International Workshop on Bismuth-Containing Semiconductors: Theory, Simulation and Experiment

18 July 2011 - 20 July 2011

Workshop Report

The international workshop on Bismuth-containing semiconductors: Theory, Simulation and Experiment was held from the 17th -20th of July 2011 in Guildford organised by Professor Stephen Sweeney from the Advanced Technology Institute of the University of Surrey in collaboration with partners in Germany, Canada and the USA.

The workshop brought together international experts from the chemical synthesis, condensed matter physics, semiconductor physics and photonic devices and engineering communities to discuss a new and exciting semiconductor material system.

The incorporation of the element bismuth into other more established semiconductor compounds such as Gallium Arsenide (GaAs) opens up a whole range of new possibilities for optoelectronic devices in communications and energy applications.

The topics covered during the workshop ranged from first-principles fundamental theoretical calculations through to the growth and characterisation of bismuth containing semiconductors and of the first actual fabricated photonic devices.

The workshop attracted presenters and participants from four continents and all the key groups in the area were represented. In addition to the various groups that are working on this in the UK (including Sheffield, Nottingham and Surrey) there were representatives from two groups in Canada, five groups in the USA, three groups in Germany and one group each from Ireland, Spain, Poland, Lithuania, Sweden, Tunisia, India, Malaysia and Japan. It was truly an international meeting.

Workshop aims

Energy generation and the more efficient use of energy is a highly topical challenge. Many researchers are working to develop new material systems to produce more efficient and less temperature sensitive devices such as solar cells, thermoelectrics, light emitting diodes, lasers and optical amplifiers (e.g. as used to drive the internet). Bismuth alloys have been proposed as key new materials to help with these challenges and the progress towards such technology was presented at the workshop.

Programme

The workshop attracted a total of 53 participants (including 16 PhD students) and proved to be an ideal forum to discuss latest results with very active discussion and debate throughout the technical and social programme. The social programme was an important aspect of the workshop and ensured that people kept together in an informal setting to continue discussions and to develop new collaborations.

The programme included the following elements:

- Pre-workshop get-together on Sunday evening at the Boatman Pub in Guildford
- Indoor BBQ (the weather could have been better!)
- Dinner at Kinghams restaurant in Shere
- Optional excursion to Hampton Court Palace
- 10 scientific sessions: Theory of Bismuth alloys (I), MBE growth of Bismuth alloys, Optical properties, Electrical and optical properties, Structural properties and analysis, Devices, MOVPE growth of Bismuth alloys, Novel alloys, Optoelectronic properties and applications, Theory of Bismuth alloys (II)

Scientific discussion

There were 33 presentations of which 6 were invited, with the invited speakers coming from Germany, the UK, the USA and Tunisia. The speakers covered all aspects of the workshop topics.

In the theoretical sessions discussion focussed on bandstructure calculations (the techniques included k.p analysis, tight binding and impurity models) which are the essential theoretical tools required to understand the physics of this new class of

materials. The theory of GaBiAs and GaBiAsN alloys were presented and the band-anticrossing theory vs. band broadening and localisation effects were discussed in great detail.

A variety of groups reported on their efforts and challenges involved in the actual growth of these materials using two different techniques, namely metal organic vapour-phase epitaxy (MOVPE) and Molecular Beam Epitaxy (MBE). The issues of the optimal growth temperature and optimal growth speed, the difficulties in incorporating Bi, its use as a surfactant in e.g. GaN and the effect of post-growth annealing were all presented. One of the main agreements was that a low growth temperature increases the Bi in-cooperation but that the growth window is small requiring careful and precise control to obtain good quality material. It was widely observed that the quality of GaAsBi initially increases with increasing Bi fraction (due to a surfactant effect) up to ~6% Bi. Materials with Bi concentrations of more than 20% were also reported.

Being a new material system the material quality is still an issue. Four groups reported on various techniques to investigate the structural properties on a microscopic scale. They showed how Bismuth alloys surface reconstruct and the conditions under which metal droplets, Bi clusters and quantum dot like structures are formed with indications for how these might be avoided.

Optical and electrical characterisation revealed the bismuth concentration at which the samples are most efficient in emitting light and the concentration at which the cross-over between the band gap and the spin-off split off band energy occurs (consistent with one of the theoretical papers). The transport properties of carriers in Bismides were discussed in terms of a hole hopping model as a means of explaining some of the low temperature luminescence phenomena.

Finally, results on first devices (infrared detectors, LEDs and optically pumped lasers) together with other ideas for novel alloys including the inclusion of nitrogen and growth on InP substrates were discussed. So far only devices with small Bismuth concentrations have been produced and so the challenges ahead for higher Bi containing devices were discussed.

Outcomes

It was widely agreed that the meeting was very successful and it was decided to hold another meeting covering similar topics next year in Canada where updates on all the current issues will be presented and particular some more results on actual devices are expected.

Some important new collaborations have been established e.g. between the University of Delaware and the University of Surrey to look at InP-based bismide alloys and their application in thermoelectric devices. In addition, the leaders of the key groups in Canada, the USA, Germany and at the University of Surrey agreed to put together a joint research proposal to NSF (USA), DFG (Germany), NSERC (Canada) and EPSRC (UK) to enable further work on Bismuth-based materials.

The majority of the presentations have been made available online for participants. Also some of the presentations are already or will be published in high profile journals including Applied Physics Letters and Physical Review B.

The feedback from all participants has been extremely positive. They all felt that the programme was very interesting and that it was well organised. They appreciated having many opportunities to discuss their ideas with each other. This will hopefully lead to new and even closer collaboration between all the involved groups, such as those already discussed above.

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