Managing Process Diversity for Opto Wafer Fabrication in a Photonics Foundry

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Abstract

Opto manufacturing at foundries is now feasible and becoming highly advantageous in cost and performance. Unlike the IC foundry, however, there are significant challenges unique to the operation of opto foundry. That is, the diversity of the opto devices with custom designs, which directly impacts how a foundry functions and how customers are served. In this paper, we will report GCS' experience and progress in opto foundry practice for the past 10 years.

INTRODUCTION

Optical devices have traditionally been produced by IDM companies in dedicated, internal 2-3" wafer fabs in a relatively small volume. Evolution in the supply chain of III-V substrates, epi-growth, and wafer fab has changed the landscape for the opto fabless companies and IDM alike. Running opto foundry in an RFIC fab has the advantage of leveraging synergy in equipment, infrastructure, quality discipline, and manufacturing system. The advantage will be particularly obvious as the opto industry moves further to PIC with more integrated functions. Not only can the development efforts of opto wafer process be minimized, production cost can also be reduced from sharing of fixed operational costs and the economy of scale in higher IC wafer volume. From the production point of view, RFIC foundry has a relatively easier logistics compared with opto. RFIC foundry serves in a leader's position by providing proprietary epi and design kit, whereas customer's involvement is in circuit design according to foundry's published design manual, thereby a follower. This leader-follower role for opto foundry is completely reversed; opto foundry faces the tough job of following different leaders (customers) who tend to lead to different destinations. For instance, opto customers typically consign their custom-designed epi-wafers to foundry. Such epi can have drastically different epi-structures and be on a variety of substrates such as Si, Sapphire, SiC or GaSb in addition to the mainstream GaAs and InP. The substrate wafer varies in sizes of 2 to 4", and can be of US or EJ cut, which affects wafer process such as wet etch with crystal orientation preference. Different epi-structures often lead to different process flows and number of mask layers.

GCS opto foundry's success in the past 10 years came largely from the efforts to sort out divergent customers' requirements and make them compatible, synergetic, and production worthy at low cost by modular process approaches. In the process, a growing library of process recipes has been accumulated to serve ever more demanding custom designs. The customized nature of opto processing requires small batches and close engineering supervision, at least initially. However, ultimately for larger scale manufacturing the demanding cost, quality, and process specifications argue for a larger scale infrastructure (tools and people) than can naturally be supported by the still relatively small volume of wafers. GCS, with its medium-scale RF processing infrastructure, meets this "not too big, not too small" sweet spot perfectly.

Meeting Opto Foundry Challenges

Efforts to standardize in opto processing at GCS have had mixed results. For instance, most customers are receptive to ohmic metal stack consolidation after the empirical data is reviewed and understood. This makes it possible to run cost effectively by batching multiple lots and wafers in a single e-beam evaporator run. Exceptions exist where device performance dictates the use of special metal recipes or in situations such as legacy products where the cost to re-qualify the product outweighs the saving from mainstream process. In most other processing steps, however, standardization is often futile as it runs counter to endless, unique innovations that drive the opto industry. As a consequence, each process flow is likely to have etches, for example, that have different requirements on depth and sidewall angle, plus the epi multi-layers are likely slightly different, which affects the etch parameters.

Different substrate types and substrate sizes require different handling techniques with respect to

wafer fragility and breakage, which are hard to deploy at high yield across dozens of people. GCS approaches this by segregating processes to a more select group of operators and technicians until the volume is sufficient to require a larger group. Different substrates also require custom tooling. GCS is perhaps the only fab in the world that runs well three different wafer sizes through a 5x reduction stepper. Likewise, three wafer sizes are run through the same load-locked ICP etchers and PECVDs.

Small batches and customization result in an explosion of mask sets: GCS's opto fab runs hundreds of different mask sets on dozens of different process flows. All of these challenges are different flavors of the difficult customize vs. standardize/automate tradeoff. The solution cannot be reduced to any one formula but it relies on a dedicated group of flexible engineers and technicians working closely together. As a critical part of the production fab system, mask ID and layout revisions are strictly controlled by refined procedures following years of trial and error. Each customer-consigned epi is given a unique P/N to facilitate wafer inventory and Lot start management by Production Control.

Examples of Challenge and Accomplishment

A few examples of specific challenges in selected process modules are given here.

Photolithography

Resist lithography is one of the most critical areas concerning the opto wafer fabrication process. Wherever appropriate, projection stepper is employed for its advantages of high resolution and exceptional overlay precision with pristine and defect-free results. As an example shown in figure 1, laser gratings with 0.06um spacings in third-order design pitch are produced using i-line steppers in our Photo process module. This is the result combining customer's unique epi-structures and mask layout design with GCS' innovative fabrication process. In another case, 2" wafers are routinely processed with a 2mm exclusion zone despite photoresists as thick as 15um, also through i-line steppers.

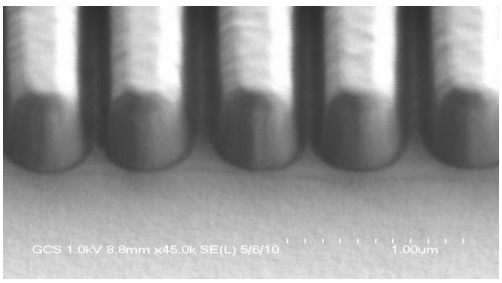

Figure 1. Laser gratings with 0.06um spacings.

Etch and Thin Film Processes

Some cutting edge opto processes approach what might be described as "InP MEMs". Production process utilizing dry and wet etches as deep as 30um and 65um, respectively, into InP-based epi-layers have been run with good yield and consistency. Needless to say, wafers with such topology pose a great challenge for ensuing process steps, but overcome with creative process approaches. Another example involves processes that require step coverage over 5um vertical features by metal layers over 1um thick, patterned by liftoff. PECVD dielectric layers more than 3um of thick is not unusual, and typically need to be etched through for vias.

Process Integration

While an attempt is made to use standard SPC techniques whenever possible, sometimes the process requirements are not achievable without targeting runs. In that case, customized process parameters are dialed in wafer by wafer. An example is the process shown in Figure 2, where a PECVD oxide multi-layer thickness is required to vary with previous InP etch depth wafer by wafer so that vertical alignment to the etch is achieved to within ±50nm. The only way to check such an alignment is to destructively cleave and SEM, which of course cannot be done routinely in production. GCS has processed hundreds of wafers without a test failure being attributed to poor vertical alignment of this highly challenging process. Using the basic building block of process, another customer's sophisticated design was implemented to produce skyscraper-like device structures by successive masks and etches with tight lateral overlay accuracy.

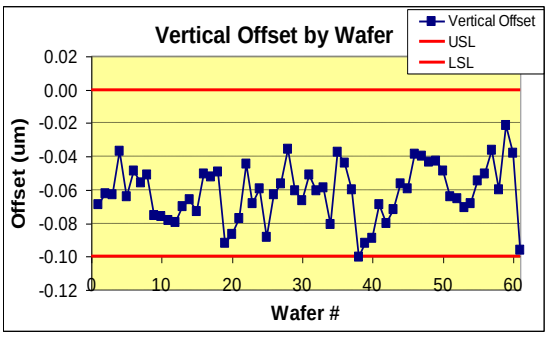

Figure 2. Laser vertical offset SPC.

Lot Execution

As part of GCS' fab system, opto wafers are managed with close coordination among several functions. On the one hand, process module engineering takes care of Work Instruction and daily

SPC associated with specific equipment and process recipes. On the other, opto process integration engineering issues process followers and oversees daily lot progress by tracking the result of each step. In contrast to RFIC production lots, which run more in autopilot mode, this is where the dispositioning procedure for opto lots differs. Production Control takes inputs from Sales and assigns priority for each lot started. Fab supervisors under Operations orchestrate lot movements with the production crew according to the priorities passed down by Production Control. Built on the solid foundation of RFIC production system, process module engineers and opto process integration engineers worked hand-in-hand to develop new processes as well as train production work force - to the high skill levels required to perform opto wafer moves. This is a daunting task that takes years of intensive efforts. In addition to serving as lot owners internally, opto process integration engineers also have to take on another role distinctly different than that of RFIC. That is, to interact with customers on practically every stage of the project, from reviewing customer's epi-structures and layout design, to taping out photomasks by working with CAD engineers, and to developing process flow and executing short loop process validation before formally launch deliverable lots. Those are, in essence, the engineering labor-intensive part of the opto foundry business

Opto Foundry Project Examples

A few examples are compiled here. Figure 3 is an example of different VCSEL fabrication process designs and GCS' solution to meet such requirements. Figure 4 shows an opto device that highlights GCS' sophisticated fabrication process capability. Still other examples are shown in Figures 5 and 6.

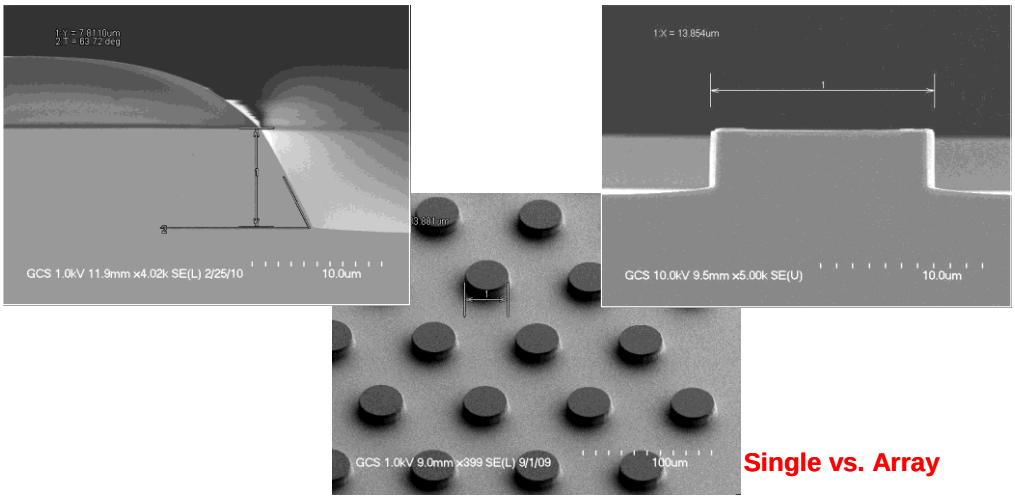

Figure 3. Different dry etch recipes to satisfy different "VCSEL" design requirements for vertical vs. sloped mesa sidewalls and single element vs. arrayed device.

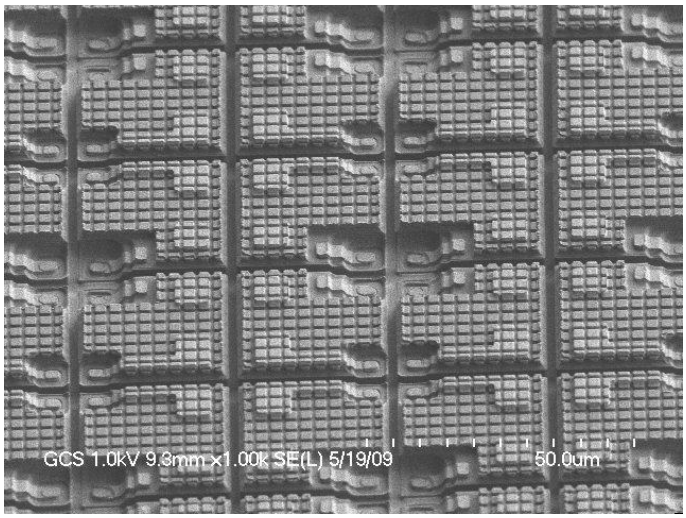

Figure 4. Opto device with 10-15um sloped or vertical sidewalls for continuous interconnect metal step coverage.

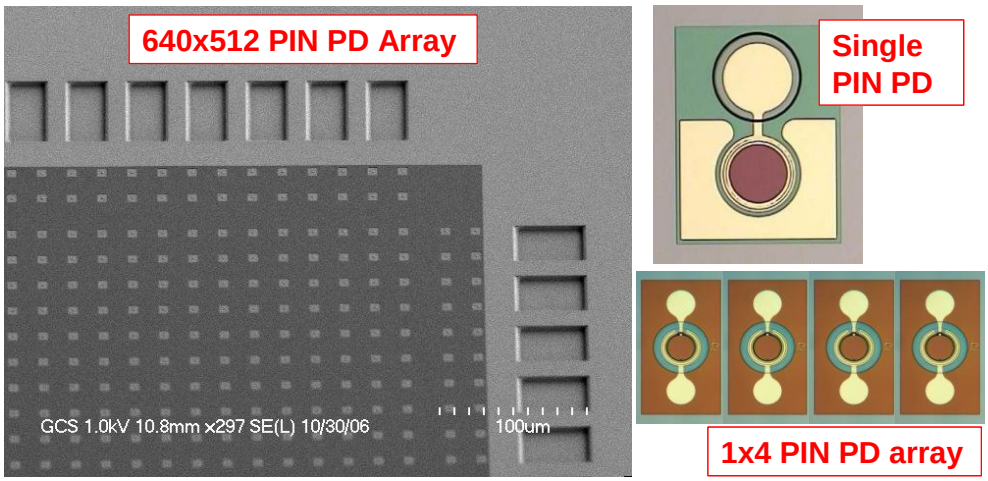

Figure 5. InGaAs PIN PD process - from simple discrete device to complicated large format imaging array.

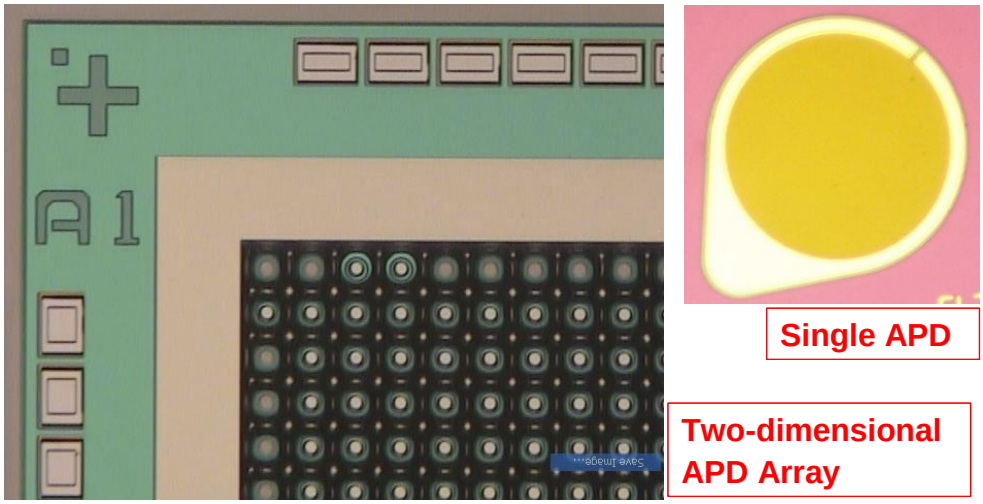

Figure 6. APD process module can produce discrete APD as well as large format two-dimensional APD array.

CONCLUSIONS

More than a decade has passed since GCS launched opto foundry services business. Like its Si and III-V IC industry predecessors, fledgling opto foundry model has taken shape. Groundbreaking work toward a production-worthy opto foundry fab management system open to the public as presented in this paper has been refined over and over again in the past years. GCS opto foundry is now serving a long list of customers, routinely producing a wide variety of photonic devices that serve consumer, industrial and military markets. Success is evident from opto customers' satisfaction.