Eurotour' 96 – The Wide Bandgap Special Rigi-Strasbourg-Cardiff

by Alan Mills

In June of this year the GaN scientific community had a unique opportunity; three continuous conferences with European locations all loaded with GaN content. Combined they provided an unguided European tour that included a taste of Switzerland, France and Wales and the opportunities to use ancient and modern transportation technology – an antique paddle steamer, a rack railway and the Channel Tunnel. Modern trains may use SiC power control devices, were any GaN emitters used for the Chunnel signaling?

The tour began in Rigi Switzerland with the history making "First European Workshop on GaN" followed by the European Materials Research Society Symposium C, in Strasbourg, France (UV, Blue and Green Light Emission from Semiconductor Materials). Here the nitride sessions were timed to follow on from Rigi. The following week the tour moved on to the biennial ICMOVPE '96 VIII in Cardiff, Wales. Since the MOVPE process is the key to the present day commercial successes of GaN emitters, Cardiff was the place to be for the latest news.

It was unfortunate to hear that in this information age, quite a few of the GaN followers had not heard about all of the meetings and would have probably attended all three. However the partially informed attended one or two and the really informed, the commercial exhibitors, and those with MOCVD tendencies, bought the full tour and put on the miles to make all three. In part the reward was auditing papers that were similar to those just attended. But, other authors did save some new morsels for the next sitting, and for those that lasted through social programmes ever presented to the III-V community. It combined local history with good culinary taste and was a compliment to the local organisors.

Nichia violet laser diode λ_Y = 400 nm under pulsed current at R.T.

EURO-GaN

European history was made when the first local Workshop on GaN opened at a mountain resort location in Rigi Switzerland. Here the current popularity around the world of GaN was once again well demonstrated. An attendance of about 60 had been anticipated but it was over subscribed by about 75%. In spite of close competition from other conferences around the world, over 100 attendees arrived. Dr. Toby Strite and his fellow organisers had spared no effort to provide a picturesque trip to, from and at the venue. But, Rigi was not on the author's map of Switzerland and neither was it on the map of the local weather gods. This part of their effort was in vain, Rigi was encased in fog the whole time and the 1996 visitors were denied the promised land.

The extent of the present levels of pan-European support for GaN soon became evident with significant representation from such countries as Switzerland, Ukraine, Poland, Russia, Germany and France, non European presentations came from as far as China together with a sizable contingent from North America.

The nitride topics covered were mostly devoted to processes and devices and ranged from epitaxial growth to the performance of the latest equipment, to materials quality, to device performance, perhaps with an over indulgence in excitons. Considerable European budget allocations have been provided for this "exciting" research but unfortunately, very little of the work appeared to be coordinated with the solution of GaN materials problems. Yes, the excitons were generated, absorbed or disappeared – but few suggestions or conclusions were offered for improvements in materials quality or layer performance. Can we suggest that these excited excitonic explorers work more closely with the device makers to advance the state of the art of GaN materials?

Up to now, GaN films exhibit high defect levels from several sources, screw dislocations, stacking faults and pyramids, etc. with defect levels in the range of 1E7 to 1E10 per square centimetre. And, because of the problems related to the production of bulk single crystal GaN, most nitride layer growth is performed on a range of hetero-substrates. These include zinc oxide, silicon, sapphire, SiC, hafnium, spinel, and lithium gallate wafers, with the majority being lattice mismatched. Most see sapphire as the near term substrate, but the SiC producers claimed that GaN on SiC is cheaper and better because it comes complete with a conductive buffer technology for backside contacts.

The only GaN bulk crystals are currently being provided by the High Pressure Research Center (HPRC) in Warsaw, Poland. Here, the production of non-nucleated GaN crystals from the liquid gallium system (at 1200 C temperatures and with up to 20 kilobar over pressures of nitrogen) is not easy and only small quantities of 4 to 4 mm crystals are available with high defect levels. Krukowski, also from the HPRC Polish group, theorized that because nitrogen behaves more like water at pressure above 20 kilobars, the heat capacity of the nitrogen will stabilise the crystal growth system. It was also stated that larger crucibles will be needed to grow larger crystals for the commercial market. Bulk crystal growth of GaN still has a long way to go as judged by other III-V materials and by the desires of the GaN device engineers, even though an order of magnitude improvement in defect levels to 1E6 was reported for the best bulk crystals by the HPRC group in Poland.

A new bulk crystal growth technique with commercial potential was

Nichia LED-based full colour display in Tokyo.

described by Lester Eastman from Cornell. Talk about a high pressure job, this new process starts with GaN powder in contact with a seed crystal compressed up to 45 thousand atmospheres inside a heated cylindrical container, all at 2000°C. The first prototype 13 mm diameter ingots are expected to be produced by the end of this year. Lester and his co-workers were seeking funding for a 50 mm diameter second generation model with plans to be making crystals by the end of 1997. When these or other processes can provide 50 mm diameter or larger wafers in commercial quantities, they may command a major share of the GaN substrate market, but until that time sapphire and SiC have the commercial edge.

A vapour crystal growth process was reported by Sakai and novel syntheses of GaN from gallium and urea, were described by S. Podsiadlo from the Warsaw Institute of Technology. This process produced the nitride as a crystalline powder after heating at 850°C.

Several authors reported on the MBE growth of GaN using plasma activated nitrogen, a process that was also used as a nitrogen source in a low pressure MOCVD process. A novel DC plasma source was described by V.B. Labedev of the Ioffe Institute in St. Petersberg where the use of a reverse magnetron configuration allowed operation at ultra-low pressures.

MBE plasma growth results reported by W.A. Davis, from the Rome, NY, Laboratory and his colleagues at Cornell University provided support for one of the current theories that gallium vacancies are responsible for the dreaded yellow emission at 2.2eV (1995 Fall MRS Meeting). Davis reported that by increasing the gallium cell temperature (and the gallium flux), in the MBE system, this yellow luminescence is reduced. Since the report by Davis, electron nuclear double resonance measurements by J M Spaeth of Paderborn University and co-workers at CNRS led them to propose that the source of the 2.2 ev yellow emission is interstitial gallium atoms, having ruled out gallium antisites in the crystal, from their work with gallium isotopes. Could we have more than one source?

Recent process advances included nitridation before buffer growth, and vapour phase epitaxy on SiC. Asif Khan of APA Optics described the growth of GaN on silicon using a gallium arsenide buffer in a hybrid MBE/MOCVD process. Based on this work it would appear that silicon has the potential to become an alternative commercial conducting substrate for the growth of GaN based electronic devices.

Cooperative development programmes are widely supported by the European Union and by the local governments and they have produced useful III-V based commercial products. However, significant cooperative efforts between US companies and Eastern European institutions were also evident here, with Cree supporting SiC and GaN research in Russia and wafer producers working with crystal growers in Poland. The intense international R&D effort continues, seeking to produce or improve commercial short wavelength emitters from the GaN alloy system, with the main focus on the ultra-violet to green spectral range of LEDs and lasers. Since most of this work is being done outside Europe, few optoelectronic related papers were presented in Rigi.

Novel electronic devices of interest included a UV detector (250 nm) from North Western University, AlGaN photo-conductors from APA Optics (cut off wavelength 240 nm), an ion implanted JFET from Sandia Laboratories which uses calcium as the p-dopant, a 22 GHz MODFET from Cornell, a heterobipolar transistor from Astralux and Cornell that can sustain a power density of 30 kW cm^{-2}. with a current gain of about 100 when operating a 525°C plus a range of nitride devices on SiC substrates.

Quite a few alternate substrate materials were presented for nitride applications, but most were summarily dismissed as unsuitable. Thus, leaving only sapphire, Si, SiC, GaAs and of course GaN as those having real potential.

RIGI rump session

At the evening session, the topic was – WHAT IS AHEAD FOR GaN? Nitride's negative considerations were: no bulk derived substrates, and a long list of needs – substrate cleavage planes, improved p-doping, lower defect levels, better metalization, thermal stress control, lower LED and laser operating voltages. Some of these sound like the GaAs of 15 years ago. The list could provide a lifetime of research for quite a few scientists.

And, competition is coming from the II-VIs in the form of a green laser with CW lifetimes in excess of 100 hours, a green LED with a lifetime of over 8000 hours with a potential output of 25 lumens per watt, and the achievement of lower defect levels (about 1E3). From SiC the competition is in the form of:- higher heat conductivity and breakdown voltage (>2000V), well developed processes and substrates, years of research leading to commercial devices.

The potential for GaN and its aluminium and indium alloys are several. This materials system lead the commercial field for blue and shorter wavelength LEDs and has good potential for the yellow and green emitters, especially since materials defects do not act as recombination centres. It can show negative electron affinity, hence it could be a good field emitter and it has the potential for devices such as UV emitters and detectors, high power, high frequency and high temperature operating transistors. If it is like the other successful semiconductor materials, by providing the funds and the research time, the future will shine in more ways than one.

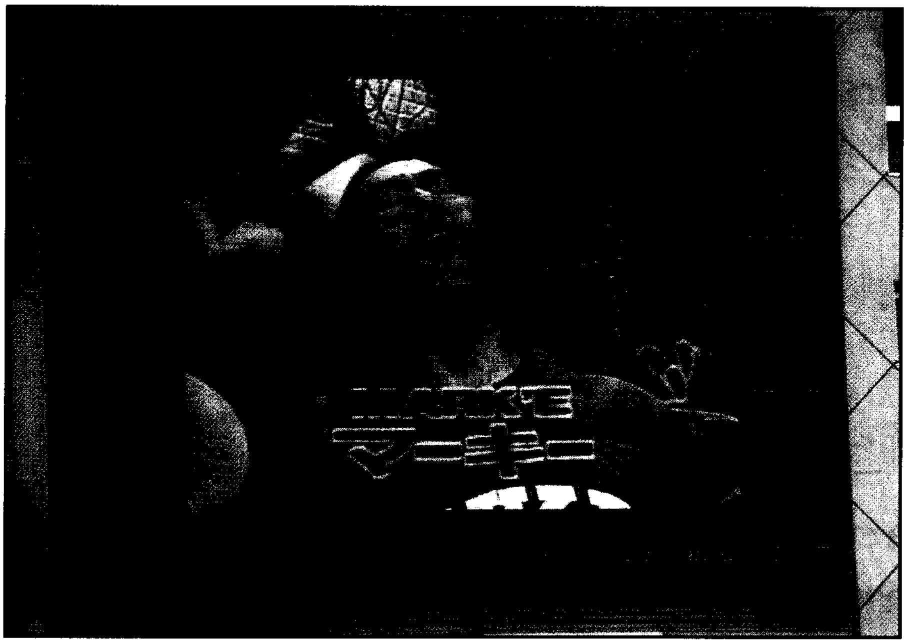
EURO-MRS

Strasbourg is a beautiful city and, highlighted by a wonderful cathedral, but its Eurocentre exhibition hall, some distance from the old town, was not ideal for this conference with accommodation scattered widely around the city and few of the hotels near to the session meeting rooms, a factor making post session meetings and discussions difficult. Additionally, the Euro-MRS organisers were not prepared for the present day enthusiasm and the attendance levels commanded by GaN and other wide bandgap related technologies.Such that several of the initial nitride papers were standing room only, much of it outside the room – not a good situation for some of the key papers. The pendulum then swung the other way with poor direction to rooms that were now too large for good audience participation. Food at the evening events was good, but at the award reception, all the hungry attendees were fought off from a beatific display of the food and thirst quenchers until the end of a long presentation ceremony. Both could have happened simultaneously!

At Strasbourg, Symposium C was devoted to wide bandgap devices, and it again brought together the two competing materials systems for blue emitters, the 'two-sixes' and the 'three-fives'. They are competing to become:

- the first to provide the short wavelength laser (blue to violet) to satisfy the high density optical storage media for CD-ROM manufacturers, and
- provide the lasers based on the final materials choice for the same application.

One could have hoped to find the answers to the above, at this Symposium but perhaps for obvious reasons, the answer was not to be found. The major players were reluctant to discuss their latest results in detail. With 3M, Philips and Sony dedicated to the ZnSe emitters and, Cree, Hewlett-Packard, Nichia and Toyoda Gosei pursuing GaN emitters, the race goes



Nichia full colour LED display uses blue InGaN SQW LEDs, green InGaNSQW LEDs and red GaAlAs LEDs.

on! But, the recent report by D. Delacourt and coworkers from Thomson CSF, could be changing the rules for the first point with their recent successes in frequency doubling. Delacourt described how the stable and inexpensive near-IR lasers may hold the key to the first commercially useful coherent blue light sources obtained by pumping ferroelectric niobate or tantala crystals with 800 to 980 nm IR-diode lasers.

The MRS rump session,WIDE BANDGAP SEMICONDUCTORS: WHAT IS AHEAD?, was chaired by Hadis Morkoç, from the University of Illinois. Much as he may have tried to elicit open comment, he often found it difficult to get audience participation, in part because he had now been moved to an oversize auditorium and people were now too far away and detached to readily interact, and in part because of the competitive nature of the present commercial II-VI and III-V wide bandgap technologies. The agenda covered today's important bandgap materials systems. Since lively discussions were difficult to ignite on this occasion, the main result of this session was a summary of the state of the art-for-the-three materials.

- SiC – the oldest and wisest Group IV semiconductor
- The chalcogenides, ZnSe and related II-VI materials in particular – long suffering from poor material properties
- GaN and related materials – the recent III-V upstart.

SiC

Well established research programmes and a more mature substrate technology, have given SiC an advantage over the other wide bandgap materials for electronic applications, at least for the time being. Additionally, desirable material properties (hardness, high break down voltage and high heat conductivity) have generated long term government support to develop circuits with important application goals. Some of these are now close to commercial acceptance. Examples include, high temperature transistors, high current and high voltage transistors and switching devices. Only in the optoelectronics field is SiC lagging GaN in the production of blue emitters, with the possible exception that SiC is also being promoted as a substrate for nitride devices.

GaN

At present, GaN technology is at a competitive disadvantage since large scale funding is only a recent phenomenon and there is no commercial source of bulk wafers for homoepitaxy. However, grown on sapphire it is the material of choice for the blue LED. GaN does have some desirable physical and electronic properties, including a negative electron affinity and it also offers the potential for high temperature and high frequency applications and for short wavelength detectors. Just how good it will be for devices such as lasers, field emitters and for high temperature and high frequency electronics will depend on the future development of its bulk materials and layer growth processes and on substrate technologies in general.

Zinc selenide

For about ten years ZnSe materials were receiving most of the worldwide funding allocated for the development of wide bandgap visible emitters in the competition to become leading manufacturers of green to blue LEDs and CW lasers.This work eventually has paid off in the development of the 100 hour plus CW operating lives of today's II-VI lasers.

However, judging by the recent large increases in conference attendance and by papers presented on nitrides, GaN now receives a far greater share of the R&D funds. As part of this change nitride laser development continues apace as new, optically pumped and electrically stimulated lasers are being described. ZnSe materials do not have the most desirable bulk properties. Therefore the eventual winner may depend on the results of the present research programmes.

In the future, all of these wide bandgap materials can benefit from improved metalization, lower defect levels, better p-doping processes and p-contracts and from improved bulk crystal growth technologies.

ICMOVPE '96

Cardiff provided both pleasant weather and location for this conference, although accommodation was tight and parking was a problem in the down town, Welsh National Arena, location ICMOVPE is one of the most important international conferences relating to metal-organic processes, especially for the group II-VI and III-V materials. Thus the Cardiff meeting attracted many international visitors, including the world's leading players in the field of blue LED and laser technology. Many came to give invited talks and provide traveling shows of their successes to date.

Seeing is believing

It is a relatively easy task to demonstrate the latest high brightness blue, green, and orange LEDs since they are easily visible to the human eye.Visible proof of the commercial effectiveness of LEDs was also provided at Cardiff, in the form of a new, locally manufactured, LED display panel (see TFR issue 4). It provided changing information about local activities in full colour, white included. Prior to this conference, large outdoor graphic displays were only available for viewing in Japan, Korea and Taiwan, see accompanying photos.

Demonstration of the current zinc selenide laser technology is relatively easy, since the human eye has good sensitivity to the blue-green light of these lasers. However, the demonstration of the violet GaN laser, the first time in Europe, was not as easy because of the poor sensitivity of the eye to this short wavelength light. Thus Dr. Nakamura of Nichia was using a UV phosphor coated sheet for this purpose. To those who were close enough to the new laser it turned out that a laundered shirt could be a better demonstration medium, since the optical brightners used in today's laundry detergents were a brilliant receptor for the pulsed nitride laser.

Business activities

In addition to its technical programmes, where the obvious importance of metal-organic processes to wide bandgap technology was shown, ICMOVPE '96 provided space for the commercial exhibitors and the medium for several MO-based companies to announce significant changes to their business operations. Both Epichem Ltd and Epitaxy Products International Ltd announced their change to independent companies, SGS Mochem Products GmbH appointed EMF Ltd of Ely in the UK as their UK and North American agents for the sale of their alternative Group-V MO-sources and EMCORE announced the organization of the company into five operating divisions.

Exhibition space was provided at each meeting and as may be expected, ICMOVPE had the largest number of participants. The majority of the exhibitors claimed to be very happy with both the quantity and quality of the enquiries received, enough to return to the next show!

Social events

The hosts for ICMOVPE provided one of the most outstanding social programmes for a III-V related event. They should be well complemented for their selections of venue, wine and food and to the vendors for their support. The use of historical and/or civic locations for the vendor sponsored events made them pleasant and educational; a wine tasting was held in one of the halls in Cardiff Castle, a buffet supper with libations was hosted in the Cardiff library and the conference banquet, together with entertainment, provided by the committee, the secretary for Wales, a political comedian and a Welsh choir, was held in the marble elegance of the Lord Mayor's chambers – the City Hall, see photos.

The conference golf tournament was the only damp squib, being carefully arranged for the only day of the week with rain, but a plentiful supply of antifreeze was consumed by the players, until they could dry out, (for some that was the next day). Lots of prizes were won and enough of a good time was had by all to be able to look forward to next year's meetings.

In summation

Euro-tour probably followed too soon after the Chiba Workshop to expect any headline making developments to be announced. But, it became obvious that GaN and metal-organic technologies are alive and well in Europe. The attendance and the papers presented indicated that European industry is in a good position to play an important part in the field of wide bandgap technologies.

The beneficiaries of the GaN technology boom are the manufacturers of production equipment and the producers of blue and green LEDS. The demand for the nitride based high brightness LED production equipment is already producing record sales performances for their manufacturers, some of which are also based in Europe.

The large increase in installed LED production capacities plus the hither to unheard of deposition uniformities, have led to much higher yields and commercial production volumes for these LEDs. In particular, the installed capacity to produce the high brightness blue LEDs has recently reached over 10 million units per month up from only a few thousand two or three years ago. With these higher unit volumes now becoming available, the 'new' market for outdoor LED displays will be able to develop on a worldwide basis.

A potential demand remains for high frequency and high temperature devices and for short wavelength detectors from GaN, but these technologies need further development before real chips and significant markets can develop. The higher density optical storage disks may also have to wait some time for their lasers, either from II-VI or III-V technology.

Alan R Mills, PhD. Euro-tour operator!