Optical Device Wafer Manufacturing in an IC Foundry

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ABSTRACT

The new millennium marked the beginning of a long slump in the telecom market. Hardest hit was the optical fiber communication sector. Costs and performance finally replaced the hypes similar to the Dot Com fads to become the fundamentals of a successful business. Technology advancement and market pressure combined to create a timely survival kit for optoelectronics players: the foundry. In this paper, we present the methodology, practices, and results of optoelectronics foundry manufacturing services at GCS in a compound semiconductor IC fab environment.

INTRODUCTION

While the III-V compound semiconductor IC industry is fast catching up in recent years the concept of foundry manufacturing modeled by the Silicon precedent, the Photonics side of the optical communication enterprise lags far behind in adopting this practice. Historically, optical devices have been produced by IDMs in dedicated 2-3 inch wafer fabs, with little wafer volume to speak of by IC industry's standard. Recent advances in substrates, epi-growth, and wafer fabrication technologies in GaAs- and InP-based optical devices have changed the landscape for the fabless and IDM alike -- manufacturing optical devices in a 4 inch fab foundry is not only feasible but also highly effective in costs and performance. The current severe market downturn further magnifies the advantages of a fabless-foundry team approach.

Over the past three years, we at GCS have been developing and steadily expanding our optoelectronics foundry menu. A major advantage of using compound semiconductor IC fab for optoelectronics foundry is due to the synergy in processing equipment and process modules. Not only can the optoelectronics manufacturing process development costs be minimized, the production costs can also be greatly reduced due to sharing of the fixed costs and the economy of scales from higher IC wafer volume. As our core IC (HBT and PHMET) fabrication services lead the way to constantly push for better technical capabilities and tool set upgrades, the optoelectronics foundry stands to benefit from the resulting new fabrication processes and the strong engineering team behind it. By leveraging its wide knowledge base, GCS has played a key role in helping Opto customers to achieve short design cycle time for numerous novel optical devices. Although our primary mission is wafer fab, we provide assistance to our customers using our expertise in epi structure design, device layout, process integration, and other custom support, which is a critical part of our overall foundry services. Quality and consistency in optical wafer delivery are enhanced by the IC production environment, manufacturing discipline, and quality control infrastructure.

OPTO FOUNDRY PRACTICE

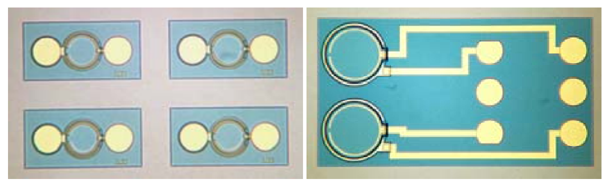
One of the challenges in running the Opto foundry stems from the wide variety of optical devices and hence the numerous fabrication process variations. Unlike the IC counterpart, where the processes are well standardized and rules published, the nature of different optical devices, ranging from detectors to lasers, and modulators or amplifiers in between, makes it impractical to do the same. The initial interactions between the customer and the foundry would focus on understanding the optical products to be fabricated. Based on specifications of generic device properties from the customer, the foundry would prescribe a suitable process flow and PCM ensemble for review, a critical function for the foundry application engineers. While the process flow can differ from project to project, with few exceptions, individual basic processing steps are drawn from the "standard" process modules, such as photolithography, metal and dielectric thin films, dry and wet etches, wafer thinning, and scribe-and-break. This modular process approach takes advantage of the commonality of individual fabrication process steps while delivering custom-design services. Managing the low volume, customized process flow optical wafer fabrication in a high volume IC production line is understandably a challenging learning experience, requiring close coordination between manufacturing and engineering groups. GCS has demonstrated the feasibility and successful implementation of this approach.

Examples of Opto Foundry Projects

A few examples of the Opto projects fabricated in GCS' IC foundry are presented here, including device performance, SEM pictures, and yield statistics.

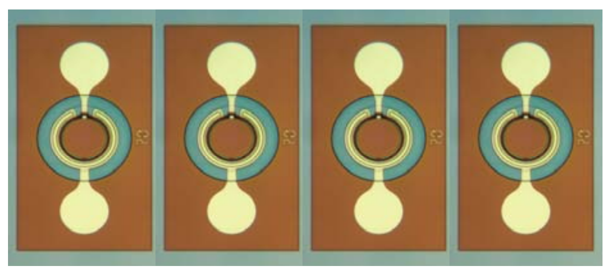
PIN Photodetector (PD)

GCS Opto process produces PIN PD's for 850nm detection fabricated on GaAs epiwafers and for 1310-1550nm detection on InGaAs/InP epiwafers. Figure 1 shows pictures of GaAs mesa PIN PD (a) and InGaAs mesa PIN photodetector array (b) on 4-inch GaAs or InP wafers for high-speed optical datacom and telecom applications. These mesa PIN PD's offer lowest possible capacitance which in turn achieves state-of-the-art performance of 23GHz bandwidth with 0.9A/W responsivity, Fig. 1(c), and 0.1nA dark current, Fig. 1(d), for an active area of 18 μm in diameter. A planar version of the photodiode process serves the lower data rate receiver and laser monitor market.



850 nm Photo-detection
Responsivity: 0.55 A/W
Dark Current: < 100 pA
Data rate: 1-10 Gbps

Figure 1(a). GaAs mesa PIN PD.



1310/1550 nm Photo-detection
Responsivity: 0.9 A/W
Dark Current: < 0.5 nA
Bandwidth: 9GHz (40μm dia.) - 23GHz (18μm dia.)

Figure 1(b). InGaAs mesa PIN PD array.

Quantum Well Infrared Photodetector

Figure 2 shows SEM pictures of the top view (a) and cross section view (b) of a GaAs/AlGaAs quantum well infrared photo-detector (QWIP) in a 640x512 array for infrared imaging applications. Its deep vertical sidewalls were accomplished by room temperature ICP dry etching.

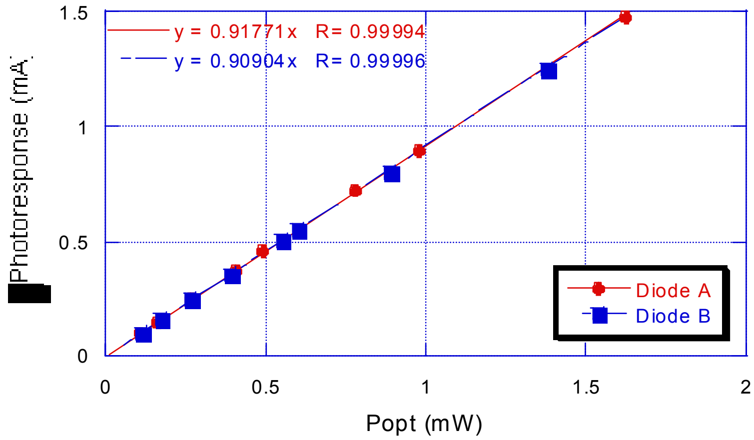


Figure 1(c). Responsivity: slope = 0.91 A/W at 1310nm.

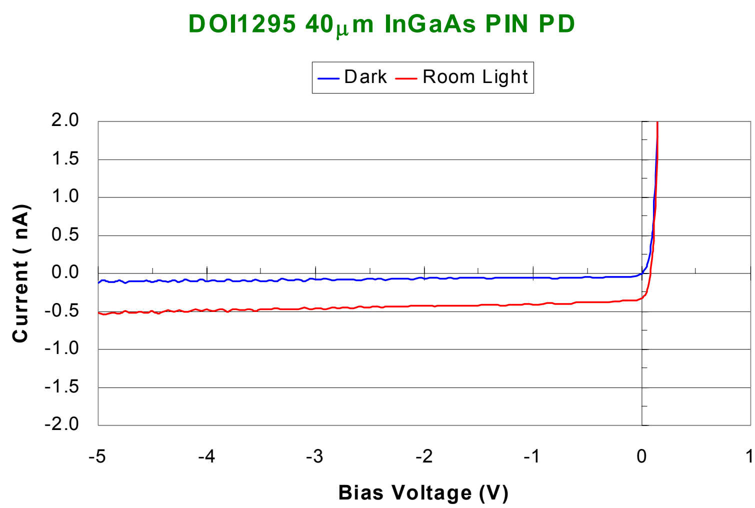


Figure 1(d). Dark current of InGaAs PIN PD.

Semiconductor Optical Amplifier

Another example is the InP-based quaternary ridge waveguide (RWG) device, shown in Figure 3(a) and (b), for applications such as SOA and wavelength converters. The clean, smooth sidewalls and floor, crafted by high temperature ICP etching through InGaAsP quaternary layers, are crucial for high performance of the devices. Figure 3(c) shows the typical L-I-V curves of a 9.6 μm ridge-width device. The wafer die yield is summarized in Figure 3(d). Visual and functional die yield is clearly much better from GCS' 4-in Opto foundry than from the other dedicated 2-inch Opto fab.

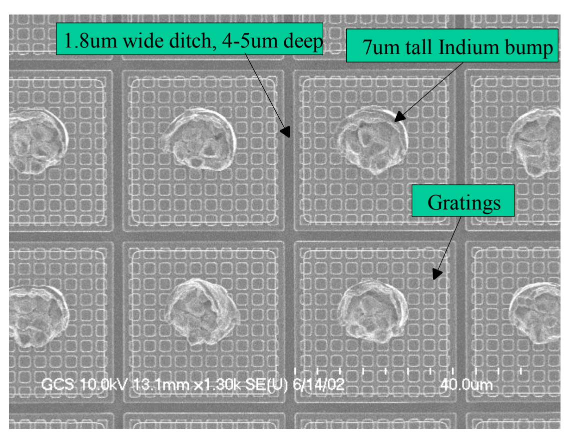


Figure 2(a). QWIP Top View SEM.

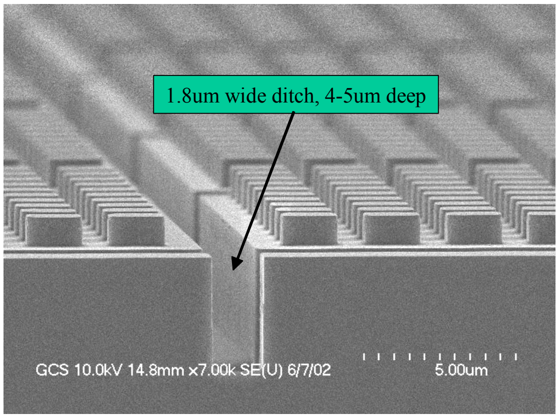


Figure 2(b). OWIP Cross Section.

CONCLUSIONS

We have discussed in this paper the manufacturing methodology and practices of GCS' Opto foundry services in a compound semiconductor IC fab environment. Built on modular fab processes and leveraging the wide knowledge base with IC production discipline, GCS' Opto foundry has demonstrated the reproducibility of superior optical devices and the viability of efficient, cost-effective services to the fabless as well as IDM Opto user community.

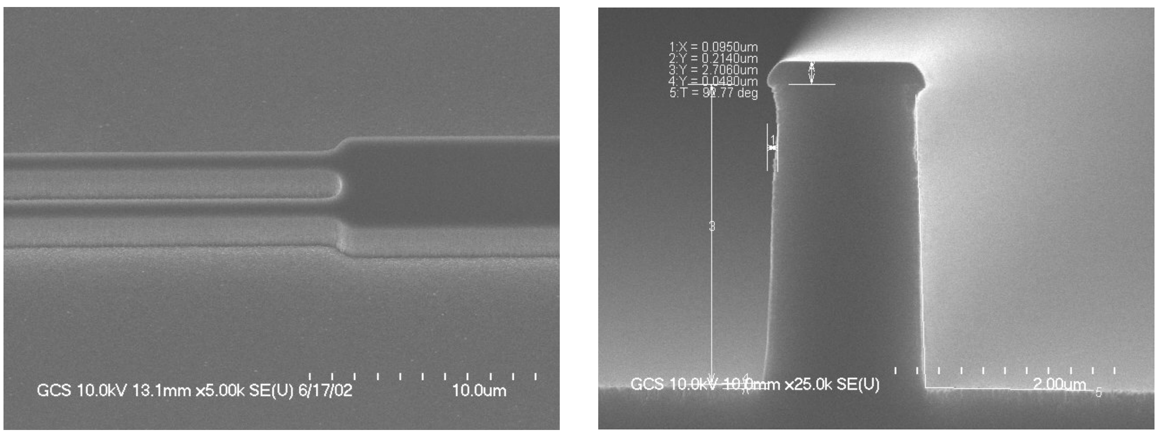
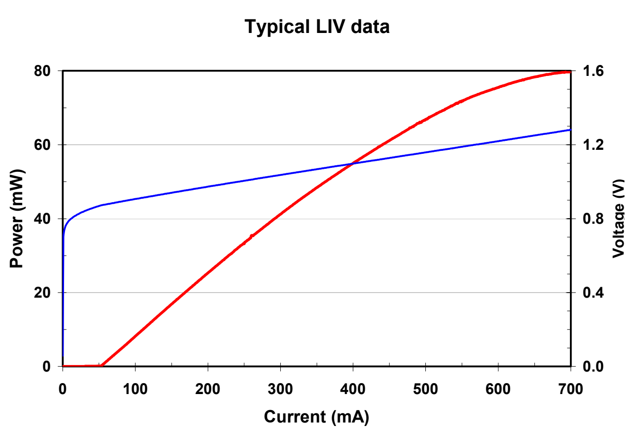


Figure 3(a) and (b). InP-based ridge waveguide device.



- **Wafer Visual Yield**
  - GCS: 94-95% (c.f. Control: 80-92%)
- **"Dead or Alive" Yield**
  - "Dead" defined by P_{max} < .25 (P_{max} median)

Length	430 µm			865 µm			1730 µm		
RW (µm)	1.6	2.0	2.4	1.6	2.0	2.4	1.6	2.0	2.4
Yield (%)	96.9	98.4	90.6	98.4	98.4	98.4	100	100	100

  - c.f. Control 10: 90.2%

Figure 3(c). Typical L-I-V curves of 9.6 µm ridge width devices fabricated at GCS; 3(d) GCS wafer visual and functional die yield statistics of InGaAsP/InP ridge waveguide devices as compared to the control from another 2-inch Opto fab.