Teaching Microelectronic Process Behavioral Models to Non-Materials Majors

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ABSTRACT

Although the number of new microfabrication facilities to be built over the next 10 years is a bit illusive at this point, it is clear that there will be a major increase in the production of semiconductor components. This dramatic increase will demand a substantial addition of technically skilled people to meet the manufacturing requirements of such devices. Personnel requirements not only include material scientists and engineers but a host of competent support people who together will implement the technology roadmap for this industry.

The task at hand is to develop a workforce that must have a new skill set which has not previously been the focus of any existing organized technical curriculum. This paper will address one approach to presenting the important process steps in microdevice fabrication to a non-materials major audience. Particular attention will be spent on the problems and challenges associated with introducing what the technical demands and expectations of the industry will be, presenting the material process unit operations as visual icons, associating sequences of these icons with material electrical properties, and finally developing a set of detailed but general process behavioral models which could be commonly used in microdevice fabrication.

INTRODUCTION

A universal character of high technology business is the magnitude of the initial investment in process facilities and personnel. Aerospace and biomedical instrumentation are two examples of technology based industries that require major capital investment and an extensive interdisciplinary workforce. Microelectronic manufacturing is poised to make a major impact upon the world market over the next ten years. The integrated circuit (IC) or chip industry is particularly sensitive to the same critical constraints of high-overhead, high-technology product oriented companies. An economically successful enterprise in this area must be able to minimize its product time-to-market. The volatility of the personal computer and allied component markets demands rapid conversion of design concepts to practical devices. In fact, at this point in time many component or systems companies elect not to fabricate their own material systems. They simply do not want to invest the time and money needed to develop the material process capability nor do they want to accept the risk of being late to market.

Despite this current manufacturing trend, a large number of microfabrication facilities will be built in the next ten years. These companies will still be required to meet the time to market constraint but are willing to accept the challenge of fabricating devices based on their confidence in their own internal competence. In addition companies which have previously operated without fabrication facilities are presently forming cooperative ventures with companies that possess fabrication capability. Although this approach will guarantee fabrication capability to the fabless companies, it does force them to share the risks associated with producing tiny and quick products that require 300 plus complicated material process steps to produce.

THE PROBLEM

A competitive microelectronics industry in the United States must deal with the following realities. First, the country's general education philosophy does not have a technology focus. At present, there is minimal emphasis in mathematics, physics and chemistry in elementary schools. Without this focus the country cannot produce a new generation of people, let alone IC industry employee's, that will be able to put high technology activity into any rational perspective. Second, other than initial attempts by governmental agencies such as the NSF program for *Undergraduate Faculty Enhancement*, there is no consistent or long-term organized national attempt to produce educated people with a substantial cross discipline component in their education. Third, the resources needed to address these two issues are not universially available within the public domain. Fourth, there is no clear authoritative pathway to facilitate the bending of the current educational system to meet the needs of the expanding IC and its supporting high technology industries. Finally, the IC industry response to this situation has been to develop an internal capability which has evolved into a multi-tier work force. Each level possesses a unique, important but isolated skill set.

To be sure, each of the listed items above combined with the abnormal production cycling that the IC industry must respond to, forms an impressive impediment to success. The industry is trying to make headway with the first three items in the list but these efforts are focused in regions where current facilities exist or future plants will be located. Ultimately, this regional strategy will not make an impact on the situation from a national perspective, nor will any local improvements gleaned from this approach really alter the long-term counterproductive impact of the current multi-level work force strategy.

In manufacturing facilities the work force has two tiers, engineers and lead operators, and the problem centers on the general characteristics of each group. The engineering personnel enter the IC industry with little or no formal training in processing. To be sure, each is talented and each has a high learning quotient, but each has an enormous amount to learn and few are given any training outside their specific assigned area of responsibility. The lead operators enter the game with sound, usually military based, electronics training or a 2 year technical degree. With this background, operators can perform the complicated tasks required as directed. However, it will be years before these individuals can successfully trouble shoot any of the common complicated problems that occur.

The deceptive part of this two-tier employee structure is the fact that this strategy has not been an issue in the past. Therefore, why should it be a problem for the future? An answer to this question includes the four education based realities stated above. In addition, the competent technologists who “grew-up” with and developed the field of IC processing are either retiring or moving to management positions farther from the process. Since these mentors are no longer directly involved with the process, their replacements are being “short-changed” and must develop the needed skill set independently. Thus the resident expertise, once responsible for this specific "in-house" individualized training is subtly vanishing and their replacements are not adequately prepared to assume the role of mentor much less to address the new demands for more product which is also smaller and faster.

This situation is now being accelerated to crisis speed by the rapid growth in the number of new fabrication facilities. This growth has upset the delicate balance between the once adequate, limited population growth provided by traditional internal development programs and the requirement for new resident experts. Therefore, the existing infrastructure with respect to education, policy formation, and mentoring capabilities is not positioned to cope with both the current and future demands of the IC industry.

AN APPROACH

The problem of providing a workforce that can cope with the constraints of decreasing time-to-market and the production of smaller, faster, and more capable devices is upon the IC industry now. Unfortunately, the optimal solution to this problem is not. Naturally, the ultimate solution involves a national attitude adjustment regarding the role of engineering, science and technology in the education system. In the mean time, the IC industry needs workers that can begin to address these constraints. One approach is to provide a different view of microelectronics processing to current IC employees as well as to students in our engineering, physical science and technology programs. This alternate view is perhaps better described as an education philosophy that provides a iterative approach to describing electronic materials processing.

The common characteristic of this philosophy is a uniform presentation to all of the groups to be trained. This presentation focuses on the material process sequence needed to manufacture chips. Emphasis is placed on describing the process sequence as a string of visual programming elements or icons. These icons provide a background independent tool that can introduce the IC manufacturing recipe to any audience.

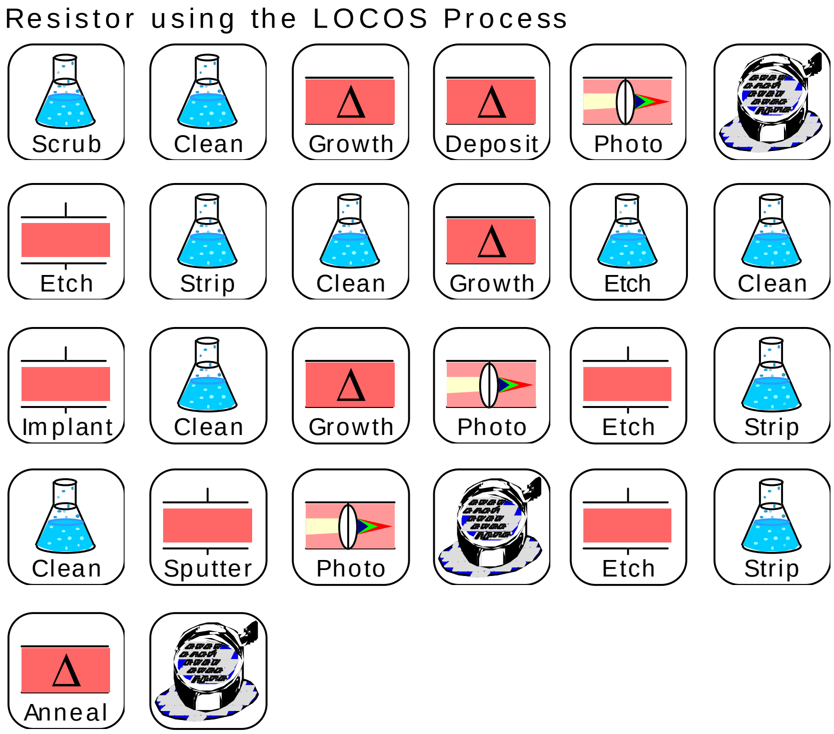
This icon approach gives the instructor the flexibility to mold the information level such that it conforms to the needs of the specific group of trainees. The same icon will represent different levels of information content depending on the viewer. Thus a string of icons will provide a depth and breadth of the subject that is dependent on the needs of the viewer. For example, support personnel in procurement are not directly involved in materials operations but must have an understanding of the process sequence. For these people, a single icon merely represents a customer that has specific and detailed needs. However, that customer also has supplier relationships with other customers in the facility. Therefore, support personnel need to understand the icon sequence because they must know how their interaction with one customer might influence the operations of another. By contrast a member of the senior technology group must blend existing production demands with new technologies that will be implemented in the production flow to address new product introductions. For this employee a single icon represents a complicated set of materials science relationships that influence the productivity and technological capability of the process unit represented by that icon. However, this single icon is still a component in an overall icon chain sequence and the technologist must address the sequential customer and supplier issues. In this case the perspective is different because the technologist is directly responsible for the production of the final device with its associated electronic properties.

The two examples just presented represent two possible audience groups with the same goals that could benefit from this educational approach but the bulk of personnel that need to understand IC process behavior models will be the operations or manufacturing personnel. These people will not have degrees in material science and may not have any initial material science or processing training. The icon sequence approach is a particularly valuable vehicle for training this group.

Figure 1 represents a general process behavioral model that illustrates a particular sequence of material process icons which produce a resistor function when implemented in silicon. Upon examination of this figure it is clear that there are many similar icons represented, but the label at the bottom of similar icons may be different. Hence, in even such a simple sequence, classes of material processes may be separated. For example scrub, clean, strip, and etch are representative elements of a chemical process functional group indicated by a flask. Similarly etch, sputter, and implant are components of another functional group indicated by a contained parallel plate plasma. In addition, repeating sequences of icons such as a clean preceding a growth are also visible in the figure.

For a typical presentation of the information content of the resistor fabrication sequence shown in Figure 1 to a non-materials science audience, the instructor will begin with a general presentation that describes the classes of unit operations as they appear in the sequence. In this case the chemical, thermal(Δ), photo, metrology(*magnifier*), and plasma classes of unit operations are introduced. Next the instructor begins again with an introduction to critical material science concepts. This will include discussions relevant to the base material, silicon, upon which the unit icons operate. With this vocabulary established, the instructor returns to members of icon classes to develop the details of the process sequence. As in the case of the individual who grew up with the process the sequence is developed through a series of successive approximations to final product manufacture. Each approximation attempts to build the final device with the skills developed to that point. Failure to accomplish the task establishes the motivation to explore

Figure 1. Sequence of unit material processes required to build a resistor in silicon.



yet another icon group to learn the details necessary to make another attempt at building the functional device. Hence, the course proceeds through this iterative process using ever increasing levels of sophistication to accomplish the task. Over the course of this iterative experience, the student develops successive levels of process behavioral complexity and a facility to assemble specific icon sequences independently. In addition the students begin to focus their attention on the more subtle aspects of the interactions between a specific icon and its neighbors. Thus by the end of the course the students will have a working vocabulary that allows them to understand, at their level, how a device is built. In addition, they understand a general behavioral model that can be applied to other device fabrication sequences. Finally, this understanding provides a vehicle for them to discuss problems and interesting issues associated with the challenges that they jointly face.

SUMMARY

It is clear that there is a need for non-materials majors to become familiar with microelectronic fabrication processes. The industry itself is going to need a significant influx of new employees to meet its manufacturing requirements. These staffing requirements are serious at present and will persist into the next century. The society in general must have an increased public awareness of the complications involved in producing high-technology and high value added products such as semiconductor devices. Public policy has not reached a point at which the general educational system is prepared to cope with these issues. This paper introduced the general structure of a course that could be applied to all segments of the population that have an interest in the semiconductor manufacturing industry. The course description was geared to a specific audience that does not have a material science background but does have a definite interest in working in the field.

Finally the paper suggested a model for the development of an alternative materials curriculum that would place the emphasis on matching the needs of the learner with the complexity component appropriate to electronic materials fabrication. The material science faculty can use the icon skeleton to develop specific courses which would benefit a variety of disciplines and interests. Two examples might be, liberal arts majors who want at least a casual understanding of chip production and its influence on society or environmental engineering students who want to understand the impact of the semiconductor industry on their field. In both of these cases, the icons would be presented and explained at the audience's level followed by the development of the icon sequences to meet the overall goal of the class.

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