1] U. Kops, P.G. Blome, M. Wenderoth, R.G. Ulbrich, C. Geng, and F. Sholz, Phys. Rev. B 61(3), 1992 (2000).
[2] H.M. Cheong, A. Mascarenhas, J.F. Geisz, J.M. Olson, M.W. Keller and J.R. Wendt, Phys. Rev. B, Rapid Comm. 57, R9400 (1998).

Contact:

Dr Steve Smith, National Renewable Energy Laboratory, 1617 Cole Blvd, Golden, CO 80401, USA

transitions is still debated. Figure 3 shows the PLE spectrum that results from detecting light at a single PL line at 1.9032 eV, while scanning the excitation wavelength.
No absorption peak can be resolved near the detection energy. However peaks as sharp as 120 eV are found at higher energy, such as the peak seen at 1.9088 eV. This absorption peak is spectrally separated from any sharp PL lines.

As the excitation energy scans through a resonance with a short-lived state, photogenerated carriers quickly decay to the detection energy before emitting, as would be expected for a quantum-confined system with at least two bound states. In contrast, many of the apertures studied also showed near-exact spectral matches between absorption and emission lines, such as is seen at 1.907 eV. This indicates a coupling, possibly between ground and excited states of a single quantum system, or multiple localized states coupled by their spatial proximity. In the former case, an as yet unknown mechanism must inhibit what should otherwise be extremely fast energy relaxation. In the latter case, the question remains as to the nature of the coupling, is it coherent or diffusive in nature?

The ability to probe extremely small volumes of this material using the MicrostatHiRes has enabled the NREL team to begin to answer some of these questions. The answers may address some long standing issues regarding spontaneously ordered-$GaIn_xP_{1-x}$, such as the existence of polarization fields and spatially indirect transitions, and help to complete the current understanding in this field. An understanding of the observed intra-dot coupling may also prove valuable to the description of interacting quantum systems.

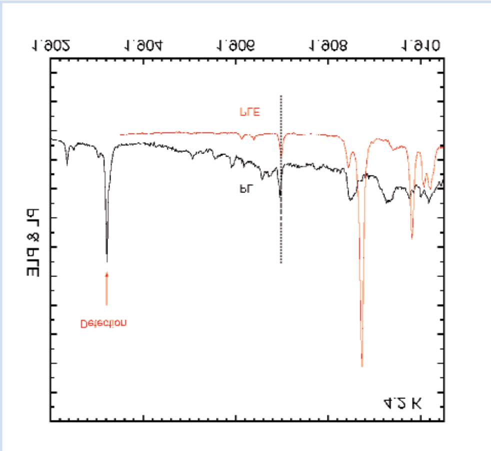

Figure 3: PLE spectra in a 200 nm diameter aperture formed on a GaInP epilayer (red curve). Detection energy set at the PL peak energy of a single quantum dot-like transition.

Oxford Instruments Superconductivity

UK
Tubney Woods, Abingdon
Oxfordshire OX13 5QX
Tel: +44 (0)1865 393 311
Fax: +44 (0)1865 393 333

Germany
Otto-von Guericke Ring 10
D-65205 Wiesbaden
Tel: +49 6122 937 171
Fax: +49 6122 937 175

Italy
Via Leone Tolstoi 86
20098 San Giuliano
Milanese
Milan
Tel: +39 02 98 2531
Fax: +39 02 98 24407

Japan
Haseman Building
2-11-6 Tomioka, Koto-ku
Tokyo 135-0047
Tel: +81 03 5245 3261
Fax: +81 03 5245 4472

Spain
Avda Mata Piñonera, 2
28700 San Sebastian de los Reyes
Madrid
Tel: +34 91 659 0740
Fax: +34 91 654 6794

U.S.A.
130A Baker Ave. Ext.
Concord, MA 01742-2121
Tel: +1 978 369 9933
Fax: +1 978 369 6616

E-mail:
superconductivity@oxinst.co.uk

Visit our web site at
www.oxford-instruments.com

Reference No: OI 600/0502

UK sites of Oxford Instruments Superconductivity Limited, operate a Quality Management System approved to the requirements of BS EN ISO 9001.

Certificate No Q4118