Optimized Planning and Operation of High Volume GaAs Epi-Wafer Manufacturing Facility

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Abstract

The markets based on the RF devices with low noise, high power, high efficiency and working at high frequency are growing and expanding very quickly. In fact the market experienced a phenomenal growth rate of 200-300% in 1997-1998. The increasing epi-wafer demand drives manufacturers to build high volume (more than 20,000 wafers/year in the facility) Molecular Beam Epitaxy (MBE) production systems with low cost and high device performance. Alpha Industries, one of the leading players in this market with in-house volume production capability, has, over the years, developed a most pertinent organizational structure which involves a constant interaction of a production group and an engineering group with an aim towards the optimization of the high volume production. In this paper we discuss the different manufacturing and operational aspects of the structure to ensure smooth functioning of such systems.

I. Introduction

MBE is considered today as the most successful epitaxial growth technique in the GaAs based manufacturing facilities, as it can provide the critical III-V herterostructures such as HBTs and pHEMTs for the use in fabrication of high-frequency, low-power devices. The effectiveness of MBE systems emanates from the fact that it is generally extremely stable and uniform even when there is a shift in paradigm from 4-inch wafers to 6-inch wafers. However, the high volume and high technology production systems, like MBE, which are quite relevant today in almost any industry, has some unique features which makes it different from others. The most important feature probably is the high-production risk. There are certain special problems associated with the high volume production systems and those are to be addressed properly because they are critical to sustain smooth functioning of the facility. The primary operational constraints are market forces, materials inventory, manufacturing growth/characterization tools, facilities, quality control, technology changes and development bottlenecks. For an MBE facility to operate smoothly and within specifications extensive tests are also to be performed and are to be interpreted by the MBE engineering group for ' Out-of-the-control Action Plan'. Thus all the different problems can be addressed as two major parts, i.e., optimum production problem/facility size problem and the implementation and interpretation of measurement/test techniques.

II. Optimum production problem/facility size problem

The determination of the optimum size of the MBE facility is a very significant problem. The optimum production is determined by the demand and supply interaction. When the demand of the MBE products is very high and the prices become higher due to the scarcity of the available products created in the market. Similarly, when the demand of the product falls, the price also falls. Thus the demand supply curve is always negatively sloped. This particular point gets more highlighted if we keep in mind the Robin's scarcity oriented definition of economics. Since according to that definition the ends or human desires are unlimited and the means to attend those desires are highly limited, so it is very natural to expect that as the demand of a particular commodity increases the price for that commodity should increase.

There are quite a few factors such as demand fluctuations, raw materials fluctuations, inventory problems, scheduling problems, threat from competitors and buyers, man-power problem and facilities problem on which the demand of any commodity depends. These factors affecting the demand of a particular commodity also depend on the nature of the commodity in general, and on the elasticity of the demand in particular. The higher or lower demand of the MBE related products (e.g. the communication gadgets) depends on the general public and cannot be predicted fully. As an example of this we can take the most pertinent one, the cell-phone. Since the cell-phone has to operate at a frequency ~ 1GHz, so the silicon process does not bail out the situation here. So the GaAs chips have to be created, and thus the

MBE facility size should increase with the increase in demand of the cell-phone, which is dependent on the desire of the public to get more closely connected.

For the further discussions, we can consider the fundamental determinants to derive the optimum size of the large-volume MBE facility. As previously discussed, the optimum size of the MBE facility, in a fully competitive market, depends on the cost and revenue (demand) model. The 'Incremental Cost' model (IRR) is necessary to decide on the timing of acquiring additional machine while the 'Break-even Analysis' model is used to decide the throughput of machines within the existing infrastructure. Thus the former method is used to decide on the capability of the facility while the later is used to determine the operational level. The choice of adding a particular type of MBE machine can be objectively determined from such predictive cost models. Once the MBE machine type is determined, the next issue is to figure out operational constraints. We have extensively used the Critical Path Method (CPM) in production to identify the critical path from raw materials (epi-ready wafers) to product wafers (Figs. 1&2). Utilizing CPM, the critical constraint for any particular path can be obtained, while the developmental feedback loop provided by the engineering group, leads to the choice of better and more optimal volume production processes. According to the above model, smooth operation may be achieved by introducing sufficient redundancy.

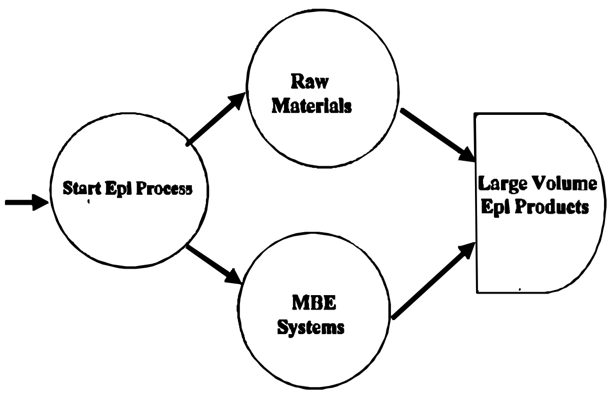

FIG. 1 CRITICAL CONSTRAINTS FOR LARGE SCALE PRODUCTION MBE PROCESS

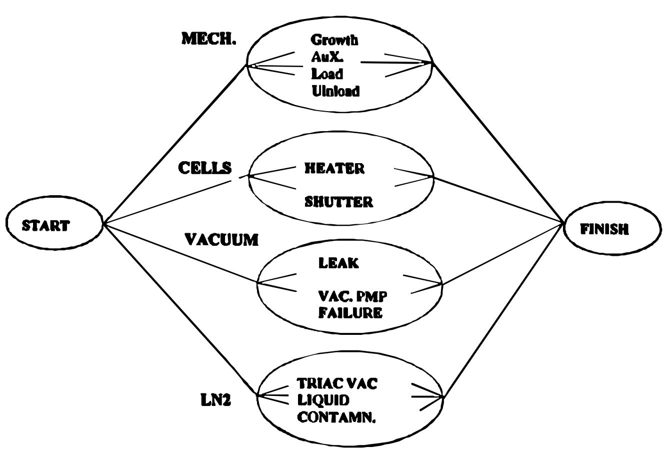

FIG.2 CRITICAL CONSTRAINTS FOR MBE PRODUCTION

III. THE ORGANIZATIONAL STRUCTURE

The key factor that plays an important role in the performance of a large volume MBE facility is the organizational structure. For the smooth functioning of 24 X 7 operation, the core-competency MBE group in Alpha has been divided into a production group and an engineering group, in accordance with the standard Silicon volume manufacturing business model. The two groups' function quite independently, though interacting with each other as and when required, to help in the smooth functioning of the system. While the production group is responsible for epi-wafer manufacturing, the engineering group fulfills the dual role of sustaining the MBE manufacturing process as well as developing new materials and perfecting new manufacturing processes, necessary for production of next generation chips. The engineering group is especially essential to chalk out strategies for out-of-the-control action plans. (Fig. 3).

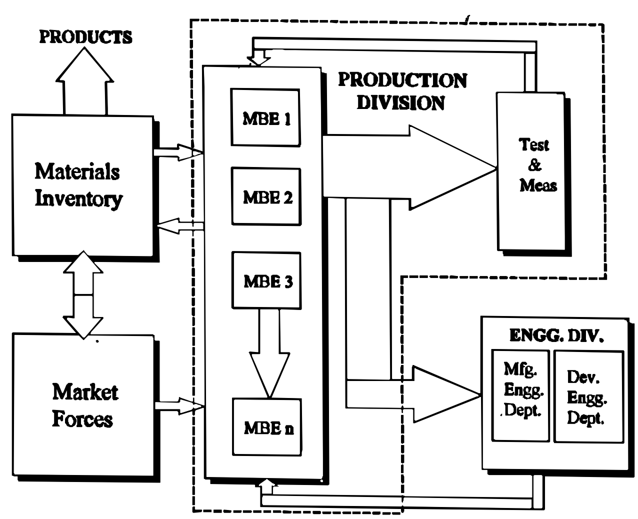

FIG.3 ORGANIZATION CHART FOR LARGE SCALE MBE PRODUCTION

IV. IMPLEMENTENTION OF MEASUREMENT/TEST TECHNOLOGY

A. *Product Control and Process Monitoring*

The feedback for the 'in-specifications' operation of the MBE facility is obtained by the constant monitoring of the production process. The monitoring is enabled through extensive test techniques used to evaluate the critical parameters of the epi-wafers manufactured. There are two aspects of the test platforms used to monitor the process. In the first step the "Operational Definitions" for each test platform has to be implemented to provide measurement consistency. The production process is the monitored by setting up 3-σ control limits for some critical parameters of the wafers like the mobility, Sheet charge density, haze, PL intensity, resistivity, composition percentage, interface roughness etc. For any points falling outside the 3-σ control limits the "Out of Control Action Plan" will get the manufacturing process within the limits. A cross-functional test platform scheme has been implemented to provide robustness necessary for volume manufacturing (Fig. 4).

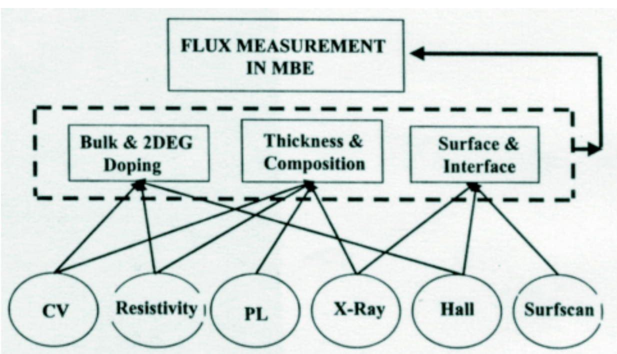

FIG.4 (a) TEST PLATFORM FOR LARGE SCALE PRODUCTION MBE

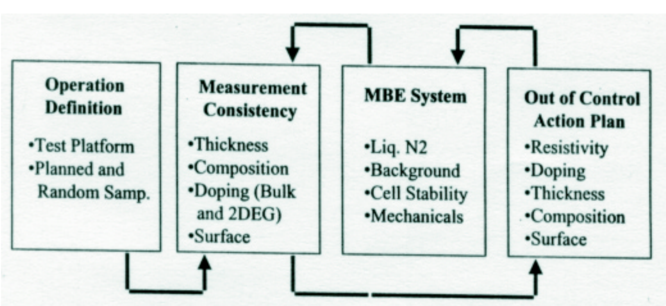

FIG. 4 (b) STATISTICAL PROCESS CONTROL FOR LARGE SCALE PRODUCTION MBE

The other aspect relates to the test platforms themselves. They have to be consistent with their measurements. Thus it is very much essential to ensure the proper functioning of the measurement tools themselves and tests have to be done to determine the accuracy and precision of such tools.

To illustrate how this concept can work, let's take the process of pHEMT production as an example. In growing pHEMT we need to ensure the material quality, the grown structure matched with the simulated structure, the proper In and Al compositions, the charge density, the mobility, the PL peak positions and intensity etc. All this information can be obtained by measuring the grown wafers. The production process starts as soon as the specification targets have been reached for the product, after the MBE parameters have been optimized for growth of the particular product. The next step is to monitor and collect all the production data and feed them into the SPC database for each test tool to build more reliable charts which can give a guide line to the feedback path designated to complete the whole operation as illustrated in Fig. 1 and Fig. 4.

B. *Problem of Developing New Products and Technologies*

Along with all the MBE related products comes the inseparable high technology factor with all the risks associated with it. The MESFETs, once the device choice with their superior high frequency performance, are no longer absolutely necessary. They are slowly being replaced by the more advanced technologies of pHEMTs and HBTs. The current GaAs based pHEMTs and HBTs technologies may, in their own turns, be replaced pretty soon by the next generation material and device structures. Therefore, it is very important for a high tech business like MBE to keep abreast of all the technological breakthroughs throughout the world and to modify the production goal accordingly. If the MBE business is to thrive, it needs to perfect the existing processes as well as squarely address the inherent problems such as using gas source, difficulties in multi-wafer capabilities, and so forth. Thus, the production focus should not remain static with respect to both the product nature and the production process. At this point, the quality of the manpower in the engineering group becomes a primary issue. To ensure this group is capable of developing new products and technologies to meet the needs of emerging markets, the company needs to invest more in attracting higher quality engineers, training new hires and updating knowledge and equipment.

V. CONCLUSION

In summary, we have presented the optimized MBE organizational structure necessary to effectively manage and sustain the production processes within the manufacturing constraints in order to deliver a continuous supply of high-quality, low-cost wafers. This has been ensured through synchronized functioning of the production and engineering groups as well as round-the-clock monitoring of the production processes, with the long term and short-term production decisions based on the predictive economic models. The authors would like to thank B. Nonamaker and S. Otenti for their enthusiastic supports. The authors would also like to thank C. McCulley for his helpful comments.