

# Introduction

This volume is organized into seven sections: (1) Standards in Semiconductor Industry; (2) Fabrication Technology; (3) Control of Particulate Contamination; (4) Defects and Gettering Techniques; (5) Material and Process Characterization; (6) Interconnection Technology: Wire & Tape Bonding; and (7) Neutron Transmutation Doping Techniques and Facilities. The papers describe the semiconductor processes used in device fabrication, from its simplest use to discrete circuits through the emerging applications to very-large-scale-integrated (VLSI) circuits.

## Standards in Semiconductor Industry

As the semiconductor industry matures, standard specifications and test methods play a critical role in the development of the industry by facilitating communications and flow of material and parts across many interfaces. W. Murray Bullis describes the activities of ASTM and SEMI in his paper, emphasizing the ever-increasing need of standardization as future VLSI manufacturing makes stringent demands on materials, control of contaminants and processing technologies.

## Fabrication Technology

To insure the required yields in the fabrication of complex devices, three issues must be satisfied. (1) an accurate and efficient simulation of VLSI processes and device characteristics which will compliment the experimental evaluation of proposed new structures; (2) improved process control at every step of fabrication from raw material to finished device; and (3) the control of defects in the material and those generated in the process. All these three aspects are discussed in this section with emphasis on the yield enhancement in devices. Work on device modeling and process simulations and new innovations in processes such as, epitaxy, ion implant, plasma etching etc. is also discussed. Furthermore, the proximity effect corrections are simulated and experimentally examined for electron-beam sub-micron lithographic patterns in a paper by Berkowitz et al.

## Control of Particulate Contamination

Semiconductor device fabrication is very sensitive to particulate contamination. The sensitivity increases

## 2 SEMICONDUCTOR PROCESSING

as the device features shrink and circuit densities increase. The contamination affects the performance and reliability of the devices. Paper by A.C.Rapa examines the various forms of contamination and their interactions which affect the functional yield and performance of VLSI devices.

Other than the particles in environment and in various chemicals used in processing, molecular contaminants and colloidal particles as small as 0.2  $\mu\text{m}$  in water are also important because this contamination can have a deleterious effect on the properties of complex devices. A Paper by P.W.Gaudet describes point-of-use ultrafiltration membrane systems and their applications in the semiconductor industry with an emphasis to the device quality.

Measuring the submicrometer particulate contamination poses real challenges as the effects of artifact introduction from sample handling and transport systems must be separated from the data. Better understanding of statistical effects on data validity is necessary. A. Lieberman describes the operation of particle sizing and the capabilities and limitations of the equipment used in the semiconductor industry for counting of submicrometer particles.

### Defect and Gettering Techniques

Today, VLSI circuits contain more than 100,000 active devices. Failure to meet the specification of anyone of these devices may prevent the entire circuit from performing within required specifications. These failures have been traced back to crystallographic defects present in the semiconductor material or to process defects introduced during fabrication. The interaction between the crystallographic and process defects is complex and usually not obvious. The effect of material defects on circuit performance has been a topic of extensive research. Gettering techniques have evolved in these research and are used to reduce the effect of defects on device performance.

Papers in this section describe the effects of wafer thermal history, interstitial oxygen and many other variables on the internal gettering. The effectiveness of external gettering on the fabrication processes is described. Finally, the traditional methods of intrinsic and extrinsic gettering are compared and the mechanisms of gettering are explained in terms of diffusion, interaction and capture of impurities by

extended defects. Diffusion enhancement of impurities by excess point defects and interstitials is investigated and verified by experimental models.

### Material and Process Characteristics

The most important requirement in the semiconductor technology is the material and process characterization for the diagnosis and prediction of the process. Theoretical concepts applied to most measurement technologies are so complex that it becomes imperative to calibrate the systems with known standards in order to achieve better accuracies. ASTM Committee F-1 on Electronics has, therefore, stressed the need to expand the Standard Reference Material Program of the National Bureau of Standards to provide reference standards for the semiconductor industry. The details of this program are available from the Semiconductor Materials and Process Division, National Bureau of Standards, Gaithersburg, MD. 20899.

Internal gettering techniques and the formations of denuded zone depend upon the initial free oxygen in silicon. Therefore, there is a major effort to improve the techniques of measurement of oxygen in silicon. Non-destructive techniques such as, the Fourier transform infrared spectroscopy are very useful. This technique and the effects of instrumental artifacts are described in the work performed at Monsanto, Digilab, AT&T Laboratories and NBS in the first four papers in this section. Some of this work was the result of detailed discussion at ASTM task force in which many persons participated. FTIR techniques are also useful in the measurement of impurities in silicon and silicate glasses as discussed by Krishnan. The amount of initial impurity concentration in polysilicon rods during the float-zone process becomes significant in producing high resistivity silicon crystal. Chiou describes a method to determine this concentration.

Next three papers discuss spreading resistance technique - a very useful tool in semiconductor industry. The effects of electromagnetic noise on the accuracy of the technique are discussed and its applications to the depth profiling in silicon implanted with low doses are described. These measurements are compared with other techniques such as, NDP and SIMS.

### Interconnection Technology

The ASTM subcommittee Fl.07 on Interconnections is very active in formulating standards for the industry. The section on Interconnection Technology is an extension to these efforts to bring out the solutions to some of the industrial problems in the wire and tape bonding. The topics of thermocompression and ultrasonic bondings are discussed with reference to the properties of alloy wires, annealing temperatures and the characteristics of bonding tools. The use of ball shear as a method for studying the effects of thermal processing on the strength and morphology of the aluminum-gold interface is described.

Tape automatic bonding has the advantage of the reduction in I/O pad spacings and substantial increase in the linear inconnection density with the potential to accomodate I/O pads anywhere on the surface of the device. Various applications of tape automatic bonding for interconnections and packaging of high density VLSIs are discussed. Further, an innerlead bonding technique for making multiple thermocompression bonds between bumped tape leads and bonding pads is described.

### Neutron Transmutation Doping Techniques and Facilities

The method used to obtain n-type single crystal silicon in the resistivity range above 10,000 Ohm-cm is to incorporate and accurately adjust the donor concentration in uncompensated, high-resistivity, p-type silicon. This method of doping is called the neutron transmutation doping (NTD). P-type silicon used in this technique is normally obtained from float-zone process by using multiple passes. This technique has been developed and successfully used for over 20 years for preparing materials used for power applications. NTD production and development, however, strongly depends on the growth of new applications and the ability of the process to produce larger diameter (>125 mm) crystals of low resistivities (<5.0 Ohm-cm).

The papers in this section cover the whole span of NTD technology and irradiation facilities from the history of an early development to the present state-of-the-art. In addition to achieving the doping uniformity, the emphasis on the design of the reactors is to extend the capabilities of irradiations to larger ingots. Estimates indicate that in certain designs, it is possible to irradiate upto 125 mm diameter ingots.

Apart from silicon, the technique has been applied to dope several other semiconductor materials such as, germanium, gallium arsenide, amorphous SI-H etc. The principal questions are (1) whether NTD technology will only be limited to power applications and therefore, will have to grow with power markets' growth rates, and (2) whether float-zone process, on which NTD technology is depended upon, can be extended to produce larger diameter (>125 mm) ingots and compete with Czochralski crystal growth technology.

Dinesh C. Gupta  
Symposium Chairman and Editor