Achieve Manufacturing Readiness Level 8 of high-power, high efficiency 0.25-µm GaN on SiC HEMT Process

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I. Introduction

TriQuint is in the third year of a Defense Production Act Title III contract to improve GaN manufacturing capability to meet future military production needs. The benefits of GaN to provide higher power density, improved system efficiency, simplified power distribution and cooling, and ultimately reduced cost have clear advantages in performance for future military systems. GaN has significant advantages over GaAs due to higher mobility, higher breakdown voltage, and higher maximum operating temperature.

The primary objective of the Title III program is to achieve a Manufacturing Readiness Level (MRL) of 8 for manufacturing S-Band and wide bandwidth (X/Ku-band) GaN on SiC MMIC components with a production line ready to support Low Rate Initial Production. In addition, the objectives of the Title III program are to establish a domestic, economically viable, open-foundry merchant supplier production capability for narrow and wideband MMICs employing GaN epitaxy on 100mm SiC substrates.

The TriQuint Title III effort builds on a long history of development and manufacturing of GaN MMICs. TriQuint's effort began in 1999 and resulted in the release of a qualified manufacturing process for GaN MMICs on 3 inch SiC substrates in 2008. A 4 inch process was released in 2010 and is in use for standard product development and foundry projects for external customers.

Through the Title III program, TriQuint is making significant progress in achieving the manufacturing maturity needed to serve the needs of future military production programs. Our approach to achieve the primary program goal of MRL 8 is to establish requirements through Key Performance Parameters (KPPs) for process and MMIC performance characteristics, assess the gaps in the metrics relative to requirements through a baseline Manufacturing Readiness Assessment (MRA) to determine an initial MRL; assess the gaps to MRL 8; improve the process; and finally repeat the MRA to demonstrate MRL 8 capability. The KPPs include process control monitors, MMIC yields, passive components (capacitors), cycle time, cost, and reliability goals. Meeting the reliability goals is one of TriQuint's top priorities.

II. Demonstration Vehicles

The Title III program is targeting specific MMIC performance requirements. Achieving those requirements required optimization of gate channel features for specific characteristics. Both the S-band performance and the wideband performance capability were optimized through field plate engineering. Subsequently, MMICs were designed to meet the requirements and are in use as demonstration vehicles for the program goals.

The S-band MMIC is designed for both high power and high Power Added Efficiency (PAE). The wideband circuit is designed for power and PAE covering X to Ku-band. Each mask set for the individual amplifiers contains a single stage test circuit, FETs for unit cell performance assessment, and test structures for FET parametric and process performance assessment. In process measurements from all the structures on the mask sets are used to assess process performance to the KPPs. In addition, post testing is done to assess reliability. This is achieved through single temperature and multiple temperature accelerated life tests; fixture performance of the MMICs; and long term RF operational testing of the MMICs.

Analysis of the data collected in processing the demonstration vehicles is used to drive improvement efforts by determining gaps to the KPP requirements. The improvement methodology is executed in three stages: (1) DOE exploration to identify critical variables, (2) confirmation to assess variable interactions, and (3) validation / qualification which is approved through our Technology Review Board.

III. Discussion

Analysis of the data collected in monitoring the process has resulted is focus on three main areas for improvement: (1) implementation of GaN specific characterization and tracking, (2) variability reduction, and (3) cycle time reduction. TriQuint's Texas manufacturing site is involved in several different processes which use silicon, gallium arsenide, and gallium nitride. With implementation of a GaN process additional characterization techniques are necessary for volume production. An example of a new characterization technique was the challenge associated with a clear substrate. A typical optical inspection is unable to detect scratches. TriQuint has implemented a Candela inspection tool. This additional characterization has allowed for measurement and categorization of defects such as scratches, micropipes, particles, etc. Figure 1 shows an example of the Candela map and what the "trench" found looks like under the microscope. This mapping allows for correlation between test failures and incoming material defects. Additional characterization techniques to be discussed are pulsed IV testing and drift measurements.

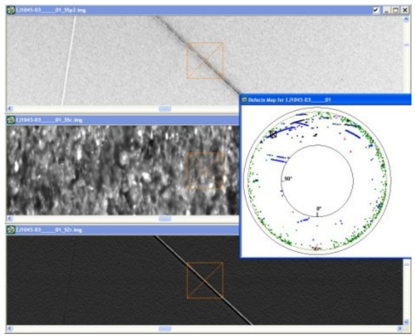

Figure 1.

Variability reduction is another area of focus driven in this project. Variability reduction has been pursued for lot-to-lot, wafer-to-wafer and within wafer sources. We have refined GaN surface cleaning steps to reduce general defectivity. Additional tightening of manufacturing process variability will be discussed related to backside process robustness.

Cycle time is an important performance parameter when measuring the manufacturing capability of an organization. TriQuint has identified several areas where improvement in cycle time can be achieved. These areas include tool redundancy, reduction in e-beam lithography process steps and structure patterning, as well as tool automation. Improved capacity and reduced processing time all make for a more manufacturable process. An example of improved capacity was the SiC via etch process. Etching of SiC is a long, difficult process. Additional capacity was needed to account for this long etching time. Output parameters for the process optimization work covered uniformity, process time, and tool redundancy. Identification of cycletime as a key output helped focus the design of experiments to achieve the desired outcome. Additional areas of cycletime improvement to be discussed are e-beam process steps and automation.

Summary

TriQuint has made significant progress in achieving a mature GaN manufacturing technology. Improvements in GaN characterization, process variability reduction, and cycle time will allow for the Title III MANTCH program to be completed with a final MRL assessment of 8. We thank the GaN Title III Integrated Product Team (IPT) for their support of this program.