Volume Manufacture of 150 mm VCSEL Epi-wafers

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Abstract

The development of volume VCSEL manufacturing at IQE is described. IQE presents its method for reactor matching and describes the new characterization tools introduced to provide the process control needed. Finally the status of IQE's new factory dedicated to meeting the growing demand for VCSELs is given.

INTRODUCTION

VCSELs have recently seen a surge in demand largely because of their inclusion in consumer devices for 3D sensing applications. This has resulted in the rapid migration from 75 mm to 100 mm to 150 mm wafers. This presents significant challenges for high volume manufacture of epitaxial wafers. As compared to other device types, VCSEL performance and yield is dominated by epitaxy rather than device processing. This has resulted in very tight tolerances for epitaxy specifications and extremely stringent on-wafer and wafer-to-wafer uniformity requirements. Coupling this with the inherent complexity of a VCSEL structure makes volume manufacture on 150 mm wafers non-trivial.

IQE grew its first working VCSEL on 2" wafers in the early 1990s and by 1994 was producing VCSELs commercially from an AX2400 reactor on 3"; the same year 4" epi was demonstrated too. In 2001 a major upgrade of reactors to Aixtron 2600 was undertaken and the year after saw red and 1550nm metamorphic VCSELs being grown at IQE. In 2008 IQE participated in the EU project Visit which lead to 40 Gb/s VCSELS being realized in 2010. The first mass production of 4" VCSELs happened in 2013 and in 2014 IQE was a partner in EU Project VIDaP which helped in the demonstration of the first 6" VCSEL epi at IQE. New Aixtron G4 tools were installed at IQE's Cardiff facility in 2016 and a year later were part of the 14 tools dedicated to VCSEL production at IQE. In 2016 IQE successfully transferred 6" VCSEL growth to its Taunton, MA production site, through qualification and into volume manufacturing.

REACTOR MATCHING

Due to the scale of the volume ramp required it was necessary to qualify multiple sites and two different reactor platforms (Aixtron G3 and G4) at IQE. To match reactors of the same type the equipment is audited to make the growth chambers identical (copy exact) and the gas handling is made as identical as it can possibly be made.

A functional matching specification is used to match product between reactors. This specification breaks the structure down and contains characterization specifications that each part of the structure must meet before the individual layers are combined to grow the full VCSEL. The full VSCEL will then be judged against the functional matching specification. Tool audits and matching specifications build on IQE's long experience in the wireless market sector.

Particular attention must be given to the doping profiles since control of these is critical to consistent performance. The complex doping profiles in high performance VCSELs require an automated analysis to reduce the SIMS trace into summary parameters on which a specification may be applied. This allows assessment of tool matching on a quantitative basis. Due to the location of the manufacturing sites it is necessary to use different SIMS vendors in high-volume production and this requires accounting for differences in quantification between the two vendors through use of a reference structure.

The final stage of reactor matching is through device performance and yield matching. At this point all material will have passed agreed specifications; matching follows a structured problem solving approach and makes use of statistical modelling techniques.

DOPING CHARACTERIZATION

Doping measurement by eCV profiling offers several advantages for VCSEL production. Firstly it measures the electrically active doping which controls the forward voltage and optical loss and secondly it is a quicker in house measurement (compared to SIMS) that can be used to control a tool through its production campaign to maintain the doping centered in specification. Older Polaron style eCV tools do not have the required GRR so IQE has invested in state-of-the-art tools from Nanometrics and WEP. IQE's experience is that these tools have different strengths and weaknesses. Our volume of VCSEL product enables us to have both these tool available and choose the tool that offers the best control of product.

Defect Classification

The incumbent measurement technology for defect analysis is the Surfscan which has several limitations such as the lack of defect classification and proprietary file formats. IQE has partnered with Camtek to introduce the Eagle-T tool for automated epi defect inspection for VCSELs. In addition to defect maps that can be used for disposition in the wafer fabs the classification of defects is currently enabling smarter defect reduction programs and defectivity OCAPs.

In situ Monitoring

All VCSEL reactors at IQE use a Laytec EpiTT ISM which measures an emissivity corrected pyrometric wafer surface temperature along with growth rate. The Laytec data enables calibration sets to be shorter, quicker and more thorough whilst offering the same or better accuracy compared to incumbent techniques. The Laytec system also enables characterization of critical layers in a VCSEL that could not be characterized by traditional means or would require complicated modelling. Through use of analysis recipes the required analysis can be loaded into the MES before the wafers are even unloaded from the reactor.

Oxidation Control

The oxidation rate is a critical parameter to control for high end to end yields. Due to the exponential dependence of oxidation rate on Al concentration conventional methods of determining the Al fraction do not have sufficient GRR to control the process and instead only see major deviations from target. IQE has installed oxidation capability and is currently correlating IQE oxidation rates with customer rates to be able to specify absolute oxidation rates.

Yield Improvement Activities

As shown in table 1, as wafer size has increased and upgraded tools have been introduced the % deliverable area has continued to increase; at the same time the number of failed wafers for reflectance is reduced.

Operational throughput is equally as important as yield and IQE has leveraged its experience in the wireless market sector to improve the run rate, up time and particle performance of its VCSEL tools as part of its continuous improvement activities.

TABLE I
REFLECTANCE % AREA IN SPEC AND REFLECTANCE FAIL RATE FOR SEVERAL REACTOR CONFIGURATIONS

Platform	**Average In Spec Area on Delivered Wafers**
3" G3	85%
4" G3	91%
6" G3	93%
6" G4	94%

Mega Foundry

To address the high demand for VCSEL epitaxy wafers IQE has invested in a new factory in Newport, based close to its Cardiff manufacturing site. Drawing on experience designing previous epitaxy manufacturing facilities the site has been designed to have a modular layout to enable the installation of additional tools without affecting the operational factory. The site can accommodate up to one hundred growth reactors.

The site has been designed with volume manufacturing in mind. The flow of wafers out of the growth tools, through the in-line metrology tools and to shipping is such that wafers have few moves as they flow through the characterization clean room, never moving against the flow.

Currently IQE has ten Aixtron 2800 G4 reactors installed all of which are currently configured for VCSEL growth. Five tools are ramping into volume production and a further five tools will enter the qualification stage shortly.

Conclusions

We have described the challenges for volume manufacture of 150mm VCSEL epi-wafers and our solutions to them. Our solutions include a formalized reactor matching procedure, new characterization tools and investment in a ‘Mega Factory’ to meet the volume demand of the market.

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Acronyms

VCSEL: Vertical Cavity Surface Emitting Laser
SIMS: Secondary Ion Mass Spectroscopy
eCV: Electro-chemical Capacitance Voltage
ISM: Insitu Monitoring
MES: Manufacturing Execution System
OCAP: Out of Control Action Plan
GRR: Gauge Reproducibility and Repeatability