A Mixed GaAs Modulator and HEMT MMIC Process Line On 150mm Wafers

J. Thompson, D.J. Warner, C.L. Sansom, P.A. Claxton and D. Parker

Marconi Caswell Limited, Caswell, Towcester NN12 8EQ, United Kingdom
Phone: +44 1327 350581, e-mail: dave.warner@marconi.com © 2001 MANTECH

Abstract

This paper describes the establishment of a 150mm wafer fab to process both GaAs optical modulators and pseudomorphic HEMT MMICs in the same facility.

INTRODUCTION

The recent huge demand for systems for Internet access and other high data density telecommunications traffic is now fuelling an expansion in optoelectronic component production volumes as well as increasing the number of MMICs required. Typical optoelectronic devices needed for these systems are semiconductor lasers (both gallium arsenide- and indium phosphide-based), photodiodes and GaAs or lithium niobate modulators. The work reported here describes the setting up of the world's first 150mm GaAs line to process GaAs modulators for telecoms applications as well as electron beam-written 0.2µm HEMT MMICs.

Gallium arsenide wafers have been processed for many years into monolithic microwave integrated circuits (MMICs) for telecommunications and radar systems, with volumes of devices relatively small compared with those of silicon wafer fabs. Recently, however, the demand for high electron mobility transistor (HEMT) MMICs for low noise, high power telecoms applications has expanded dramatically, and this has resulted in the establishment of several GaAs process lines running 6" (150mm) diameter wafers instead of 3" or 4" substrates. The setting up of these lines, and sometimes of whole new wafer fabs, has been reported previously at Mantech conferences. [1-5]

WAFER FAB CONSTRAINTS

Gallium arsenide wafers have been processed at Caswell since the 1970's, with the present facility used for making MMICs on 3-inch diameter wafers since 1992. The present cleanroom suite was designed in the early 1980's for 4" and 5" silicon processing in class 100 conditions. The fabrication area, of 1000m^2, is modular in design with long narrow clean areas interdigitated with service chase areas housing the equipment utilities. The return air flow for the cleanrooms is through the hollow walls. MMICs are made in prototype and small scale production volumes as a foundry activity, as well as for standard product MESFET- and HEMT-based integrated circuits. Caswell has been involved in the development of optoelectronic devices for two decades, and since 1998 the wafer fab facility has also accommodated the equipment necessary to process GaAs Mach-Zehnder modulators, GaAs lasers, plus InP lasers and photodiodes. At the start of this work there was therefore a variety of equipments in the facility, from manual photoresist spinners and simple hotplates to fully automated and PC-controlled sputtering systems.

In order to process sufficient optoelectronic and microwave devices to service customer requirements over the coming years it was decided to upgrade the wafer fab facility, starting in mid-2000. The decision was made to convert the modulator and MMIC processing directly from 3" to 150mm (6") diameter GaAs wafers, missing out the transition through 4" wafers already undertaken by many other GaAs fabs. This decision was dominated by two factors: the need for bigger wafers due to the dimensions of modulator devices (about 30mm long); and the recognition that well-established silicon processing tools and techniques could be accessed at 150mm, reducing the technological risk and ensuring a swifter conversion process. The target was to generate sufficient capacity to multiply the supply of working dice more than twenty-fold. However, the task was complicated by the need to retain an ongoing, and increasing volume, production capability to process 2" indium phosphide and 3" GaAs laser, modulator and MMIC wafers within the same cleanroom facility for the duration of the conversion to 150mm. It was also necessary to retain a research and development capability at all three wafer diameters to bring the next generation of products to the marketplace.

These simultaneous requirements posed particular difficulties in terms of floor space and access to essential services such as process gases, electricity and ultrapure water. The initial planning for the upgraded facility concentrated on identifying surplus equipments that could be immediately removed to start to create space for new tools. Duplicate equipments from the existing 3" line also had to be removed at this early stage, from which stemmed the need to improve the planned maintenance of the remaining tools in order to minimise equipment downtime and to maintain an increased level of production. The opportunity was taken at this stage to re-site certain equipments to improve the process flow within the wafer fab and to reduce the amount of walking between cleanroom modules for the process technicians. Detailed planning then concentrated on siting probable new tools for 150mm processing in between existing equipments that had to be left in place for the duration. After tool selection and order placement, detailed facilities sheets and dimensional drawings were obtained from suppliers and used to refine the cleanroom floor plan, and to enable the installation of the required services to each tool. Difficulties arose on more than half of the equipment installations, where the information provided by the supplier did not match what was required by the tool when it was delivered. Ninety percent of tools were also delivered significantly later than the agreed delivery date, with the recent upsurge in demand for semiconductor processing equipment being the most frequently quoted reason. As a consequence the new equipment installations (Figures 1 and 2) ran three months later than planned, necessitating very rapid commissioning and new process development in order to recover the demanding programme schedule. Many suppliers were however extremely cooperative in assisting with training and with the development of the required processes on their tools.

STAFF AND PROCESSING LOGISTICS

The wafer fabrication and epitaxial growth activities need to reflect the flexible manufacturing system. The requirement to house R&D and production processing in the same cleanroom suite, and to process 2" InP , 3" GaAs, and 150mm GaAs-based wafers within the same environment stimulates the need for a system with an unusual range of processes and production disciplines in a single operating environment. It was necessary to find optimum solutions to such organizational issues if we were to realize our competitive advantage, and exercise our capability to grow and process both MMIC and photonics based wafers in a single facility.

The expanding market for broadband communications systems has presented Marconi with an excellent opportunity to exploit the photonics materials research and manufacturing skills of Caswell Technology. The rapid ramp-up in demand dictated that the wafer fabrication and growth upgrades at Caswell must take place in parallel with an increased throughput from the existing lines. This challenge is perhaps the hardest of all to accommodate, since process engineering skills are needed in three areas simultaneously. These areas are:

(i) to sustain and improve the current process lines;
(ii) to train new staff as the current lines expand;
(iii) to engineer new processes for the 150mm line.

Thus the first phase of the line upgrades involved a vigorous recruitment campaign to establish an enlarged process engineering group, and additional metal-organic vapour phase epitaxy (MOVPE) growth engineers. The phased recruitment of wafer fabrication and MOVPE growth technicians occurred later. It became clear as the expansion gathered pace, that the training of technician staff was the limiting factor in determining capacity. This resulted in novel approaches to training being sought, such as sub-contracting initial practical skills training and training in group sessions rather than one-to-one (Figure 3).

Although the original intention was to opt for maximum flexibility, with experience the wafer fabrication activities were split into two organizations. The low-volume 2" InP based process line was clearly demanding different skills and disciplines compared with the high-volume 3" and 150mm GaAs based lines. Hence this operation was "ring-fenced" with its own manufacturing system re-defined. Dedicated staff (both process engineers and technicians) now operate this line.

Whilst the InP line is run on a small batch basis, the high-volume lines employ a flexible batch size approach within a cell-based manufacturing system. These 3" and 6" lines use kanban JIT scheduling and cycle-time reduction techniques to drive down delivery times and time-to-market dates for new products. Some aspects of the manufacturing system are common throughout the wafer fabrication and growth areas. All processes, for example, are controlled via the PROMIS manufacturing execution system, including its advanced SPC facility. This is the cornerstone of a six-sigma approach to wafer fabrication process design, which also makes use of statistical process design and optimization software.

GaAs MODULATORS ON 150mm SUBSTRATES

Processing optoelectronic devices on 150mm substrates poses two main areas of concern:

(i) stepper lithography on severe topography;
(ii) substrate quality.

Electrical isolation of the GaAs modulator is achieved using a trench and airbridge scheme which is believed to be unique to Caswell for GaAs optoelectronic devices (Figure 4). This process results in a significant topology on the wafers where feature height variations of >8μm are typical. This means that it is essential to have resist processes capable of ensuring full coverage of these structures. Failure to achieve this will result in etching into the waveguide sections at the air-bridge landing points. Stepper lithography has been established to cope with these demands, which are shared to an extent by HEMT MMICs.

For all GaAs modulators, optical loss is a key parameter. It is well known that substrate defects such as slip, strain or dislocations will dramatically increase the loss. 150mm wafers have been evaluated before and after MOVPE growth and the effect of substrate quality assessed. A thorough evaluation of 150mm substrate suppliers has been undertaken and results indicate that the best low loss device performance is achieved by using low dislocation density VGF or VB substrates.

PSEUDOMORPHIC HEMTs ON 150mm SUBSTRATES

The main concern in making the transition from 3" substrates to 150mm for the HEMT MMIC process was the definition of 0.2µm gate features. Currently stepper, electron-beam and X-ray lithography are the principal candidate approaches, with the latter considered somewhat experimental by most manufacturers. Stepper processes are used for 0.5µm HEMT MMICs for mobile telephone applications, but additional linewidth reduction and phase-shifted masks are needed to achieve gatelengths around 0.2µm. We have selected an electron beam-written recessed gate technology on MBE epi wafers for our new line. To the best of our knowledge this is the first application of electron beam direct write across whole 150mm wafers for HEMT devices. This technique minimises the effect of the mesa isolation topography at gate definition and allows continued use of the well-established mushroom gate process already used on 3" wafers.

CONCLUSIONS

The rapid rise in demand for photonic-based communication systems has resulted in a large increase in activity to supply the necessary devices. There has been a significant commitment by materials and equipment suppliers to meet these needs. Marconi has risen to this challenge by establishing a combined process facility for manufacturing both GaAs modulators and HEMT MMICs on 150mm diameter wafers. Lessons learned from the silicon semiconductor industry have been invaluable in setting up this capability.

ACKNOWLEDGMENTS

The enthusiasm and commitment of the Caswell process engineering and equipment maintenance teams are gratefully acknowledged.

REFERENCES

[1] M.R. Wilson, K. Adams, E. Huang, *Riding the Wireless Wave with 150mm GaAs Manufacturing,* 2000 GaAs MANTECH Technical Digest, pp. 245-248, May 2000.

[2] Y.C. Pao, D. Glajchen, *Establishment of a Full Functional Six-Inch PHEMT Manufacturing Wafer Fab,* 2000 GaAs MANTECH Technical Digest, pp. 251-254, May 2000.

[3] J. Mikkelson, *Integrated Circuit Production on 150mm GaAs Wafers,* 1999 GaAs MANTECH Technical Digest, pp. 55-58, April 1999.

[4] O. Berger, R. Hochmuth, *The Siemens 150mm GaAs Production Facility,* 1999 GaAs MANTECH Technical Digest, pp. 59-62, April 1999.

[5] J. Gedaly, *Economic Justification of a 6" GaAs Wafer Fab,* 1999 GaAs MANTECH Technical Digest, pp. 63-66, April 1999.

Figure 1. New equipment installation in the 150mm process line

Figure 2. New equipment installed and commissioned

Figure 3. Training in problem solving techniques

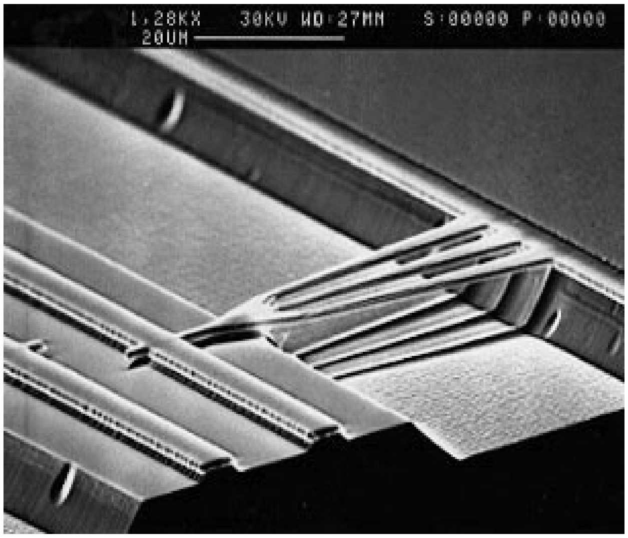

Figure 4. Modulator trench and air-bridge structure