A Case Study in Support of the Captive Fabrication Facility

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Abstract

Conventional wisdom and a large body of data suggest that a captive fabrication facility is not a cost effective or technically sound business decision. This paper will present the contrarian viewpoint that there is a rationale for a niche, captive fabrication facility. Motivating factors like the nature, quantity, variety, and cycle time of the product will be presented. The operational challenges and decisions - including facility and tooling, metrics, and other engineering considerations - that have been made over a decade will support this alternate model and justify the vertical integration of semiconductor device fabrication in a mm-wave and THz test and measurement company.

INTRODUCTION

In high volume manufacturing (HVM) applications, the foundry model has been proven for silicon and is increasingly common for GaAs and other III/V applications. Companies like TSMC and WIN are the most prominent examples. Economies of scale govern in this paradigm and the ability of a foundry to serve multiple customers with multiple processes makes technical and business sense. On the other end of the spectrum, with low volume, niche production (LVNP), the assumptions that give the foundry model an edge are not necessarily valid. Over time, and if successful, the captive fabs that support these niche technologies may eventually morph or be subsumed into a foundry model, but this does not mean for some transient period it does not make sense for them to exist and be successful.

Virginia Diodes, Inc. (VDI) started as a spin out company from the University of Virginia (UVA) in 1996. The original, and current, mission of VDI was to make the terahertz region of the electromagnetic spectrum as useful for scientific, military and commercial applications as the microwave and infrared bands are today. Initially, VDI focused on providing scientists and engineers (mostly in the radio astronomy community) with diodes they could use for frequency multiplication and mixing. Eventually the customer requested that the diodes be integrated in waveguide based components or packages and then into complete transmit and/or receive systems or radios. The diode fabrication continues today with most parts being used in the test and measurement products that VDI provides to the mm-wave and THz industry.

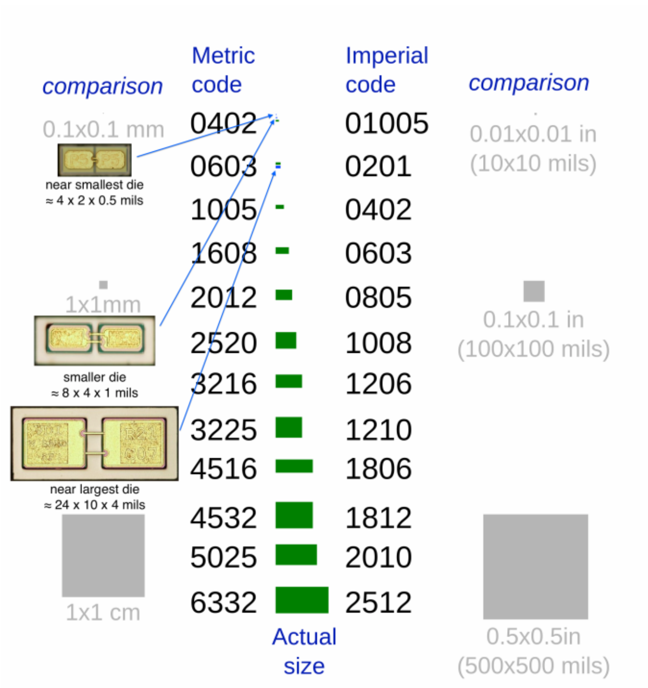

Figure 1. VDI die size comparison. [1]

MOTIVATION FOR STARTING A FABRICATION FACILITY

When VDI started, it was a two person weekend and part time operation. The rational for fabricating diodes in a prototyping manner was that this was how the processing was being done at the university and so there was no reason to change the process. Space and time was rented from the university in a manner similar to most small businesses like this. As VDI matured and started integrating its diodes into higher level assemblies and selling more diodes, the decision of whether to continue on in a university setting, outsource the fabrication to a foundry, or invest in it's own cleanroom had to be addressed. The physical size of the diode product, the low volume of many different parts, and the need for quick design to product cycle time were major factors in the decision making process.

mm-wave and THz diode products historically are waveguide based. For diodes used as multipliers or mixers, parasitic impedances limit device performance particularly as frequency increases. Diodes that are either flip chipped onto, or integrated with, mm-wave and THz circuit traces outperform diodes integrated into MMICs. The die size also scales with frequency. That means that working between 50 GHz and 3 THz, die size range between something comparable to 0402 and much smaller than that (Figure 1). For the smallest size die, this means that a 4 inch wafer would produce 10k to 100k or more die, most of which would go unused over the lifetime of the product. At 0402, singulation techniques used in a conventional fab, such as thin then dice, are viable, but as die size moves to something on the order of 50 x 100 x 10 µm singulation has be accomplished by a more specialized process like dice before grind (DBG) with a manual collection. Both the volume of parts and singulation concerns lend themselves to processing with smaller substrate sizes and practically that means fabricating with pieces of wafers instead of whole wafers.

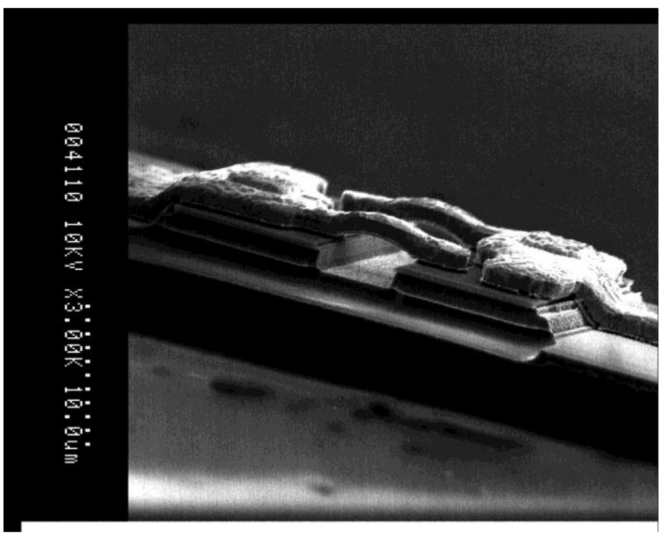

Figure 2. Extremely thin die.

In addition to the high number of parts that can be fabricated from a small amount of raw material, there is a low volume of these parts required in the higher level assemblies in which they are placed. This does not mean, however, that the number of part numbers/types is correspondingly low. Parts have to be designed and fabricated specifically for each of the dozen or so bands within the THz spectrum. This frequency scaling per part leads to a large library of part numbers/types. Having this library of parts fabricated at a foundry, is not cost effective and limiting the library would constrain the performance of the higher level assemblies (components and systems).

VDI has, and continues to, innovate quickly in the THz market, with the primary driver being an improvement in the amount of power, sensitivity and bandwidth that can be extracted from the diodes. A prime factor in the innovation speed is the design to device cycle time. Using design tools like HFSS, a THz trace with integrated diodes can be transferred to mask and the fabrication completed typically within 3 months and much faster, 4 to 6 weeks, if necessary. Achieving this speed using an outside activity would be challenging and costly.

Finally, as expected with most niche applications, there is some special processing that allows VDI's product to achieve the industry leading performance that it has. One example is the capability to produce extremely thin die on the order of 5 µm thin (Figure 2). VDI operates as a trade secret company and protection of intellectual property (IP) is therefore a priority. Though foundries operate with protection of IP as a top concern, not releasing IP gives more of a guarantee that it will not get into the public domain.


Figure 3. VDI fabrication facility.

Taken separately, the above motivations do not necessarily make a case for operating a captive fab. Taken together, they play off of each other and create a strong case. For instance, for some of the higher frequency parts where a practically endless supply of parts are created from even a piece of a wafer, another design of parts can be quickly turned with negligible impact to the bottom line.

SUCCESSFULLY OPERATING A NICHE, CAPTIVE FAB

Based on the above motivations, VDI started a captive fab and has been successfully operating it for a decade, both in terms of successful product and the bottom line. During that decade, VDI has grown every year on a year on year basis. Captive fabs can and have been a drag on many companies in the past, but VDI has been successful due to proper planning and some key decisions.

The fabrication facility and tools in it were scaled to the size of the product. Instead of buying a 3 or 4 inch GaAs processing line and adapting it to the product being produced, the facility and tools were considered on an individual basis. The fab itself occupies 1200 sq ft of ISO 7 (class 10K) space (Figure 3) with appropriate chase space and associated dirty (grinding) process space. It is operated and maintained with a team of 6 to 8 engineers and technicians. The facility looks like a failure analysis lab at a larger semiconductor manufacturer from the outside perspective, but is equipped for photolithography, dry etching, wet etching, and deposition techniques.

A copy exact “lite” strategy was used to replicate the tools and resources that were used when renting space and time at UVA. In most cases this meant finding, and sometimes refurbishing, vintage bench top and rack mounted tools. All of the tools are either manually or semi-automatically operated, with no autoloading capabilities required. Since the initial outfit, tools have been kept on a planned maintenance schedule and upgraded or replaced as necessary. In appropriate cases, when new bench top type equipment has been brought to the market, it has been purchased.

Coming from a university, proof of concept type culture, it would have been easy to continue on in that manner and not compile process and end of the line statistics. Instead, VDI chose to use combination of statistical data, engineering knowledge, and small business acumen to make fabrication decisions. Key process and end of the line data has been taken consistently since the fab was started. With the low volume and high number of different parts, the statistical analysis that is used is challenging and does not always conform to stringent statistical rules implemented by larger fabs.

Statistical data has been used to perform tool qualification, track process variation, build specifications, and make decisions on new tool requirements. For example, a programmable hotplate was qualified for anneal of ohmic contacts. A process skew across temperatures was conducted and contact resistances were measured, the data was analyzed and a final process determined (Figure 4).

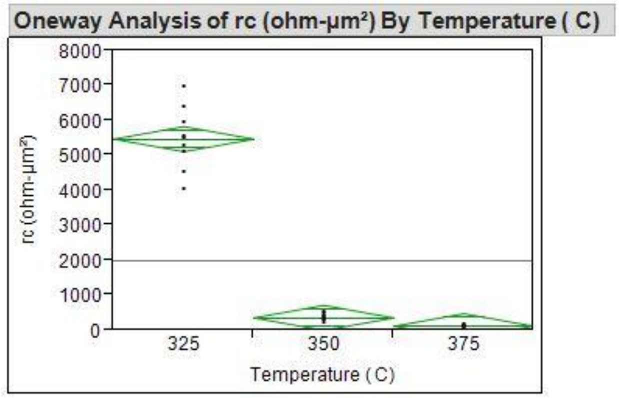

Figure 4. Typical tool qualification Oneway ANOVA.

An interesting example that highlights the large number of products, but low volume is tracking of DC electrical data (reverse breakdown in this instance) over different products and lots (Figure 5). In this instance that data showed certain lots had lower breakdown voltages than would typically be expected. This analysis prompted process changes that were qualified and made to compensate for this change.

In a final example, statistical data has been used to determine that a new tool was required. The difference between a design dimension, and the associated as fabricated dimension, is tracked by lot number (Figure 6). Based on the lot to lot variability, an engineering decision was made that the end of the line electrical data would be less variable, lot to lot, if the printed dimension were less variable. A new lithography tool was purchased.

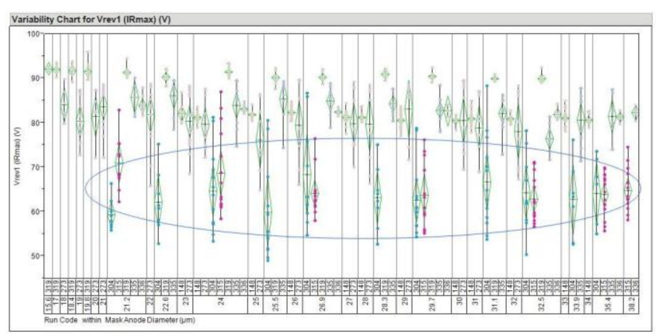

Figure 5. Lot variability chart.

Focus on providing a consistent product to the rest of the company has been maintained by being disciplined in the diode fabrication. A Manufacturing Executive System (MES) was set up using a collection of off the shelf software products like Microsoft Excel and a commercial Manufacturing Resource Program (MRP) so processing was not allowed to drift. In an ISO type fashion the processing for each piece of wafer is defined and then executed as defined. This discipline to not tinker with the tools or the process has allowed the fabrication group to not get sidetracked and focus on real problems.

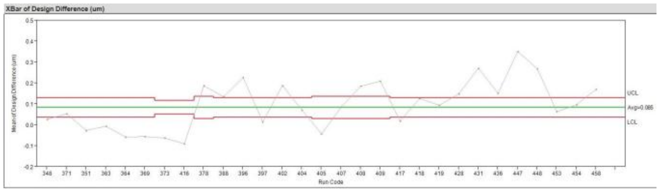

Figure 6. SPC chart.

An additional part of that discipline has been maintaining the tools and keeping the facility clean. Since starting the fab a decade ago, VDI has operated a planned maintenance system that includes employee and vendor based maintenance. This is sometimes overlooked by smaller organizations and has helped avoid unscheduled tool and line down situations. In addition to keeping the fabrication facility tidy on a day-to-day basis, semi-annually the fabrication group completes a top to bottom cleaning of the facility. This type of attention to detail and discipline may seem silly to some, but it is crucial to maintaining and improving fabrication capabilities.

VDI has continued to focus on producing diodes and has not gotten distracted by moving into areas where there is known technology and products. There are two components to this. One is not trying to produce products, transistors for instance, for which the fab is not equipped and for which the company does not have the expertise. Amplifiers and other mm-wave components that are used in the frequency extension modules that VDI produces are purchased from a host of established vendors. Broadening the fabrication efforts to include a product that is more suited to HVM does not make technological or business sense.

The other component of staying focused on a core competency is to know when to outsource activities. Staying aware of the market, including attending shows like this and IMS, gives visibility to changes in other companies capabilities. For instance, the opportunity recently arose to have a vendor pick and place some of the larger, more frequently used parts. The pick and place tool did not need to be purchased, but the ability to accomplish pick and place with these larger parts was demonstrated. Another example of a slightly different form of outsourcing deals with gold plating solution. Instead of spending valuable engineering time on regulating the solution’s chemistry, it is purchased as a ready to use solution, used for a short period of time, and then reclaimed.

On the flip side, if it becomes obvious from a quality or throughput perspective that insourcing a process is the sound technological or business decision, then VDI is ready to do that as well, as long as it doesn’t take us away from the core competency of fabricating world class THz Schottky diodes.

Conclusion

For a decade VDI has been fabricating diodes in an appropriately sized, captive fab. The diodes are placed in waveguide packages (or blocks) for use as frequency upconvertors or downconvertors. The waveguide blocks are placed alongside other mm-wave components to produce full transmit and receive systems. VDI has a line of frequency extension modules, with the diodes at their core, that extend the capabilities of vector network analyzers, signal generators, and signal analyzers to above 1 THz. These high end THz test and measurement systems have been and will continue to serve the general mm-wave and THz communities. As mm-wave communications gain momentum, VDI’s extension modules will be used increasingly by the compound semiconductor community to test high frequency MMICs. That the core technology behind these units is based on compound semiconductor technology seems fitting.

It is unknown how long the mm-wave and THz industry will continue to be a niche part of the microwave industry. Correspondingly it is unknown how long it will be justified, from either a technological or business point of view, for VDI to run a captive, niche fabrication facility. VDI has shown, through a decade of business success, that in the correct environment the LVNP model is sustainable.

Acknowledgements

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References

[1] Base image copied from http://en.wikipedia.org/wiki/File:SMT_sizes,_based_on_original_by_Zureks.svg

Acronyms

HVM: High Volume Manufacturing
LVNP: Low Volume, Niche Production
VDI: Virginia Diodes, Inc.
UVA: University of Virginia
DBG: Dice before Grind
HFSS: High Frequency Structural Simulator by Ansys
MES: Manufacturing Execution System
MRP: Manufacturing Resource Program