Integration and Qualification of a Second Site HBT Epitaxial Wafer Foundry

David Troy, Andreas Eisenbach*, Paul Cooke, Tony Pearce*,
Graham Clarke*, Iwan Davies*, Susan Barne*

IQE RF LLC, Suite 215, 265 Davidson Ave., Somerset, NJ 08873, USA, Dtroy@iqep.com, +1 (732) 271 5990
*IQE Europe Ltd., Pascal Close, Cardiff CF3 0LW, Wales, UK

Abstract

Within the IQE Group, a natural opportunity existed to establish HBT epiwafer production at IQE Europe (UK facility) as a second site and back- up capability to IQE RF (US facility). To successfully complete the transfer, an "integrated" approach was adopted focused on getting all aspects of the manufacturing process from raw materials, epitaxial growth, and QA review through to shipping practices either aligned or at least identified as an acceptable differentiator.

An initial baseline technical capability was developed that matched selected HBT structures and device performance across both sites. Wafers were then supplied for reactor qualification. A sustaining effort was established to align and match all critical metrology functions, critically including large-area device fabrication. Concurrently, common raw material consignment and production planning was adopted such that the UK facility reactors can act as a "virtual" wafer supplier to the US facility. This has enabled both manufacturing sites to be routinely employed for HBT epiwafer supply.

INTRODUCTION

In any sustained manufacturing environment, the ability to source starting material(s) from multiple sites provides a key option to mitigate supply disruption due to unplanned or unexpected events. Dual site sourcing also allows a degree of flexibility for production planning and optimization of capacity enabling quick response to unexpected changes in demand. In the case of HBT epiwafer growth, a natural opportunity existed to establish IQE Europe (the UK facility located in Cardiff, Wales) as a second site for HBT epiwafer manufacturing to IQE RF (the US facility located in Somerset, NJ). Both sites were well established in MOVPE wafer growth, but differed significantly in terms of core technology and product mix.

To be effective, it was essential that wafers grown in the UK facility were matched for all relevant wafer characteristics. Further, wafers needed to perform consistently through customer processing and produce acceptable device yields. Essentially, all grown product needs to be statistically indistinguishable and within the distribution of previously manufactured and shipped material to satisfy customer needs.

DEVICE MATCHING

The most immediate issue was the obvious difference in MOVPE reactor platforms employed at each facility (US: Emcore/Veeco, UK: Aixtron). Both reactor styles (Veeco E400/E450 and Aixtron 2600G3) have well-established track records of volume manufacturing of electronic and optoelectronic products.[1,2] There are, however major conceptual differences in reactor design such that direct adoption of Veeco growth parameters, growth conditions etc. on the Aixtron platform was not possible. The planetary individual wafer rotation and single-inlet basis of the Aixtron 2600G3 is in sharp contrast to the high-speed fixed- wafer multiple- injector design of the Veeco E400/450. Temperature monitoring capability and typical gas flows were also markedly different. These disparities ensured there was a huge potential for distinct within wafer, wafer-to-wafer and run-to-run populations between the facilities.

Prior HBT development was taken as the starting point for tuning the UK facility HBT process to match the qualified US facility production process. Complete material calibrations, identical to those grown in the US facility, were grown and characterized at both sites. Data from the US facility was used to gauge the alignment for key material parameters. The UK facility growths were iterated until the material data fell within the established manufacturing control limits of the US facility. In particular, and specifically for HBT epilayer growth, GaAs:C p^+-doping, InGaP bandgap and lattice matching, and InGaAs contact properties were brought to a common standard traceable to ongoing production requirements at the US facility.

In addition, substrate-to-buffer interface properties were confirmed such that the UK facility process replicated the US facilities HBT/BIFET interface. The US facility process relied on in-situ substrate cleaning to remove unwanted electrically active contaminates. Since the interface properties are not generally apparent in large-area HBT device characterization, extensive use of epitaxially grown MESFETs and Hg-probe or Polaron CV was employed to match the UK to the US facility. Fig 1 shows the CV measurement of two MESFET n-GaAs/ud-GaAs/substrate structures utilized to investigate the substrate-buffer interface. The sharp drop in capacitance of the optimized growth sequence clearly demonstrates the cleanliness of the substrate-buffer interface.

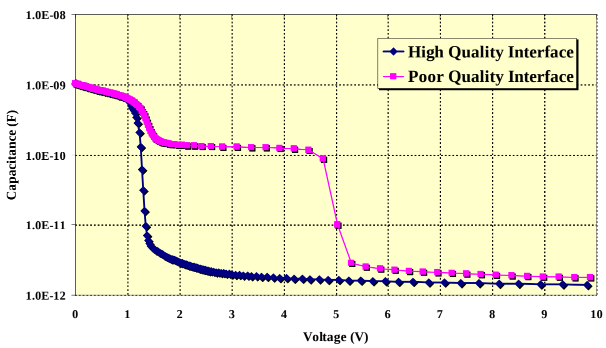
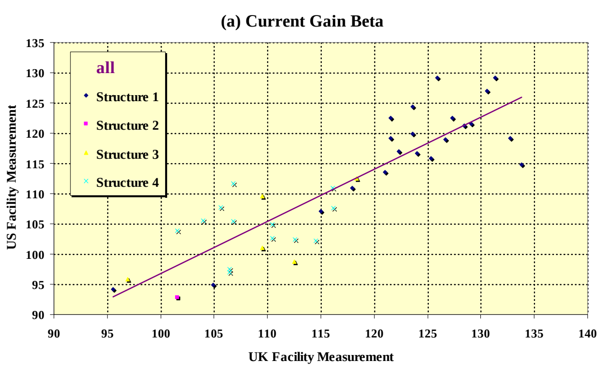
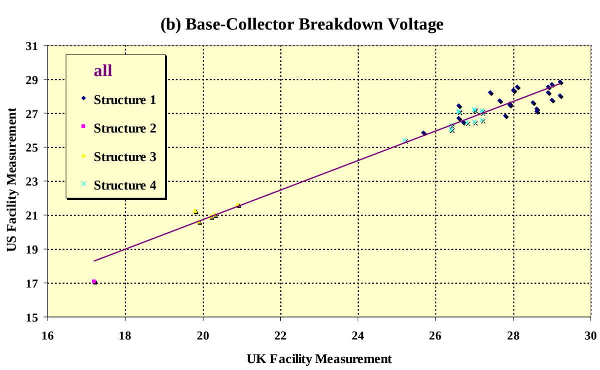


FIG 1: MESFET CV PROFILES OF ALIGNED AND UNOPTIMIZED SUBSTRATE-BUFFER INTERFACES.

Selected customer HBT structures were then grown and analyzed at both facilities. A key aspect was the availability of large-area HBT device fabrication at both sites. Typically, whenever possible, wafers were fabricated in both locations to build up a cross calibration database. Fig 2 shows the results from both sites over a range of key HBT parameters and structures. At this stage, the correlation was considered sufficient to ensure the UK facility large-area HBT results would provide a predictor of the US facility results.





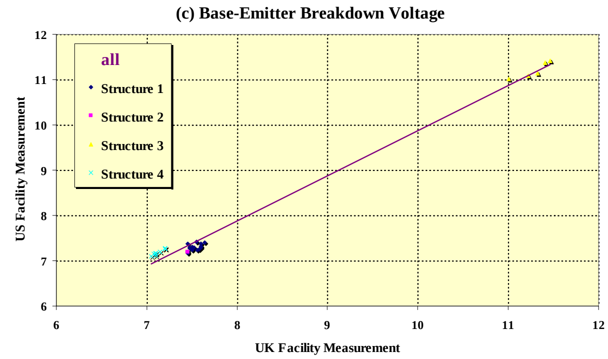


FIG 2: X-CORRELATION FOR SOME TYPICAL HBT DEVICE PARAMETERS SUCH AS (A) CURRENT GAIN BETA, (B) BASE-COLLECTOR BREAKDOWN, AND (C) BASE-EMITTER BREAKDOWN VOLTAGE.

METROLOGY

Materials and device metrology capabilities within each facility were largely tied to the historic volumes and product mixes at each site. These differed significantly, as the UK facility was geared towards lower volume, optoelectronic products whereas the US facility was already producing a significant volume of GaAs RF epiwafers.

Wherever possible, throughout the transfer process, wafers from growth runs were characterized at both facilities to correlate measurement setups and obtain matching data between the facilities. The measurements included morphology (Surfscan particles and haze, visual inspection), sheet resistance and device parameters. Fig 3 shows the distribution of measured haze from both facilities using Surfscan 6220. Site 1 refers to the UK facility while site 2 refers to the US facility. We observed a 7% difference in the mean haze value between the 2 sites. Although statistically significant, this offset was considered to be negligible by comparison to the typical control limit range and no change was made to the measurement systems.

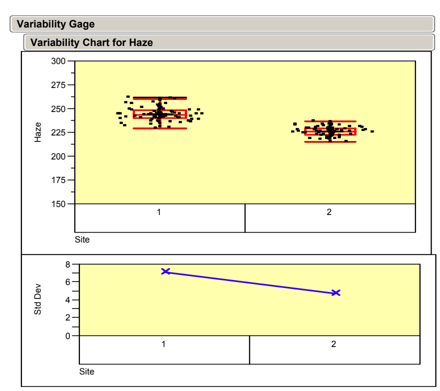


Fig 3: MEASURED HAZE DISTRIBUTIONS BETWEEN FACILITIES.

However, there were instances where more appreciable differences were noted. This included non-contact sheet resistance measurements on the overall HBT structure. A consistent offset was apparent between the two facilities despite the use of nominally common measurement sets (Lehighton 1300/1510). Upon investigation, this was traced to the qualification standards employed at each facility.

Within the overall focus to provide a consistent dataset, identified discrepancies were resolved based on the US facility prevailing production history. Offsets were established such that the UK facility data could be used as a predictor of the US facility results enabling the development of a consistent and continuous product stream. Maintenance of the offsets was confirmed by routine sample exchange between the two facilities.

INTEGRATED MANUFACTURING

In addition to matching the material properties and understanding the metrology offsets, it was clear very early on that a successful deployment of the UK facility capacity for HBT production would require a more comprehensive or "integrated" approach that encompassed the entire epiwafer manufacturing flow. All aspects of the manufacturing process were targeted for alignment or at least identified as acceptable differentiators due to reactor platform or geographic location. The technical team was enlarged to form a broader transfer team that was tasked with facilitating a viable manufacturing path for HBT wafers from UK facility to end customers.

The initial UK-US production flow was established as simple vendor-customer relationship. Wafers were requisitioned from the UK facility, evaluated (screened) in the US facility and then forwarded to the final customer. This was effective for small volumes, but at the expense of delays associated with receiving and retesting wafers at the US facility. It did, however, have the advantage of intrinsically ensuring a common and consistent outgoing quality level as all wafers went through final QA at the US facility.

The next step was to effectively "start" all UK facility grown wafers within the US facility electronic manufacturing system. This meant that the incoming wafers were no longer treated as externally purchased supply but rather as an extension of internal capacity and capability. In its most practical manifestation, incoming wafers are matched to US facility-style electronic travelers. These were pre-populated in the UK facility to facilitate their onward routing through test, etc., in the US facility with minimal manual intervention or human oversight. This also established a coherent data stream such that adding or removing steps (e.g. duplicate or additional testing) could easily be accomplished without loss of traceability.

The production planning function continues to be driven by the US facility which provides internal forecasts to both facilities by HBT product line. Therefore, the reactors at the UK facility appear to the US production planners as pseudo on-site reactors, and are added to the US facility production plan as qualified reactors. Electronic access from both sites to measured data was established. For the purposes of report and label generation, all UK facility grown wafers appear exactly as US facility wafers would, except with a different reactor ID.

Wherever possible, current "best practice" was were adopted, or alternatively, gaps identified for future improvement activities. One of the most mundane yet critical was the ability to rapidly ship wafers transatlantic without breakage.

With its background in smaller volume optoelectronic materials, the UK facility was accustomed to shipping wafers using individual wafer containers or "pucks". Larger volume shipments, typically made in cassettes, required modifying this approach and adopting the US facility techniques of packaging and labeling. Sourcing the software and hardware to produce a common label proved a difficult issue. Although seemingly simple, getting the correct wafer information on a common size, clean room-compatible label, and adaptable to specific customer requirements proved a sizeable task. Custom software was eventually developed and deployed at both facilities, superseding that previously used at the US site. For both the packaging and labeling, specifications were established and training was provided. In addition, shipping personnel were transferred between facilities to develop first hand experience and to identify materials and supplies needed and used on a daily basis for wafer shipments.

HBT Production

As currently established, a variety of HBT structures are routinely manufactured at both facilities. Fig 4 demonstrates the normalized distributions of large area device parameters for a selected HBT product currently manufactured at both facilities. Normalized beta, base sheet resistance and within wafer beta uniformity are shown by reactor and location. In this case, two reactors are located in the US facility and one in the UK facility. All results are taken from large area HBT processing completed at the US facility. Average beta values are well matched but there is a slight offset in the mean Base sheet resistance. A corresponding offset was also observed in the "burn-in" and was consistent with the expected trade off in beta/Rsh ratio with burn-in. This offset was later addressed by adjustments to the US based reactor recipes. It should be noted that the distributions include both deliverable and calibration ("dial-in") results and not all wafers represent conforming product. In the case of within wafer beta uniformity, the process developed at the UK facility produced a tighter distribution. Since this was an improvement over the results typically observed from the US based reactors, this was taken as an area for future work and investigation on the

US tools. Similar analysis of the remaining large area HBT electrical results provided both facilities' technical teams with tangible improvement goals in order to further each facilities continuous improvement efforts.

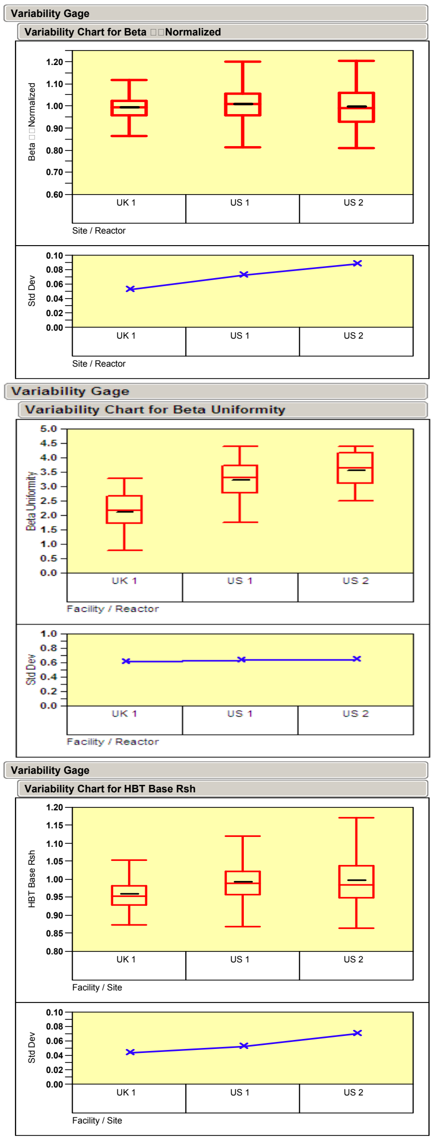


FIG 4: VARIABILITY PLOT BETWEEN REACTORS AT UK AND US FACILITIES FOR HBT DEVICE PARAMETERS. (A) CURRENT GAIN BETA, (B) BETA UNIFORMITY, (C) BASE SHEET RESISTANCE

Fig 5 demonstrates the normalized HBT base sheet resistance for the same HBT structure as a function of time. The individual site data represent results from three reactors. The gaps in site data over time represent a change in product mix for a given reactor, either due to customer demand or reactor maintenance. The initial production control limits were taken from the US facility production history but were subsequently updated by incorporating the results from the UK facility. All production controls are now periodically reviewed ensure the reactors run consistently. The result is that multiple reactors, reactor platforms and manufacturing facilities are used to supply customers with a sustained supply of material that is globally consistent in terms of measured HBT parameters.

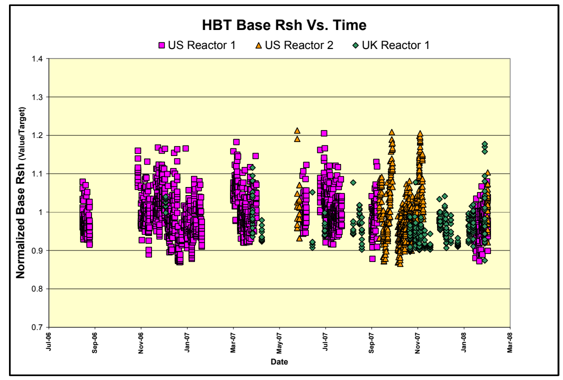


FIG 5: BASE SHEET RESISTANCE VS TIME FOR 3 REACTORS FROM TWO DIFFERENT FACILITIES.

CONCLUSION

The transfer process included customer qualification and corporate integration in order to meet our customers growing needs. This project was started with the idea of providing additional capacity to meet customer demand and transformed into methods to consolidate and integrate our business units to better serve our customer customers base. Improvements were realized in terms of problem solving, measurement, growth techniques, IT databases, logistics, and production control. In addition, the capability to match product from different reactor platforms provided insight into future optimization paths on both toolsets. In summary, the teams from different facilities converged on methods and systems to answer the needs of the business.

ACKNOWLEDGEMENTS

The authors would like to thank all the employees at both the UK and US facilities that contributed to making this technology transfer a success.

REFERENCES

[1] P.M. DeLuca, J. Rodrigues B.K. Han, N. Pan, "*High Uniformity 6" InGaP/GaAs Heterojunction Bipolar Transistors*," "GaAs2000" European Microwave Week, p. 64, 2000. 2000

[2] J. Silver, P. Cooke, E. Armour, S. Ting, L. Kapitan, M. Ferreira, D. Tilli, C. Palmer, "*High-Volume Manufacturing of InGaP /GaAs HBT Wafers*" GaAs MANTECH, 2002.