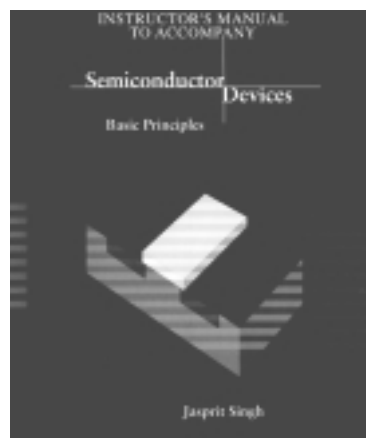

Chapter

5

PROCESSING OF DEVICES



A discussion of crystal growth, lithography, etching, doping, and device structures is presented in the following overview figures.

SEMICONDUCTOR DEVICE PROCESSING: AN OVERVIEW

Semiconductor technology generates hundreds of billions of dollars of revenue worldwide. Manufacturing plants costing several billion dollars fabricate devices.

COMPONENTS OF DEVICE PROCESSING

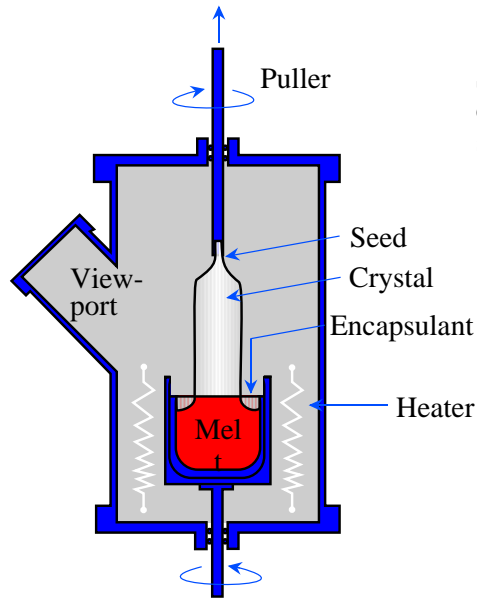
- Bulk crystal growth for substrates
- Epitaxial growth for active device region and doping
- Ion implantation/diffusion for doping
- Lithography to define various regions of devices
- Etching of materials

As technology advances, the challenges in processing become greater.

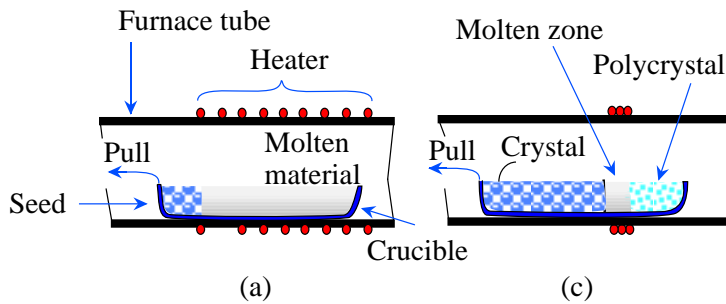
BULK CRYSTAL GROWTH

Bulk crystal growth techniques are used to grow large crystals from which substrates are sliced. Substrate availability is a critical component in the success of a technology. Established technologies are:

- Silicon: Up to 30 cm diameter substrates are available.
- GaAs: Up to 15 cm substrates are available.
- InP: Up to 10 cm substrates are available.



Schematic of Czochralski-style crystal growth used to produce substrate ingots.



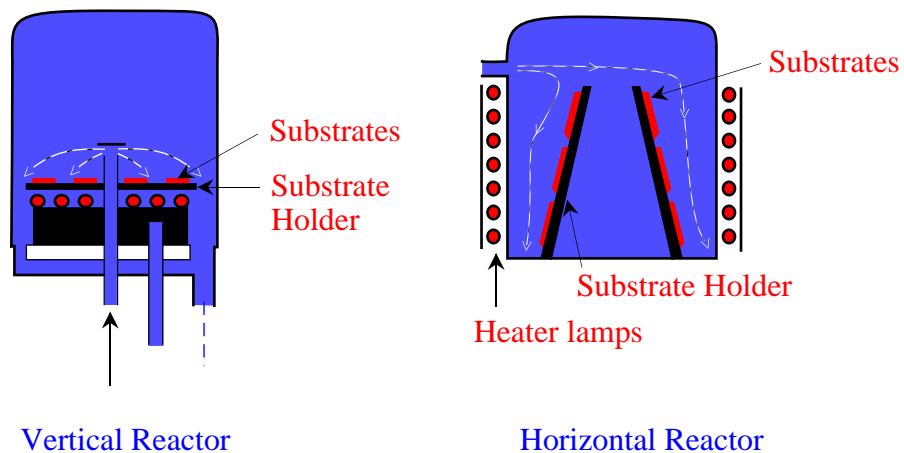
Crystal growing from the melt in a crucible: (a) solidification from one end of the melt (horizontal Bridgeman method); (b) melting and solidification in a moving zone.

EPITAXIAL CRYSTAL GROWTH

Epitaxial growth is used to deposit a few microns of high quality material which forms the active region of the device. Techniques used are:

- Vapor phase epitaxy (VPE)
- Molecular beam epitaxy (MBE)
- Metal organic chemical vapor deposition (MOCVD)

Gases containing the species needed in the crystal flow over a substrate. Deposition occurs via appropriate chemical dissociation.



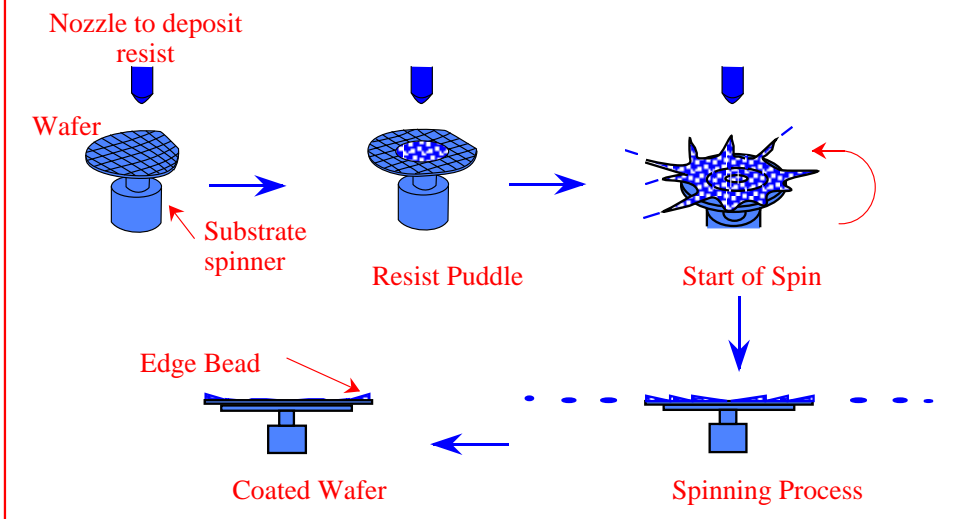
Reactors for VPE growth. The substrate temperature must be maintained uniformly over the area. This is achieved better by lamp heating.

LITHOGRAPHY: MASK GENERATION AND IMAGE TRANSFER

PHOTORESIST COATING

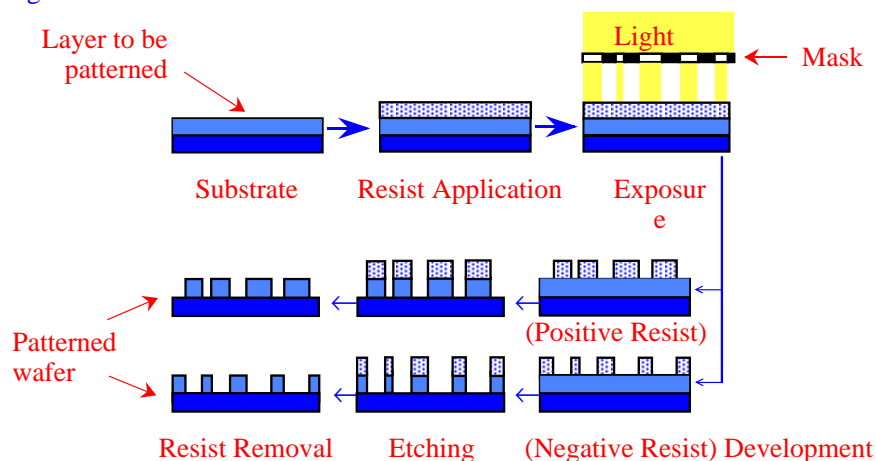
In order to transfer an image to a wafer, the surface of the wafer has to be made sensitive to light. To make the wafer (which is usually covered by a thin oxide film or some other dielectric passivation material) sensitive to an image, a photoresist is spread on the wafer by a process called *spin coating*. For the resist to be reliable it must satisfy three criteria: i) it must have good bonding to the substrate; ii) its thickness must be uniform; and iii) the thickness should be reliably controlled over different wafer runs.

Spin coating of a resist on a wafer: A photosensitive resist is "spun" onto the wafer.



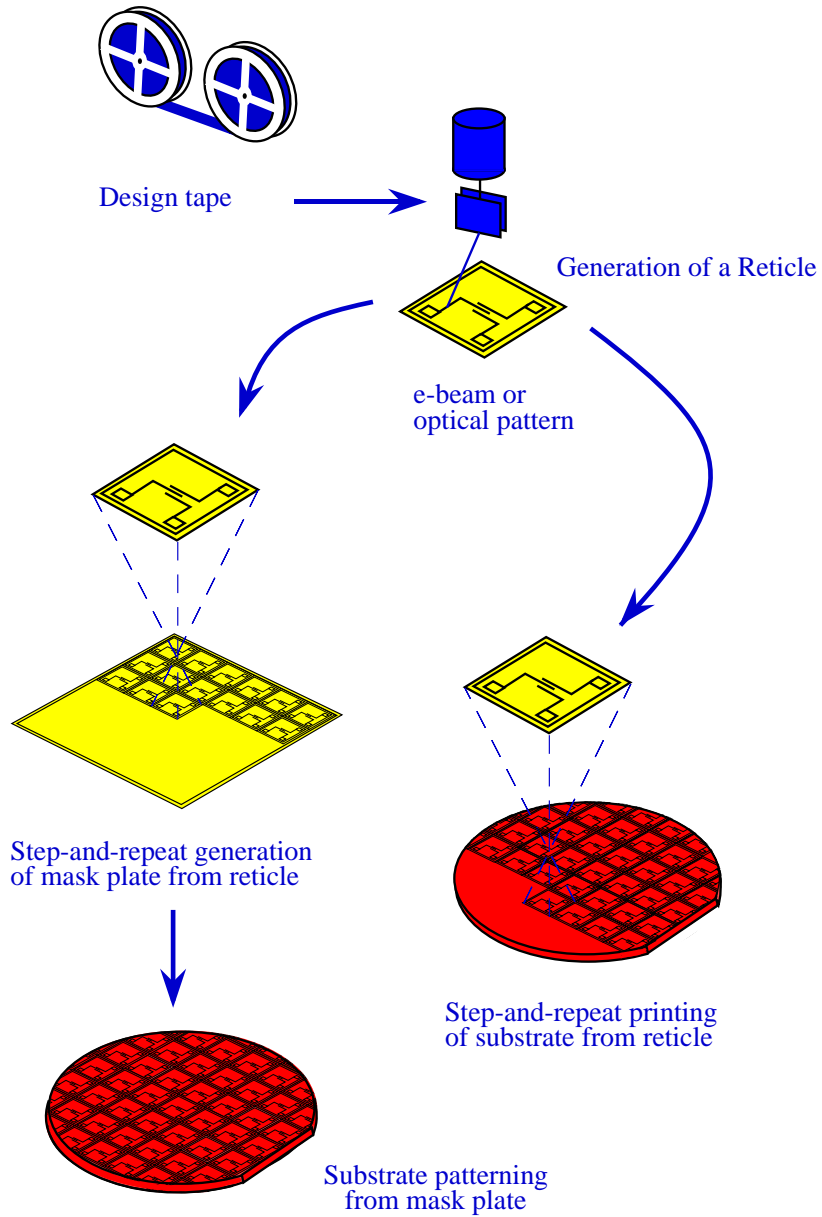
MASK GENERATION AND IMAGE TRANSFER

Transference of an image to the resist by using a mask and etching of the exposed regions.



LITHOGRAPHY: MASK GENERATION AND IMAGE TRANSFER

The processes used in the generation of a mask for lithography.



DOPING OF SEMICONDUCTORS

DOPING TECHNIQUES

EPITAXIAL DOPING:

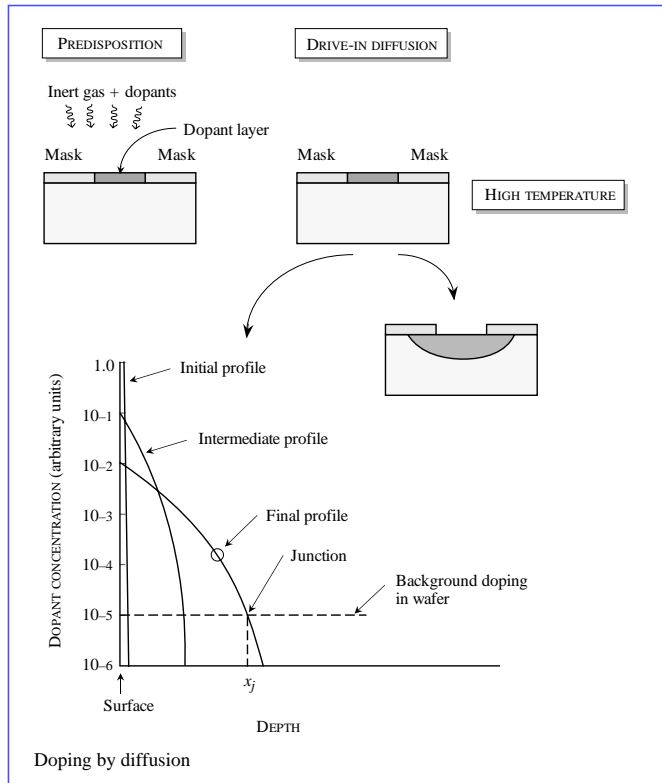
- + Highly controlled doping
- + Easy to switch from *n*- to *p*-type
- Cannot alter doping laterally
- Expensive

DIFFUSION DOPING:

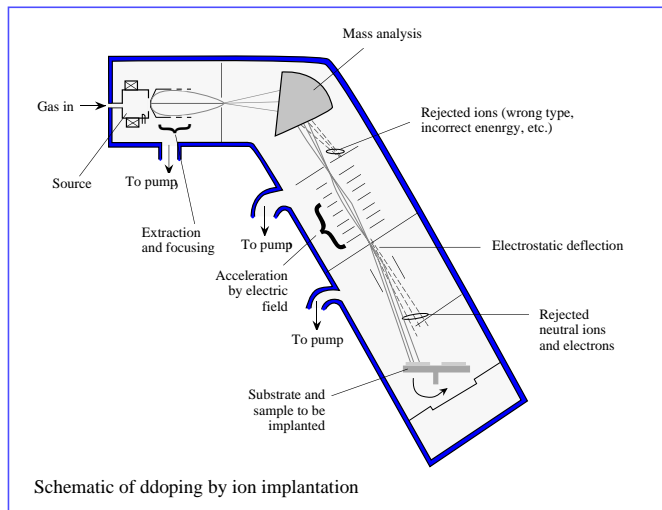
- + Can have lateral control over dopants
- Dopant profiles are not sharp

ION IMPLANTATION:

- + Inexpensive for mass scale applications
- Dopant placement is not very precise



Doping by diffusion



Schematic of doping by ion implantation

ETCHING

Once an image is transferred from a mask to a wafer, one has to remove or etch material from selected regions to form the final device. Specially designed etchants allow one to remove material in a selective manner once the resist has been patterned. The choice and control of the etching process is crucial if the features in the resist film are to become a part of the substrate.

APPROACHES TO ETCHING

WET CHEMICAL ETCHING

- Regions in the wafer are “dissolved” away by chemical reactions.
- Technique cannot produce sharp “sidewalls,” since etching is isotropic.

PLASMA ETCHING

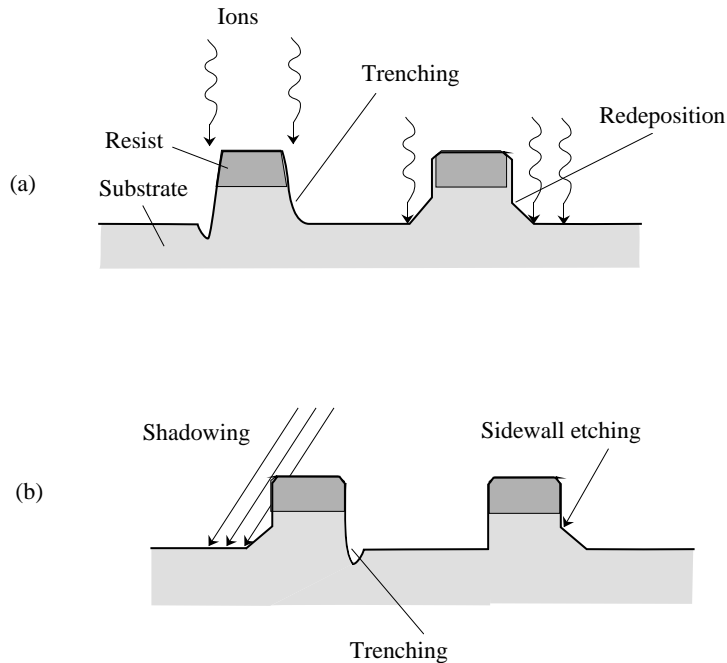
- Ions are created by generating a plasma by rf discharge. The ions react with atoms on the wafer. Ions can also be accelerated and their energy controlled for selective etching.

REACTIVE ION BEAM ETCHING

- Ions are accelerated in an ion implantation chamber. The beam is focused and used to etch materials. Very small regions can be etched selectively.

ION BEAM MILLING

- Ions beam is used to “chisel” off material from a wafer. The process is physical rather than chemical. Feature sizes $\leq 0.1 \mu\text{m}$ can be produced.



The importance of geometric effects in ion beam milling. In (a) the perpendicular incident beam can produce trenching effects as well as redeposition causing sidewall “ears;” (b) if the beam comes at an oblique angle and the substrate is rotated, the trenching and “ear” formation can be balanced.

INTERFACES BETWEEN MATERIALS

○ – oxygen
● – silicon
Si-O bond: 1.62 Å
O-O bond: 2.65 Å

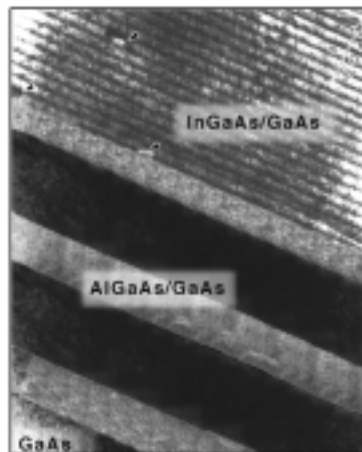
$a = 5.43 \text{ \AA}$
Si-Si bond: 2.34 Å

SiO₂
Si
Rows of Si atoms

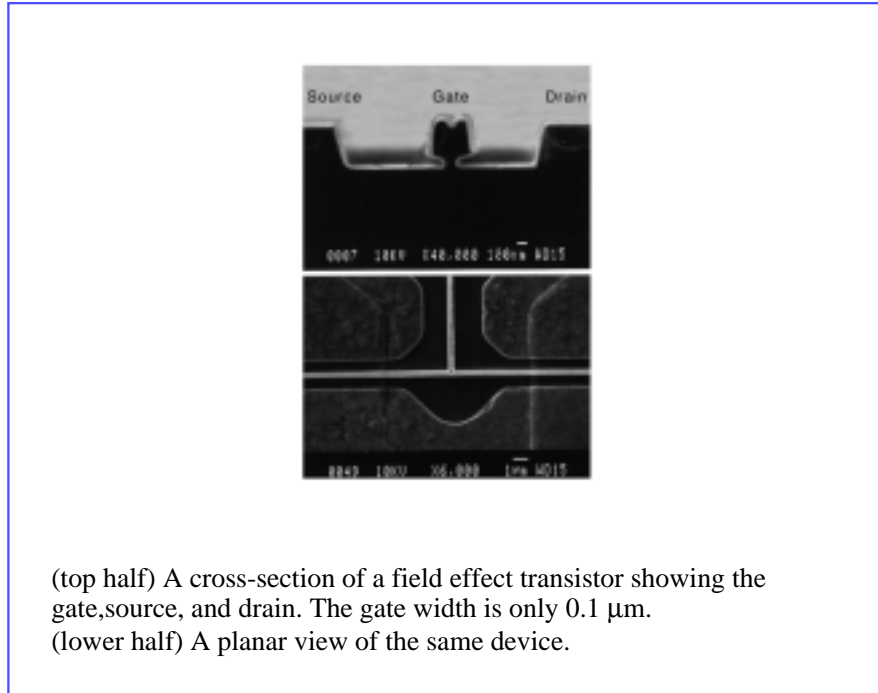
Si/SiO₂ is the most important interface in microelectronics. Interface is rough over $\lesssim 5 \text{ \AA}$ even though Si and SiO₂ have such dissimilar structures.

Interfaces between compound semiconductors with similar crystal structure

Interfaces can be abrupt to a monolayer



EXAMPLES OF HIGH-PERFORMANCE MICROELECTRONICS



A high resolution picture of a bipolar transistor with 1 μm emitter fingers.

