Applications of Microscopy in the Microelectronics Industry

Presented by John Mardinly, Intel Corporation
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Mr. John Mardinly of Intel Corporation, former president of NCSM, gave the Physical Science Presentation at the December 7, 1995, NCSM meeting held in Albany, CA. "Applications of Microscopy in the Microelectronics Industry" was the speaker's topic. Mr. Mardinly began by giving some background on integrated circuits. He had wafers to show as examples while stating that the value of each one exceeds $100,000 at $500 per chip and there are numerous chips on each wafer. The individual chip he showed had 3.1 million transistors, with 237 pins and 237 connections per device. The new Pentium Pro will have a mind-boggling 5.5 million transistors packed onto the same size chip. These minute geometrics have catapulted microscopy of all kinds into great demand at Intel, where he says they use "dozens and dozens" of SEMs routinely, for instance. The purpose for microscopy is practical. If the device doesn't work, it is "junk". Every hour a production run is stopped costs several hundred thousands of dollars. In determining the causes of problems, optical microscopy is unable to resolve any but gross structure. The magnification and resolution of electron microscopy is vital to the understanding of failure in integrated circuit manufacturing.

As an introduction to microscopy applications with microelectronics, Mr. Mardinly gave a brief overview of the construction and production of integrated circuits. Formed with a silicon wafer base, transistors are created upon the surface and interconnected with aluminum pathways that are layered between insulating silicon dioxide with tungsten inter-connections. 'Doping' is used to modify the semiconducting silicon to create the source, drain and gate of each transistor. When voltage is applied, the transistor can either allow current to flow or not flow, forming the basis of the binary machine language, the '0' and '1'. If the microprocessor works, it can do arithmetic and perform logical functions. In order to create accurate circuits, lithography and photoresist are employed for placement of components which are formed from three basic processes. These include oxidation of silicon (insulating layers), metal sputtering (precise placement of pathways), and doping by ion implantation (transistors). Not meaning to digress too deeply into the theory of solid state electronics, Mr. Mardinly stressed the trend of the semi-conductor industry to place smaller components more closely upon each chip to create a faster and more powerful integrated circuit. This process he related to "eating your young" as the semiconductor industry is required to obsolete their own products. The enormous demand for these products has given Intel the ability in the past 27 years to grow to 46,000 employees and to be worth an estimated value of $15,000,000,000. Forty million Pentium Processors are expected to be sold this year, amounting to a rate of more than 1 per second. The charismatic leadership at Intel Corporation has been key in the success of this business, where one motto is known to be "Only the paranoid survive."

In the production and design environment, things do not always go perfectly. That is, said Mr. Mardinly, where microscopy comes in. At Intel, many types of microscopy are used for analysis. For cross sectioning precision, the crew at Intel has been using the "FIB - that's no lie!" joked the speaker. Much like an SEM, the FIB has a chamber, column, scan generator and display. Using gallium ions instead of electrons, the FIB can image, cut and etch. Mr. Mardinly stated that the SEM does not always reveal what the problem is. The FIB can cut two free surfaces and perform 'on the spot' cross sectioning abilities, and therefore is key in diagnostic analysis.

Atomic force microscopy is employed to analyze the smoothness of polycrystalline silicon. The AFM allows for a comparison of texture, important for maximizing the performance of the device. As a plus, the AFM requires little specimen preparation. It is used for measuring heights to calibrate depth of evaporation layers and measure depth of etch, for instance.

Mr. Mardinly said he works mainly with a TEM equipped with a light element x-ray detector, CCD camera for acquiring images, and a TV camera. The Intel system is linked through E-mail for immediate response worldwide. This is extremely valuable when fabrication is down, a cost of "a couple of hundreds of thousands of dollars per hour". Problem solving with the TEM has included unique situations tracing problems to their root. In one case, etching to remove metal was found to be actually redepositing titanium and forming an unwanted connection. This caused a loss of $1 million in chips, he stated. In another case, the TEM showed traces of residual tungsten to be forming bumps in the aluminum pathways. Once, a plasma etch was found to be reacting with the interior of the chamber and contaminating the wafers. EDS may not always be adequate to locate the source of problems. Electron diffraction and a computer data matching system are valuable tools to pinpoint structural defects of materials.

Mr. Mardinly noted that the semiconductor gate is a critical factor to speed in the integrated circuit. Pentium processors with 3.1 million transistors must have all 3.1 million working perfectly. High resolution microscopy is required to examine these minute devices. In one case, EDS with TEM was able to pick up fluorine in a sample. With the use of high resolution Fourier Transform imaging, a positive identification of the phase of impurity was determined.

With millions of transistors, to find the exact address of a failure is no trivial accomplishment with traditional polishing techniques. The FIB has been used successfully to prepare cross-section specimens for the TEM. Electrical engineers locate the address of the problem, and then use the FIB to "nibble" into the sample to the proper spot. Mr. Mardinly said there is not much field of view, but high resolution of specific areas gives adequate information to determine causes of failure. In conjunction with other instrumentation, infrared emission microscopy is used to indicate electrical leaks on test structures. At 1000x magnification, the detectors operate during processing and locate areas for cross sectioning. Then the FIB is used to prepare TEM specimens to determine the fault.

For thick sections, Intel has been using the Gatan Imaging Filter to improve resolution of problem spots. The beam interacts with the sample, giving off energy in the form of 'tagged' electrons which are detected by spectrometry and run through a series of imaging filters. In thermocycling tests, a mechanical weakness of a tungsten aluminum contact exceeded the acceptable production failure rate. EDS resolution was too low to solve the problem, but energy filtering provided the necessary information.

The field emission TEM is giving Intel striking resolution improvements in imaging, Mr. Mardinly stated. The LaB6 filaments, 100x brighter, the microanalysis probe is 10x smaller, allowing for equal resolution. The contrast transfer into reciprocal space, however, allows the field emission TEM information transfer of close to 1 Å. The Field Emission (FE) TEM also exhibits high voltage mechanical stability. Traditionally, high resolution has come at the price of higher voltage and greater specimen damage. With the small probe size, "stunning" contrast is achieved, resulting in high resolution pictures. The brighter beam is useful for selected area diffraction (SAD) with nonconvergent rays, producing diffraction patterns for phase applications.

The development of microelectronics has been related to a function of the calendar year. Termed "Moore's Law" after an Intel founder, the function has not deviated for the past 27 years, noted Mr. Mardinly. To date, the decrease in device size and increase in components gives a 1995 Intel memory chip 16 Megabytes of memory, running at 133 MHz. By the end of 1996, the Pentium Pro will be 200 MHz. The 1 million transistors of the 1989 microprocessor became 3.1 million in 1993, followed by 5.5 million in 1995. Mr. Mardinly projected that following Moore's Law, the integrated circuit of the year 2000 will have 50,000,000 transistors, running on low voltage at 200 - 300 MHz. Housed on a one inch by one inch chip, this reduces the size of the metal pathways to 0.15 - 0.25 microns. ■

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