Relocation of Cobham's MMIC Wafer Fab

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Abstract

After more than twenty-five years of operation at the ITT site in Roanoke, Virginia, Cobham Sensor Systems has relocated its MMIC wafer fab and part of its MMIC design capability to Blacksburg, Virginia. Beginning in early February 2010, Cobham ceased manufacturing operations in Roanoke and began the complex task of disassembling the entire equipment set, packing up work in process and all associated documentation, and relocating the combined operations to a modern 50,000 ft^2 facility in nearby Blacksburg, Virginia. In doing so, process performance and Cpks had to be established the same in Blacksburg as they had been in Roanoke. To establish production turn-on it was necessary to show that MMICs made in Blacksburg exactly matched the historical baseline performance and reliability of MMICs made in Roanoke. In October of 2010, Cobham announced the successful completion of this activity.

INTRODUCTION:

In the early 1980's, ITT Defense established a new division, in Roanoke, VA, to develop GaAs MMIC's using MESFET technologies. Over the course of the next fifteen years, the ITT Gallium Arsenide Technology Center (ITT-GTC) developed world class capabilities for fabricating high performance defense and commercial MMICs using the patented MSAG process. In March 2000, ITT sold this division to M/A-COM, a unit of Tyco Electronics. M/A-COM operated the Roanoke MMIC division until September, 2008, when it was divested to Cobham, a large UK based aerospace and defense company.

Throughout this history, the Roanoke wafer fab operated in manufacturing space attached to ITT Night Vision property, with design and administrative offices at nearby locations. In 2009 a modern facility in Blacksburg, Virginia, became available, sized such that the Cobham-Roanoke Fab, Design, and Test operations could be combined under one roof. This site had formerly housed a silicon wafer fabrication company and therefore contained the basic infrastructure necessary for the Cobham MMIC operation.

Subsequently, in the spring of 2009, Cobham made the decision to move the Roanoke Operation to the newer facility in Blacksburg, VA. The plan was in essence quite simple: conduct build-ahead manufacturing during 2009 to provide continuity of product delivery in 2010; shut down all operations in Roanoke in early 2010; move equipment and personnel to the new location; bring up the equipment and processes during spring and summer of 2010; satisfy all process and product qualification requirements; resume MMIC production in October 2010. In addition to meeting the aggressive schedule for the move and qualification, an over-arching objective was that the process and products made in Blacksburg had to exactly match performance, quality, and reliability defined by the historical baseline from Roanoke. To help reduce risk and in order to achieve the "Blacksburg Same as Roanoke" (BSR) objective as quickly as possible, the entire Roanoke equipment set was moved and used in the initial qualification of the process in the Blacksburg facility.

RELOCATION PLANNING:

Cobham uses a project management system called Life Cycle Management (LCM) for planning, executing, monitoring, reporting, and maximizing success for large-effort projects. LCM was used extensively throughout all stages of this relocation project, with particularly high emphasis during the planning phases. The complete relocation project was broken into self-contained, but interacting segments. Stakeholders having primary responsibility for budget and schedule were assigned to each segment of the move project. Examples of functional segments included: clean room upfit; relocation of shipping and receiving; regulatory permits; test equipment move and recalibration; process equipment decommissioning and moving; process equipment re-installation and qualification; unit process qualification; full-process qualification; product performance requalification; and reliability qualification. In all, there were approximately 40 major segments of the relocation and qualification plan, each with its own stakeholder. Many of the larger segments were broken into smaller segments with assistant stakeholders assigned.

All of the top-level planning was backed up with in-depth detailed planning, quantifying resource requirements of all types (materials, outside contractors, internal labor resources, etc.) as well as resource interactions and schedule requirements. Microsoft Project was used to integrate and manage all the detailed planning. As an example of the extent of the detailed planning involved, the MS Project file that was generated for the first half of the relocation plan contained more than 2000 lines of inter-related actions with details for all the resource requirements and schedule elements needed to complete each task.

The detailed planning helped avoid many pitfalls that would have otherwise contributed to schedule delays or cost over runs. There were many instances where it was necessary to deviate from the plan, but due to the significant effort that was put into the plan and assessment of options, problems were easy to recognize quickly, getting the attention needed for fast and cost-effective resolution.

Figure 1 shows the top-level schedule for the re-location project. All top-level tasks and milestones were achieved on or ahead of schedule. The complete upfit in the new building, including major modifications to the clean room was done in just three months. In addition to completing the full re-qualification of MMIC fabrication per the schedule, note that backside processing was qualified first and product deliveries were interrupted by only one month until RF test and dice-pick-and-inspect were back on line shipping product from inventory that was built up in 2009 prior to the move.

SITE REMODELING:

The Roanoke wafer fab had evolved from a facility designed for MMIC R&D to one focused on small-scale MMIC production – but hampered by the constraints of the R&D clean room design. Therefore moving to a new clean room facility offered many opportunities for improvement. For example, maximizing uptime generally requires redundant equipment capability and this is best accomplished by grouping similar tools or processes; but, due to the clean room layout and space limitations in Roanoke, it had become necessary to scatter process tools into different clean room bays even though their functional capabilities were similar. To rectify this, the best placement for reinstallation of the Roanoke tool set in Blacksburg was carefully evaluated and defined.

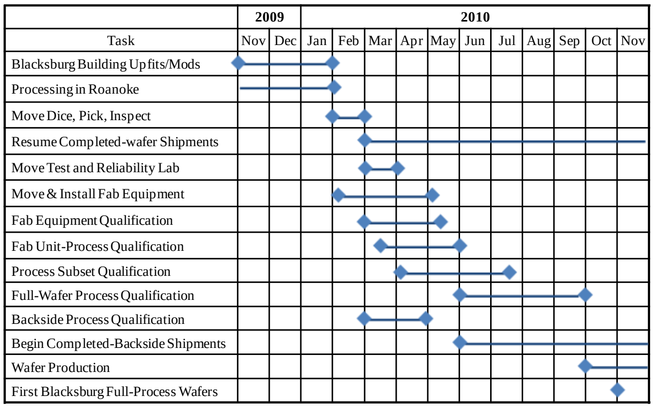

Figure 1. Top-level schedule of major tasks and milestones for re-location project. All tasks were completed as planned.

In determining best layout for the clean room, consideration was also given to future growth, with the anticipation that the move to Blacksburg would provide opportunity for new equipment acquisition, increased wafer volume, and implementation of next-generation MMIC technologies. Although the exterior dimensions of the overall clean room were fixed, Cobham was able to rearrange many of the interior walls to allow for a regrouping of like-tools and to provide properly sized chase space for extensive bulkhead mounting. As an example, all of the etch and "liftoff" tools were re-grouped into a newly sized Wet Process bay, immediately adjacent to the metal deposition tools. Many of the tools were installed "bulkhead mounted", whereas they had not been in the old Roanoke facility. This arrangement not only improved process flow, but it also improved operator efficiency by providing a coordinated metals processing area and a cleaner, neater workspace.

In some cases the redesign of the clean room was also an opportunity to restructure the basic product flow. For example, due to the R&D heritage, the photolithography bay in the Roanoke facility was situated at one end of the clean room layout with the implant bay at the other end. With emphasis on ion implantation for the MSAG process, this arrangement was clearly inefficient, requiring much long-distance transport of wafers many times during the MMIC fabrication process. The new arrangement in Blacksburg corrected this deficiency; the photo bay is in the center of the overall clean room space (like the hub of a wheel) where it should be, between ion implant and metals deposition which naturally leads to better product flow.

Another improvement opportunity presented by the move was consolidation of all clean room space into one centralized location. In Roanoke there were five distinct clean room spaces housed on several floors and in separate buildings. This gave rise to substantial inefficiencies due to the amount of wafer travel required between floors and buildings. For example, backside processing was located on a different floor from the main clean room; dice, pick, and inspect (DPI) were in another clean room space in a different building; and on-wafer circuit test was located in yet another building, miles away. The move to Blacksburg allowed Backside, DPI, and On-Wafer final test to be gathered contiguous to the main clean room.

Equipment Move, Re-Install, and Re-Qualification:

Cobham faced the prospect of moving several "one of a kind" tools, and some significantly large and complex tools such as ion implanters and steppers. One very deliberate aspect of the move was to move and reinstall the process exactly as it was in Roanoke. This meant that even though it might have been an opportune time to replace old tools, replacement would further complicate the task by requiring process development and the potential for process shifts. Thus, using the exact same equipment set as in Roanoke would reduce risk of delay in getting the Blacksburg process qualified. The disadvantage was that if a tool was damaged as a result of the move, Cobham was at risk for down time until repair or replacement could be implemented. Therefore, every possible precaution was taken to minimize risks of damage during de-install and transport, and to maximize first-pass success for the re-install and qualification for each process tool. As part of this precautionary approach, each tool was assigned a team consisting of the process engineer "owner" and an equipment maintenance technician to plan, supervise, and be "hands on" at every step in the de-install, transport, and re-install process. The actual move and transport of the equipment by the moving company was carefully supervised by each "process equipment owner" and actual transport was limited to a few process tools at a time.

As part of the de-install process, it was required that the Roanoke installation be fully documented beforehand. This meant labeling all cables, gauges, hoses, and gas lines, and photographing all sides and connections to the tool (and ancillary components). All detached components and such were then packed and labeled with the equipment entity number so that they could be readily located at reinstallation. This served as backup to the equipment manuals and significantly eased the reinstallation process.

Although Equipment Maintenance and Process Engineering teams were responsible for over 90% of the tool-set relocation, the steppers and ion implanters were contracted to be de-installed and re-installed by experienced vendors. The OEM performed the work for the steppers. For the ion implanters, an experienced after-market service provider, in conjunction with the in-house team, successfully performed the disassembly and reinstallation.

MMIC Process Transfer and Re-Qualification:

The foundational guiding principal in all elements of the process transfer and re-qualification was that performance and reliability of MMICs fabricated in the Blacksburg facility must match performance and reliability of MMICs made in the Roanoke facility – or "Blacksburg same as Roanoke" (BSR) for short. JEDEC recommendations were used to guide the process re-qualification effort, particularly for the reliability aspects of the requalification. The major elements and phases of the process requalification and their qualification requirements were as follows:

1. All process tools meet manufacturers operating specifications
2. BSR for all unit process Cpks
3. Cpks for all process subsets (e.g., ohmic contact formation) satisfy BSR
4. Cpks for all Process Control Monitor (PCM) pass/fail parameters for all device types and test structures achieve BSR
5. BSR for Standard Evaluation Circuits (SECs) representing each device type and circuit application
6. BSR for production MMIC performance
7. BSR for process and product reliability, per JEDEC recommendations, including accelerated life tests

All qualifications underwent formal review followed by documented certification by the LCM Review Board.

Re-Qualification Details and Results:

Unit Processes: There are well over 100 in-process characteristics measured for monitoring and control purposes for the Cobham MSAG process. Requirements for unit process re-qualification were that the short-term Blacksburg Cpk had to be as-good-or-better-than the Roanoke-historical Cpk for each and every in-process control parameter. The unit-process qualification involved much more than simply turning a tool back on, loading the recipe, and making a run.

Deposition rates, etch rates, photo exposures, etc., had to be carefully tuned so that the in-process results matched the Roanoke capability in every way – then multiple runs had to be made to collect sufficient data for Cpk calculation and comparison. Even though the same process equipment was being used in Blacksburg, initially not all unit-process results were BSR. A number of special-cause differences were discovered. For example, in order to satisfy the facility-equipment requirements in the new facility, process-water-conductivity was different in Blacksburg compared to Roanoke – with consequences to some of the processes involving RF-generated plasmas. In each process tool where an RF power supply was inductively coupled with the process water loop, the change in process water conductivity resulted in a change in power delivered to the process chamber, requiring that processes be re-tuned to reproduce the Roanoke-baseline performance. Other differences associated with the re-location were found and compensated for with the end result that Cpks for all unit processes met the BSR requirement.

<u>Ohmic FETs:</u> Implant, TiWN gate metal deposition, cap-and-anneal, and ohmic contact formation all contribute to establishing the primary dc characteristics of an MSAG FET. Therefore, a primary objective for assessing the initial "health" and capability of the MSAG process in Blacksburg was to make an ohmic-level dc-testable FET and compare it to the same type of FET made in Roanoke. This capability was achieved in early May, 2010, less than three months after starting equipment installation in the Blacksburg facility. Figure 2 shows the excellent match in dc characteristics between the first Blacksburg FET and a typical Roanoke FET.

<u>Process Control Monitors (PCMs):</u> As part of Cobham's standard process control and wafer acceptance, a barrage of PCM tests are performed on every wafer. Every FET type in the MSAG library has a defined set of dc and RF parameters that are measured after wafers are fully processed. Many of the measured PCM parameters have documented acceptance limits which are applied to the test results to determine wafer acceptance for production wafers. The method of using Cpk was again applied to the PCM data for comparing the process in Blacksburg to the process

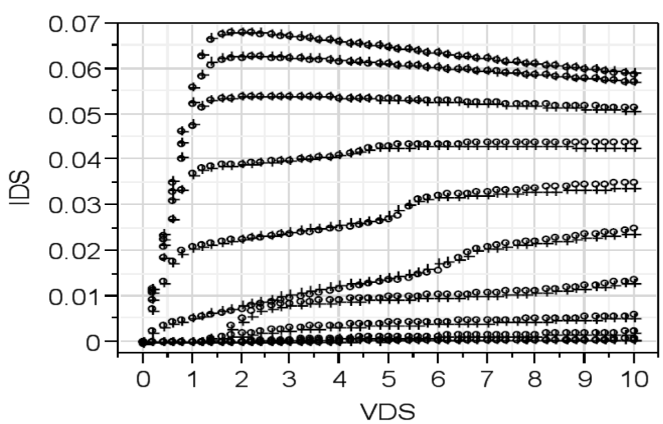

Figure 2. dc IV plots of MSAG 5A FET showing identical behavior Blacksburg (○) vs Roanoke (+). Data was taken at the ohmic-level part of the process at which point FETs are fully functional for dc measurement. .

in Roanoke. PCM qualification required that, for every PCM parameter with documented production acceptance requirements, Cpk satisfy the BSR requirement. There were 37 PCM dc and RF parameters that were subjected to this qualification requirement. Wafers coming from the full-process qualification runs were used to provide the data for this qualification effort. In all, nearly 500 wafers processed with standard-value process parameters in Blacksburg contributed to the full set of data used for the PCM Cpk comparisons and process qualification. The BSR criteria was satisfied for all 37 of the PCM parameters subjected to the qualification assessment. Figure 3 shows an example of the PCM qualification and certification. Idss mean values and distributions for the MSAG BFET are nearly identical for Blacksburg and Roanoke.

<u>Product Performance:</u> The high-performance MSAG process includes seven different FET types along with process options which can be used depending on the application of interest for a particular MMIC. All aspects of the MSAG process had to be re-qualified at the product level, demonstrating equivalent performance in Blacksburg as in Roanoke. Contributing to this aspect of the qualification was the performance assessment of standard evaluation circuits (SECs) which demonstrated simple-circuit performance characteristics covering the range of device and process variants available to Cobham's customers. With successful completion of the SEC phase of the qualification, the more difficult task of full-circuit performance qualification remained. This part of the requalification, along with the reliability re-qualification was the most resource and time-duration demanding phase of the entire relocation effort. In order to satisfy JEDEC recommendations for multiple non-concurrent process lots for characterization of each major device and circuit type and to support the JEDEC-required reliability tests, a minimum of 250 wafers were scheduled for processing with 4-6 week cycle time over a period of 4 months leading up to the scheduled production turn-on date. In order to achieve the short cycle times needed to support the aggressive schedule requirements, the newly-occupied Blacksburg fab was set up to run 24x5 even though the volume demands were low. Operating in this fashion, more than twice the minimum required number of wafers were processed to support both the circuit performance qualification and the reliability qualification. The final step in performance qualification was the on-wafer-test (OWT) performance assessment of production circuits. Seven different production mask sets were chosen

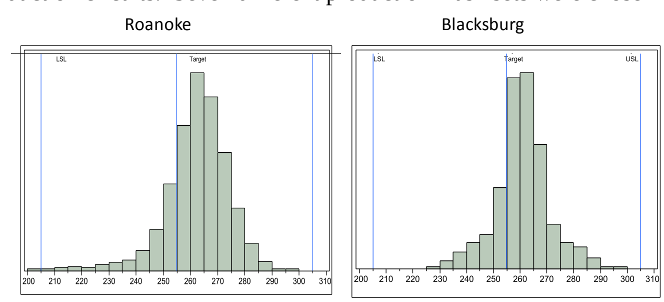

Figure 3. Histograms for BFET Idss comparing Roanoke to Blacksburg. Here, the short-term Cpk for Blacksburg was demonstrated to be slightly better than that for Roanoke.

for use in this phase of the process re-qualification in Blacksburg. Circuit functions that were covered included the following: S-band T/R Control, S-band High-Power Amplifier, Broadband Low Noise Amplifier, Ku-band Limiter, Broadband Limiter-plus-LNA, and X-band High-Power Amplifier. A minimum of three full lots, per the JEDEC recommendation, from each of the above-mentioned seven mask sets were processed and OW circuit tested. Aggregate OWT results from each mask set were compared to the Roanoke-production OWT data base. Requirements to pass the OWT qualification requirement were, for wafers fabricated in Blacksburg, that the OWT data for all specified parameters fall within the normal distribution of production-fabrication performance results for wafers processed in Roanoke. This requirement was satisfied for all seven mask sets for all the above mentioned circuit types. As an example of the comparison method and results, Figure 4 shows results comparing Blacksburg data to Roanoke data for small signal gain from a

Broadband-Low-Noise Amplifier. Results varied for different parameters across the different set of circuits, but, ALL of the circuit types on the seven mask sets evaluated in this re-qualification phase passed the equivalent-performance comparison criteria.

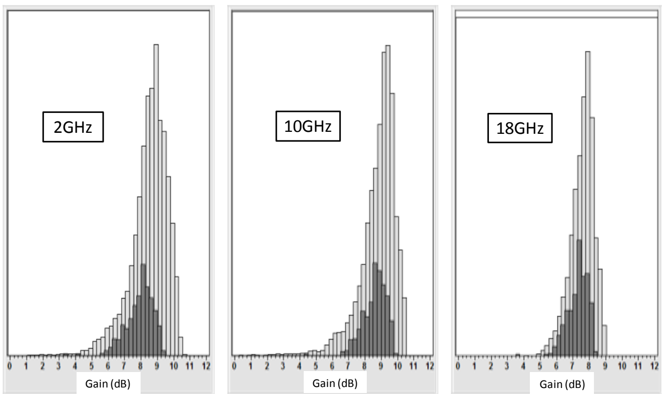

Figure 4. Histogram plots which illustrate the Roanoke (▫) vs Blacksburg (■) performance comparison, over frequency, for small signal gain of a Broadband Low Noise Amplifier. Performance-comparison behavior similar to this was obtained for all specified parameters on this circuit as well as the other circuit types tested as part of the OWT circuit performance qualification.

Reliability: With reliability being of utmost concern to customers, reliability re-qualification received a substantial portion of the overall re-qualification resources and effort. JEDEC recommendations were used to define the sampling requirements and the set of reliability tests to be performed. The sampling requirements and the length of time required to run some of the reliability tests (e.g., six weeks or longer for some of the tests) were significant factors in establishing the original re-qualification schedule – even with all the primary process and MMIC characteristics qualified, production turn-on could not proceed before all the reliability re-qualification requirements had been completed. The primary elements of the reliability portion of the re-qualification plan are summarized in Table I below along with a simple statement of the results, namely that all reliability test results satisfied the BSR requirements.

Table I. This list of reliability tests was obtained from JEDEC recommendations that apply to process requalification. Devices made in Blacksburg satisfied all the test requirements listed below.

Test Description	Test Vehicle	Specification - Method or Conditions	Sample Size	Result
High Temp Unbiased Bake	PCMs and SECs	275°C Air Bake 168 hrs	3 Lots, 1 wafer/lot	Pass
Temp Cycle	Interconnect Test Structures and SECs	JESD22-A104 Cond G -40°C to +125°C 500 Cycles 10 Minutes soak	3 Lots, 1 wafer/lot	Pass
Time Dependent Dielectric Breakdown	on-wafer using 1970	EIAJ-988	3 Lots, 1 wafer/lot 8 devices each	Pass
High-Voltage Reverse Bias	FETs and SECs	1-100mA/mm RB leakage	3 Lots, 1 wafer/lot 8 devices each	Pass
Arrhenius Verification	5A SECs	Operation-to-Failure at High Temp	7 DUTs, 1 control per set point temperature – 2 Temp (T1-T2)	Pass

Of all the reliability tests listed in Table I, the Accelerated Life Test (or Arrhenius Verification) is of particular interest to the user community. This test provides an assessment of the transistor-technology MTTF for the standard wear-out mode and also provides assurance there are no new mechanisms that could result in premature normal-operation failures. The MSAG process has always demonstrated excellent long-life characteristics and, through the use of the TiWN refractory gate, does not suffer from gate sinking. Simple power-amplifier ICs made in Blacksburg were subjected to highly-compressed RF drive accelerated life testing, and, as shown in Figure 5, the life data for the ICs made in Blacksburg exactly matches the historical life-test data obtained over the years for ICs made in Roanoke.

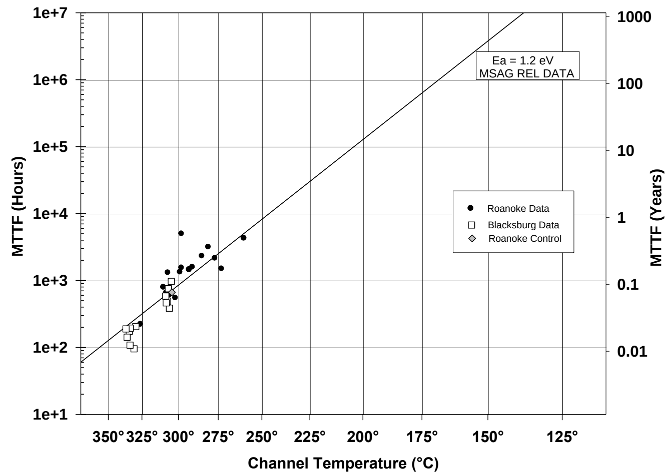

Figure 5. Arrhenius plot of RF-biased accelerated life test results for MSAG FETs. Blacksburg results (□) match results from tests performed in Roanoke on Roanoke-fabricated devices (●).

Manufacturing Resumption:

Because the relocation involved a complete shutdown of the MMIC manufacturing process, it was necessary to resume operations as quickly as possible so that new products made in Blacksburg would start contributing to the revenue stream. A very aggressive schedule for the move, equipment installation, and process qualification was set at the very beginning of the planning effort. Due to the re-qualification requirements for multiple-non-concurrent process runs across all process and production product types, that phase was planned to take more than half of the total eight-month relocation schedule – even with a 24-hour-per-day operation in place to achieve short cycle time. As described above, all aspects of the plan were executed successfully, within budget and on schedule. Success was due to many factors, not the least of which was the dedication and positive attitude expressed by all those involved. Through the heroic efforts of the entire team, the schedule was indeed met and MMIC production resumed early in October 2010, as in the original plan.

Acknowledgements:

The authors are indebted to the entire staff and management of the Cobham-Blacksburg organization for their tireless efforts in successfully completing the relocation and qualification of the Cobham MMIC process. In particular, the Equipment Maintenance Group managed by Wayne Bond, the Facilities staff managed by Chris Nielsen, the Operations staff managed by Melanie Bond and Terry Reed, and the Wafer Fab engineering staff are all due accolades and congratulations for a job exceedingly well done!