OLE CLEO article on “In Situ Monitoring”

“What you see is what you grow”

ISM boosts opto components yields

The world of semiconductor optoelectronics component manufacturing is on the verge of revolution in productivity. In situ monitoring, ISM, says Roy Szweda, will enable higher than ever degree of control, reduce costs, improve existing devices and enable new ones. European researchers and companies are at the leading edge of this new technology.

Modern device manufacturing processes are exceedingly complex. At the same time they are under pressure to drive up yields and thereby create cheaper devices (see OLE article on MOVPE markets). Key to the success of this is a precise understanding of what is happening with the process as it is actually happening. This must be in real-time so that the process can be adjusted and productivity maximised.

For the development of ISM as a practical commercial product an holistic approach has been necessary and many parties have been involved in its ongoing development.

We look at ISM for metallorganic chemical vapour deposition (MOCVD) mainly centred on a collaborative project in Germany but at the same time also a French effort in a related field. OLE spoke to Dr. J.-Thomas Zettler, of the newly-formed company LayTec GmbH. Based in Hardenbergstr, it is a spin-off from the Technical University of Berlin, Germany. Also we spoke to Jobin Yvon in France to find out more about a new camera sensor for the monitoring of dry etching processes for opto device manufacture.

Epi and etching

Two of today’s key process steps are epitaxy and etching. Epitaxy is the process whereby precise thicknesses of semiconductor are used to build up a device. Conversely, dry etching involves selective removal of material. Knowing as much as possible about how things are going is crucial. This applies not only to the R&D of new devices but also mass production. The latter being particularly acute in today’s booming opto device business.

ISM is becoming one of the most important adaptations for MOCVD layer growth analysis. These methods are very important procedures for layer growth and previously were not possible at the typical higher pressures used by MOCVD. Importantly, ISM techniques have also rapidly closed the process monitoring advantages that high vacuum processes such as molecular beam epitaxy (MBE) layer growth processes enjoy. MBE is commonly used for the production of diode lasers for data storage applications.

“In fact the situation is now reversed”, says Zettler. “The fundamental problem of window depositions, which has been solved for MOCVD by window purging, remains to be solved for MBE”.

Today’s optoelectronic component manufacture is relying increasingly on advanced epitaxial deposition systems such as MOVPE. The news frequently reports further purchases by companies around the world. Interestingly one of the world leaders in the field is located in Europe. These systems rely on precision control while at the same time improving production yields. Key to this trend is the use of ISM. As we said earlier, co-operation has been important in the development of ISM. To build existing knowledge, a new pan-European ISM project has been commenced which will likely have a big impact on future development. This project is scheduled within the Fifth Framework programme for research, technological development and demonstration on competitive and sustainable growth. It involves LayTec in partnership with project leader the MOCVD equipment company AIXTRON AG, Aachen, Germany.

Dr Michael Heuken of AIXTRON’s R&D lab explained the project: “The milestones of this shared cost project include combining the MOVPE with the embedded optical and XRD sensors; then making in-situ measurements, to interpret the measured data in terms of stoichiometry roughness, voids, interface and surface quality, growth rate, homogeneity and doping; and feeding the information back to crystal growth. We will correlate ex-situ data with that from the in-situ data to develop a closed loop control system.

“We have a reactor equipped with a LayTec RAS system here in our lab which has already shown very good improvements in process control for a wide range of growth processes and materials.”

In situ monitoring (ISM) has received a great deal of interest in the past couple of years and will be a critical component of MOCVD R&D and production systems for the future. Optical ISM is coming of age and being introduced for production MOVPE systems rather than being just a retrofit. This because of the improvement in techniques - particularly interferometry – to provide information needed for a production system and is easier to implement. Plus growth of nitrides for blue-green LEDs etc. is not as well behaved as other materials. “For the other III-V's it was the real-time sensitivity of RAS to doping levels, its patented anti-wobble-techniques and its direct combination with reflectance monitoring that finally caused the breakthrough even in the necessarily rather conservative growth community,” says Dr Zettler.

Techniques

As the pan-Euro ISM project has done, ISM is conveniently split into in-situ sensors and in-line (post-growth) sensors. “In general for MOCVD and MBE, RAS and reflectometry will do the industrial ISM job. This is also based on in-situ research with SE but SE, RS and XRD will be attached for certain applications in-line”.

ISM techniques presently under consideration include:

- Spectroscopic ellipsometry (SE)
- Reflectance anisotropy spectroscopy (RAS) and reflectrometry,
- Raman spectroscopy (RS)

Also under consideration is the non-optical technique of X-ray diffraction (XRD). However, this is less convenient and equipment cost is somewhat higher than for optical.

Throughout the semiconductor industry, and not just in III-V epitaxy, optical probing methods are being developed to measure such parameters as temperature, surface composition, layer thickness and refractive index on the wafer during growth. ISM methods can also be used to measure and control the chemical composition and flux of chemical vapour source beams used for deposition of semiconductors and other materials.

ISM is not just required for R&D, device makers and epiwafer manufacturers such as laser diode producers are in dire need of ISM. It has become vitally important to be able to measure the actual temperature on the wafers as they are grown. For example, in the manufacture of lasers such as DFBs or VCSELs, after visual inspection manufacturers presently have to reject as much as half of the epitaxy as being unacceptable for further processing. If temperature control were available the reject rate would, it is said, be reduced to near zero. Thus ISM has potentially great impact on yields and thereby costs.

Optical diagnostics have the advantage that they can be used at atmospheric pressure. They can also be used at reduced pressure even in the presence of plasmas. Because they are located outside the reactor vessel they therefore do not interfere with the ongoing process. So too, since they have low incident energy and are non-contact they have minimal effect on the growing epilayer. They can be used for a variety of reactor susceptor and heater configurations so that they can be used for either fixed or a rotating wafer system.

At present, optical diagnostics are the most popular ISM. Some commercial reactors have already been equipped with it. “With ellipsometry (phase measurement) you are sensitive to monolayers,” says Dr Zettler. “With RAS using the symmetry effect, sub-monolayers can be detected with reflectometry when the technique is properly used. Less than 50 nm of layer thickness are needed for growth rate and composition measurements”.

The main scope of the group at the Institut fuer Festkoerperphysik (IFP) of the Technische Universitat Berlin (TUB) is the combination of optical analysis methods with MOCVD, which allows in situ growth studies. Techniques under study include reflectance anisotropy spectroscopy (RAS), spectroscopic ellipsometry, and elastic light scattering. “Detecting the difference in reflectance for light polarized along two perpendicular crystal orientations RAS is highly surface sensitive for cubic materials whereas spectroscopic ellipsometry gathers information from the entire light penetration depth,” he says.

“Based on the experimental set-ups at the TUB, a commercial LayTec EpiRAS(TM)-200 sensor RAS-system is being used at the Ferdinand-Braun-Institute (FBH) to study device-related issues like exchange reactions at hetero-interfaces, control of doping and GaInAsP composition in dependence on growth parameters”. Close collaboration between the partners is bringing a valuable research tool into a production environment where it allows for improved process control and shorter development cycles.

GaN and silicon

Another important contributor to the development of ISM is underway at the North East Wales Institute (NEWI) where work has focussed on making quantitative measurements that are useful to the epi grower and to provide a basis for in situ control. According to Prof Stuart Irvine of NEWI: "There is need for more in situ diagnostics due to the non-classical nature of much of these growth processes”. At NEWI work has focussed on making quantitative measurements that are useful to the epi grower and to provide a basis for in situ control. "We installed one of these systems (called Epiref) for Boeing in Anaheim for process control of their CdTe onto sapphire. This has been very successful and has formed the basis for a modified system to cope with GaN-onto-sapphire which we have been testing at the University of Gent and in collaboration with Edith Bourret at Lawrence Berkeley National Laboratory in California". The software is to be licensed to UK MOCVD reactor company Thomas Swan (a subsidiary of AIXTRON AG) for running their interferometer that will fit onto their very successful showerhead reactor.

Notably, the well-known suppliers of equipment to the epitaxy market generally offer ISM systems. ISM systems have been available from specialist suppliers of peripheral MOVPE equipment for some time. For example, the NTM1 system from the Israel-based company CI Systems. This was a dual-channel electro-optical monitor for temperature measurement for MBE or MOVPE.

Another requirement is the impact on available computing power especially for a closed-loop ISM system. Data gathering will require fast computers able to handle a great deal of data in real-time. However, this volume of data is really only a side effect, says Dr Zettler: “Complex real-time analysis is now integrated in our sensors. Also, intra-networking with the MOCVD reactor’s own computer with other sensor systems is now possible. We are working on that. A software user interface adopting to the process engineer has now become now a standard feature of our products.”

The next step in the evolution of ISM is to provide closed-loop feedback control of the growth process.

Certainly, it is now not unusual for an epiwafer manufacturer to be faced with the loss of an entire load of expensive wafers. Modern MOVPE can handle 8 x 3-in wafers per run and each run might last several hours. Since each wafer can produce thousands of dice, a lot is at stake. Anything that can help avoid run failures will receive serious consideration from everyone in the business.

While ISM will add significantly to capital cost of MOVPE reactors it will provide a rapid return on investment, say its proponents. The first systems to fully install and exploit ISM will be those that are highly optimised for mass production of opto and other devices. They will find most significant take up with manufacturers of devices where capital cost is of less concern than CoO and, most importantly, cost per die. This applies most rigorously to the makers of opto devices such as blue-green LEDs.

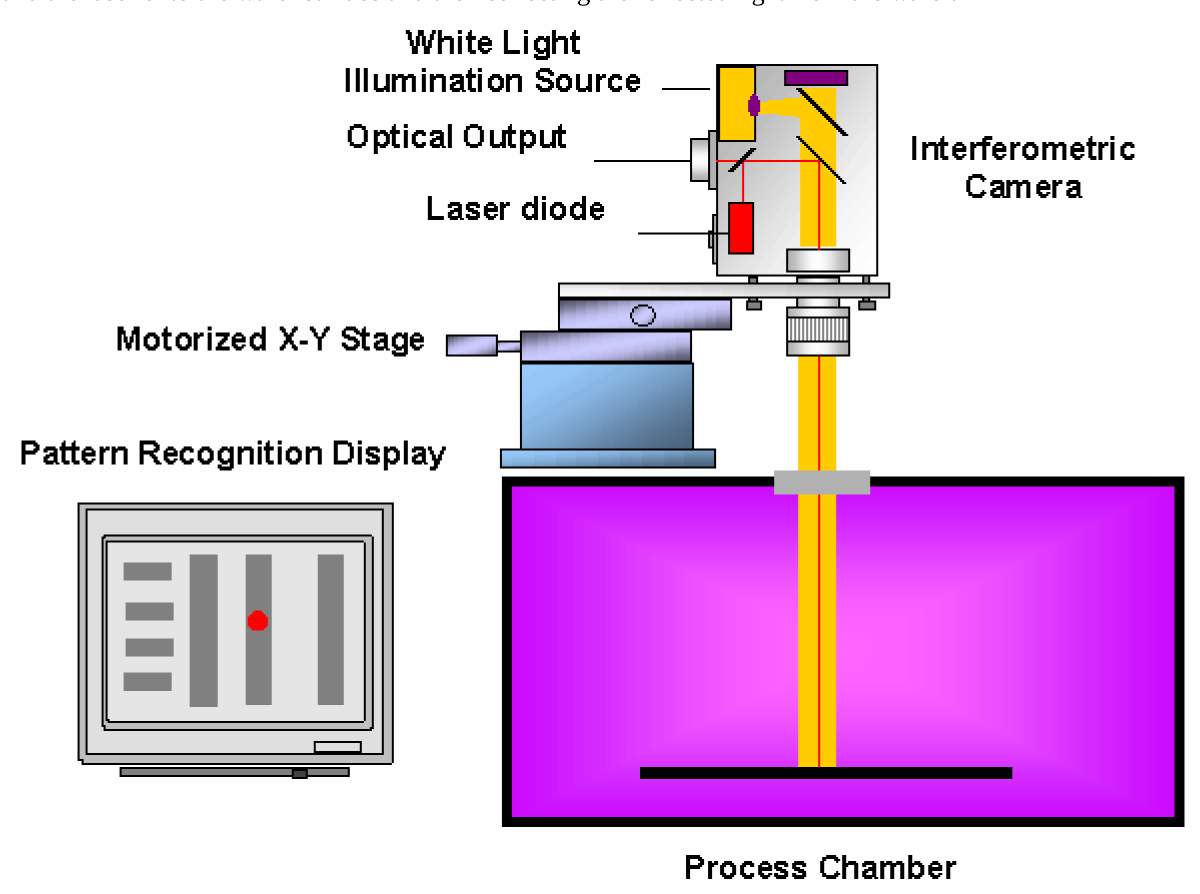
SIDEBAR

Pierre Perrot, Sales and Marketing Director, Jobin Yvon Sa, Arpajon, France, “There has been a great demand for improved end point detection techniques for advanced etching of III-V ternary multi stack layers”. Current etch rate and end point monitoring techniques are based on three methods. The first is to use timed or a blind etch as it is known, this offers no monitoring of the etch process. The second is to use optical emission spectroscopy (OES) which is a secondary measurement of the process and requires a large open area, fast etch rate, and a detectable emission line from the etch products. The third is laser interferometry, a primary measurement, based on light interference of reflected beams from several layers in the stack.

“We have developed a new endpoint camera sensor for dry etching of $Al_XGa_{1-X}As/GaAs$ layers. Compared to other interferometric techniques, this new sensor camera takes advantages of the use of a

905 nm laser diode combined with imaging capabilities. Combined with the well known ISA - Jobin Yvon - Sofie multisensor, the MULTISEM 550 platform, we have today a complete solution for a total control of etch processes in the field of III-V based devices".

The new infrared interferometric camera is manufactured by the Thin Film Group of Instruments SA / Horiba. The system is based on the use of a 905nm laser diode as a probing beam for making interferometric measurements of III-V materials. The system is composed of the 905nm laser diode, a silicon photodiode for signal acquisition, a CCD chip for producing a video image of the wafer surface, an illumination source for the CCD, and a set of objective lenses for focusing the illumination source and the laser onto the wafer surface and then collecting the reflected light from the wafer.



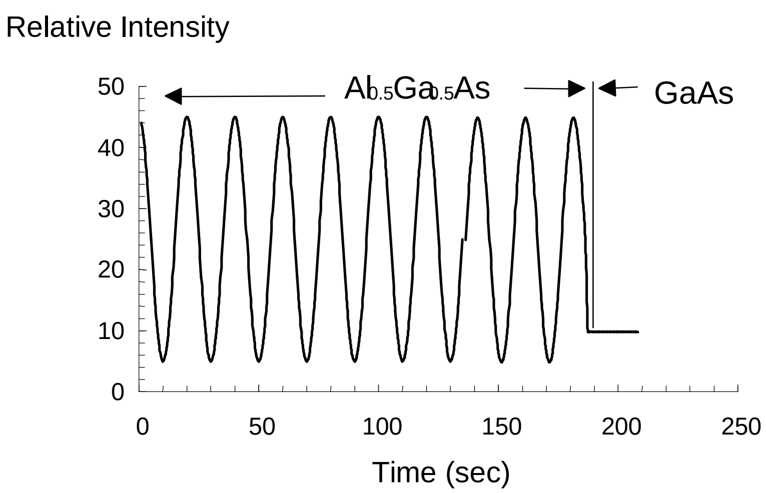


Figure. A signal pattern from $Al_{0.5}Ga_{0.5}As$ /GaAs (top) and $Al_{0.92}Ga_{0.08}As$ (bottom) layer with incident 905 nm wavelength laser during dry etching.