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Challenges and Trends in Semiconductor Fabrication

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Current Challenges and Trends in Semiconductor Fabrication

Integrated circuit chips (IC) are being manufactured in progressively and dramatically smaller sizes. As of this writing, chips as small as 130 nanometers (nm) across with layers only a few atoms deep are being made. The Semiconductor Industry Association (SIA) foresees the production of chips with critical dimensions of 90 nm by the end of 2004. (For comparison, the atomic radius of silicon is 14.6 nm, and visible light has wavelengths of about 400 to 800 nm. In a very short time, microminiaturization of chips will be limited by the size of atoms. New chemistries and technologies are being developed rapidly to meet the nanometer scale needs of the semiconductor industry. The most important ones are discussed below.

NEW MATERIALS

- High-k materials
  Of all the circuit elements on a chip, capacitors take up the most room, so their size must be decreased in order to make ultrasmall chips. Initially, this was accomplished by decreasing the thickness of the SiO2 film on capacitors (gates), but when the film is too thin, current leakage is unacceptably high. In 2003, Intel announced the development of a new group of materials (high-k materials), including strontium titanate ($SrTiO_3$), barium strontium titanate (BST or $BaSrTiO_3$), hafnium dioxide (HfO_2), zirconium dioxide (ZrO_2), and titanium dioxide (TiO_2), which are now coming into use for gates.
- Low-k materials
  In ULSI, charge leakage between adjacent metal lines can become unacceptably high. Highly insulating (low-k) materials are being developed as dielectrics (insulators) to insulate adjacent metal lines from each other, thus reducing "cross talk." Low-k materials, which are particularly important with copper metallurgy, include silicon nitride, silicon oxynitride, silicon carbide, silicon oxycarbide, and tantalum nitride.
- Supercritical carbon dioxide (CO_2)

Use of supercritical CO2 as a solvent in many steps of the semiconductor fab process has been spurred by toxicological and environmental concerns. Supercritical CO2 is now used or under development for applications below 65 nm, sometimes in combination with surfactants which create water-in-CO2 emulsions and promote the solubilization and subsequent removal of hydrophilic substances. Applications include stripping of photoresist, metal ions, and residues; silylation of silicon wafers; and drying and repairing low-k materials.

- Ultrahigh purity deionized water
  As semiconductor devices shrink, reduction of ionic contamination in deionized (DI) water becomes critical to avoid metal deposition on wafers. The ITRS 2001 guidelines call for a total metal contamination on the wafer surface of < 7x109 atoms/cm2 for 130 nm devices. Environmental concerns also necessitate the use of high purity, recyclable DI water. More than 110 gallons of ultrapure rinse water can be used to process a 200 nm wafer, and waste/reclamation/recycling issues take on gargantuan proportions. An increasingly widely used method of maintaining the ultrahigh purity of DI water while recycling it is to purify it continuously while in use by means of ion exchange membrane filter devices in-line.

NEXT-GENERATION PHOTOLITHOGRAPHY

Several techniques are under investigation for making chips with smaller CDs and enhanced resolution:

- Extreme UV. UV light with wavelength of about 13 nm can be used to print images down to about 30 nm.
- Electron beam imaging: An electron beam is used instead of light.
  Ion projection lithography: Hydrogen or helium ions are used instead of light.
- X-ray lithography: X-rays are produced in a synchroton (an expensive procedure).

NANOTECHNOLOGY

A breakthrough development in semicon fab is nanotechnology. At the current rate of technology development, the size of the smallest features on microchips will be limited by the size of atoms in a few years. Molecular electronics or quantum electronics are technologies now being developed to replace transistors with molecular switches. Synthetic organic polymers can be used to construct nanotubes and nanowires with a wide range of properties, from insulating to conducting. The first functional carbon nanotube transistors, made in 2003, were constructed with catenanes. These compounds have different conformations with very different tunneling currents, and they can be used in a manner similar to conventional transistors with on-off states. In some cases, polymers form nanotubes by self-assembly. A host of new technologies in molecular electronics will be needed for the production of nanochips; some are currently under development and almost ready for commercial use. Nanotechnology is also revolutionizing the healthcare field, particularly in the development of new methods of drug delivery.