ADVANCES IN LOW-COST COMPONENT MANUFACTURING: AVANTEK'S DIE MANUFACTURING FACILITY IN NEWARK, CALIFORNIA

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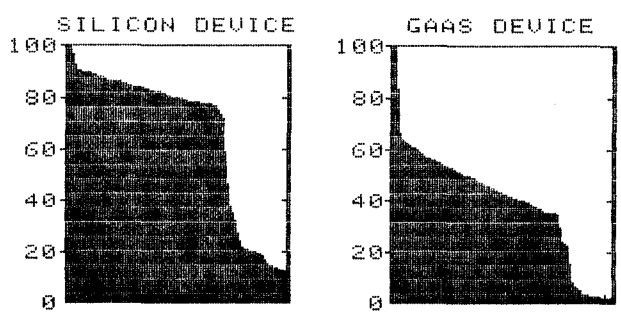
ABSTRACT

The microwave semiconductor industry is changing. Unit demand is rising and pressure to reduce price per function follows. If the industry is to meet these challenges, it must evolve rapidly. Analysis of the digital silicon industry may provide clues as to how to proceed.

INTRODUCTION

In discrete microwave semiconductor die production with its small chip sizes and two-inch wafers, it is not uncommon to print in excess of 20,000 chips per starting wafer. Unfortunately, it is also not uncommon to sell only a very small percentage of the total chips started to the customer. Total process yield, measured in unit ships per wafer start (US/WS), ranges between one and ten percent. By comparison, the digital silicon industry (DSI) US/WS values commonly run from 50 - 70 %. This order-of-magnitude difference in total yield reflects directly on product cost. Today, a 64K DRAM costs approximately $.40 to build; a discrete low-noise GaAs transistor costs approximately $4.00 by comparison.



TYPICAL MICROWAVE PROCESS YIELDS
(CUMULATIVE BY STEP)

If the microwave semiconductor industry (MSI) is going to grow and mature from a research and development "laboratory" environment building one-of-a-kind oddities into a modern factory environment building thousands, hundreds of thousands, or even millions of specific products it must evolve. There are parallels to be drawn between DSI and MSI, and perhaps lessons to be learned.

GENERAL FLOW

A typical microwave semiconductor manufacturing flow runs as follows:

materials production (epitaxy and/or ion implantation);

wafer fabrication (photo-lithography, thin film depositions, etching, etc.);

wafer sort (DC characterization of every die on whole wafers);

dicing (saw or scribe/break to separate whole wafers into individual die);

wafer evaluation (DC/RF characterization of a small sample of every wafer built on carriers or in packages);

circuit evaluation (characterization of a small sample of selected wafers -- based on wafer eval results -- built in the customer's circuit);

allocation (setting aside all or a portion of a wafer for a particular customer's specific circuit needs -- usually based on circuit eval results); and

visual/assembly/final test (assembly/test for packaged parts only).

One of the primary differences between MSI and DSI is the evaluation loop. This adds considerably to total processing time, inventory levels and forecasting problems.

ELEMENTS OF CONTROL

Understanding the available control elements is important in any factory. Knowing where the starter is, where the accelerator is, where the brake is, and when to use these controls is factory management. A key measure of the quality of factory control in a semiconductor environment is yield. As previously stated, DSI total process yields of 50 - 70 % are common while MSI total process yields of 1 - 10 % are the norm. In MSI, as in DSI, yield is inversely proportional to product cost (to first order). Clearly these relatively lower yields (and associated higher costs) present an opportunity for MSI manufacturers. Amazingly enough, microwave

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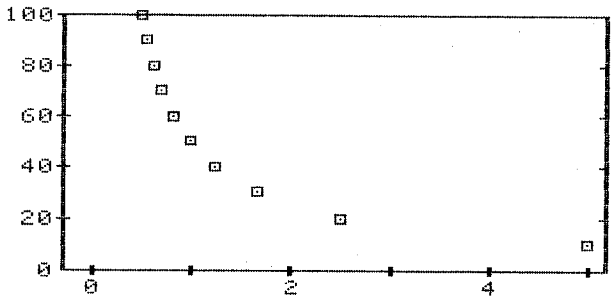
customers are just as interested in price reductions and reduced forward pricing as are DSI customers!



MFG COST VS TOTAL PROCESS YIELD

(IN DOLLARS, FOR $5K WAFER COST)

There are a number of elements which impact product cost through process yield and productivity in a semiconductor factory. All of the following elements have been demonstrated historically in DSI factories and represent "business as usual" for them. The descriptions of these elements and arguments for their consideration in MSI factories follow.

ENVIRONMENTAL CONTROLS

Various factory environmental controls strongly affect the total process yield. Air-born particles landing on a wafer can damage critical geometries on die during photo processing. As the active die area rises (with larger power FET designs or new MMIC designs, for example), this problem is aggravated. Large swings in ambient temperature, coupled with dissimilar coefficients of thermal expansion of wafers and photo masks, result in mis-registration of die during a multiple-layer fabrication process. Humidity outside a fairly narrow range can, at one extreme, cause poor definition during the printing process, and at the other extreme, lead to electrostatic discharge (ESD) damage to work-in-process. Transmitted vibration amplitudes above certain levels can lead to poor-definition problems in critical die features. Vibration in the 2-20 Hz range is particularly harmful because it is so hard to damp out in mechanical systems.

There are also a number of environmental factors that affect productivity more than yield. Factors such as work flow patterns, absolute temperature values, aisle spacing -- even colors in the workplace -- strongly affect worker productivity. These factors may not be exciting from an engineering standpoint, but the results of changes in them can be easily measured, and can be significant.

Control of many or all of these factors will reduce losses and improve factory productivity.

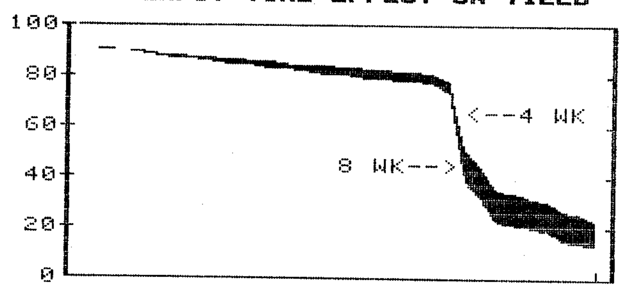
VOLUME EFFECT

DSI factories have recognized the relationship between volume and yield for years: as volume in a line increases, with all other variables remaining constant, process yield increases. These increases are separate from the result of normal engineering improvements. Whether they result from improved operator training or some other factor is not clear, but now that MSI factories are manufacturing some products in sufficient volumes this phenomenon is being felt in our industry too.

THROUGHPUT TIME IMPACT

The apparent inverse relationship between total process cycle time (throughput time or TPT) and process yield is widely recognized in the digital world. While it is equally unexplained in microwave, this phenomenon has been observed and can be used in our industry. Cutting TPT can significantly improve total process yield (as well as reduce inventory costs).

THROUGHPUT TIME EFFECT ON YIELD



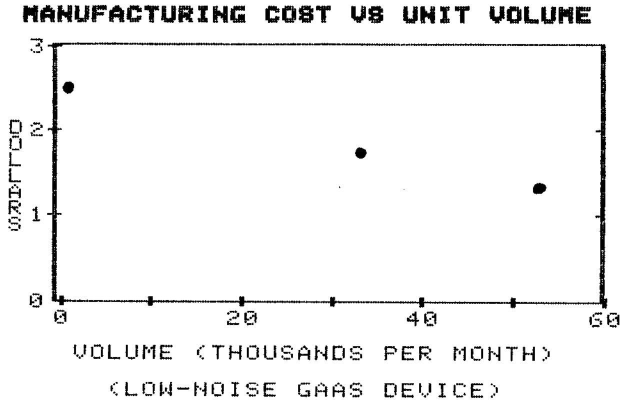
(CUMULATIVE BY STEP)

(VARIED FAB TPT IN WEEKS)

EXPERIENCE CURVE

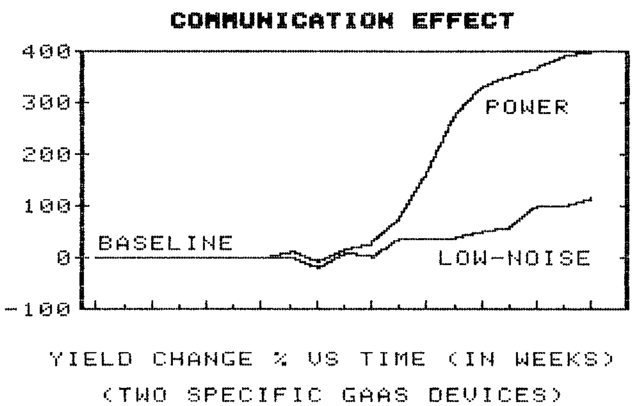
One of the prime tenets of DSI is that added unit volume and time put into the manufacture of any product leads to improved yields and efficiencies, and therefore to reduced product costs. The rate of cost reduction versus time is well-documented and a primary constituent in "forward pricing" strategies so familiar to high volume DSI customers. Again, as MSI manufacturing volumes reach high enough levels, this effect appears in our industry as well. While the rate of cost reduction is not well-defined (there is too little data yet), the trend is clear. The necessary reductions in manufacturing cost per unit function to support continued expansion of our product demand are feasible. This bodes well for the long-term growth and vitality of our industry.

The following chart demonstrates the experience curve effect in practice for a low-noise GaAs transistor over significantly different activity levels (and over a two-year period).



COMMUNICATION

Call it what you like (Hawthorn Effect is popular), defining a goal and communicating it to the entire work force is a powerful tool in the arsenal of yield/productivity improvement. Recently, over a three-month period, specific targets of overall process yield were defined. By focusing on the goals, communicating to every employee their part in the overall task and how the team was progressing on a daily basis, yield and productivity improvements of 200-500% were



achieved. Providing the right tools to do a job is obviously important, but communicating intensely via small group meetings to draw on the human resources available in a factory is probably the single biggest impact that can be had.

FACILITIES

Maximizing the available benefits to be derived from the factors described above can most easily be effected in a facility designed to support them. Avantek analyzed the results of five years of intense yield emphasis in our business, coupling a significant amount of DSI experience with 20 years of MSI experience, versus the costs involved. Based on the analysis, in 1985 a $20 million MSI factory was constructed incorporating many elements designed to both facilite further yield and productivity improvements as well as increase our overall manufacturing capacity. This factory was scheduled to go on-line in 1986. However, yield and productivity efforts in the existing factory during construction of the new one resulted in such significant improvements that the new factory implementation date was delayed at least one year. The cost savings represented by this delay (a direct affect of application of the principles described above) exceeded $5 million.

The final table lists design criteria for the new facility actually achieved during construction.

CONCLUSIONS

Microwave semiconductor manufacturing is coming of age. In many ways, MSI is parallelling DSI but is 10 - 15 years behind in manufacturing technology. The lessons of 30 years of DSI processing are being examined for areas of commonality. By making the appropriate choices, microwave can bridge this gap in a short period of time, taking advantage of the lessons of DSI without paying the huge price. Avantek's experience clearly supports this contention.

NEWARK FACILITY DESIGN CRITERIA

ELEMENT	WAFER FAB	LIGHT MFG	OFFICE / SUPPORT
TEMPERATURE	69 +/- 0.5 F	40 +/- 5 % RH	40 +/- 5 % RH
AIRBORN PARTICLES	CLASS 10 0.3 MICRONS	CLASS 10,000 0.5 MICRONS	NA
VIBRATION	< 0.1 MICRON RMS, 0 - 20 Hz	< 0.1 MICRON RMS, 0 - 20 Hz	NA
NOISE LEVEL	NC 65	NC 65	NC 45
SQUARE FOOTAGE			
-- INITIAL	16 K	10 K	42 K
-- ULTIMATE	35 K	25 K	65 K