

Preface

Semiconductor chips are similar to computer program modules in that they embody algorithms that are duplicated or mass-produced. The process of duplicating programs involves writing as many copies as required from one computer-readable medium into another. No matter how difficult an algorithm it embodies, any program module can be duplicated simply and correctly without further intellectual effort on the part of the programmer. Thus it can be said that a programmer's task is completed once he has thoroughly checked out the master copy of his program, since all duplicates will behave as the original.

Like a programmer, an engineer designs an algorithm; but instead of leaving it in computer-readable form, he packages it into a chip of semiconductor material. This design and packaging is an achievement by itself; but his task is not completed until the chip can be successfully duplicated. The feat of manufacturing semiconductor circuits represents a repetition of the original design achievement, not just once, but as many times as the part is produced. It is precisely here that the similarity between program duplication and chip manufacture breaks down. Cost, yield, and quality control in semiconductor manufacturing can require a considerable additional engineering effort on the part of the manufacturing organization to reproduce each type of chip designed in the engineering laboratory. While the semiconductor end-product may still look the same as the original, the processes it undergoes in order to become a working part under cost, quantity, and reliability constraints, as well as the machinery used in its duplication, are most likely quite different and may well be as intellectually challenging as the original design. In fact, because of their complexity, some chips do require design changes to permit their manufacture, or to increase manufacturing yields—something unheard of in program duplication.

The editors of the *IBM Journal of Research and Development* decided to pursue the manufacturing theme for our readers, with the idea of highlighting key technical advances that have enabled IBM to maintain its leadership position in semiconductor manufacturing in the VLSI era. Together with an advisory committee, headed by Paul P. Castrucci, we developed topics for this issue after consulting with the engineering population working in IBM's semiconductor manufacturing facilities worldwide. The goal was to emphasize IBM's manufacturing contributions to semiconductor technology rather than simply to catalog the processes. Beyond reiterating ideas that may be familiar to many *Journal* readers about the technology that starts with a highly purified form of silicon obtained from sand, the papers should provide new insights and perspectives that could be expected to have developed during the process of converting engineering ideas to practice. While not tutorial in nature,

the issue should be of interest to technical professionals working in the field of semiconductors as well as to those working in related disciplines. The eleven papers in this issue, selected from more than three times that number received, represent a sampling of problems which IBM manufacturing engineers encounter in the mass-production of integrated circuits.

The paper on semiconductor manufacturing by Carre, Doxtator, and Duffy provides the reader with an overview of current semiconductor manufacturing as practiced in IBM plants in Europe, Japan, and the United States. Manufacturing engineers from these diverse locations meet regularly and share experiences with their counterparts who produce identical or similar products. Problems which occur in one facility are solved jointly, and preventive measures are planned to avoid occurrences of these same problems at other locations. Friendly competition between facilities in yield management, cost control, and quality are measured, and success stories are related, compared, and repeated at other sites.

The yield management paper by Stapper, Castrucci, Maeder, Rowe, and Verhelst goes into more detail about the scientific and practical aspects of predicting yields and measuring the production line against yield models. However, no attempt is made to cover, in one paper, all of the details required to make a yield model work, *e.g.*, the methods used in understanding and controlling the processing chemistry, the avoidance of contaminants, the determination of test points, process parameters, adequate tests, etc., or the corrective measures needed to keep processes within acceptable limits.

Complementing this treatment of yield management is the quality control paper by Melan, Curtis, Ho, Koens, and Snyder. It explains the need for process data gathering and how the information acquired daily can be used, either immediately or weeks and even months later, to provide clues for uncovering quality or yield detractors, thereby enabling the shipment of highly reliable parts which are interchangeable with equivalent parts manufactured elsewhere or at different times.

In the logistics and product dispositioning system paper by Burgess, Koens, and Pignetti, the system aspects of semiconductor manufacturing are further disclosed. The availability of data (from which decisions by manufacturing personnel can be made) is exploited. Routine decisions are made by computers, thereby utilizing individual operators and engineers more efficiently by saving them for the more challenging problems and decision making, and, incidentally, increasing product quality and plant productivity.

Two complementary papers deal with the chlorobenzene single-step liftoff process. The first paper, by Halverson, MacIntyre, and Motsiff, presents a detailed analysis of the complex mechanism of liftoff. Such an understanding is required before actual process control, described in the following paper by Collins and Halsted, can be achieved in on-line manufacturing situations.

The oxygen incorporation paper by Murgai, Patrick, Combronde, and Felix provides another example of some of the processes that must be thoroughly understood and mastered before control (*e.g.*, uniform oxygen concentration on the order of 25 parts per million atomic) can be achieved and successfully repeated during crystal growing.

Typical problems investigated by manufacturing engineers are the limits in metrology available with current equipment, as described by Rottmann; feature size control (or the causes of variations thereof), as studied by Frascch and Saremski; and the optimization of plasma processing using statistically designed multiparametric experimentation, as presented by Bergendahl, Bergeron, and Harmon.

Other manufacturing engineering responsibilities are the improvement of existing manufacturing processes and the development of new ones for both current and future products. An example of these is represented by the paper on electron-beam proximity printing by Bohlen, Greschner, Keyser, Kulcke, and Nehmiz. While directly writing on wafers with electron beams is a very versatile method of manufacturing semiconductor devices and is also ideal for engineering development of one-of-a-kind chips, the use of masks in photolithographic systems has its advantages and is under continuing investigation. The paper describes a prototype proximity printer which was designed and illustrates its capabilities for manufacturing use.

With these papers, the editors wish to share with our readers the intellectual activities and the practical requirements and experience that successful semiconductor manufacturing entails. We thank Paul Castrucci and his committee, as well as Stanley Kirschner and the legion of reviewers and referees who have aided in the selection and editing of these manuscripts for this issue.