Lecture 15

Microfabrication – Pattern Transfer (VIII)

- Additive Processes: Lift-Off
  - Lift-Off
  - Spindt Process
- Planarization
  - Stringers
  - Chemical Mechanical Polishing
  - Planarization with Polymers
  - Resist Etchback

Lift-Off

- Lift-off is used with metals that are difficult to etch with plasmas.

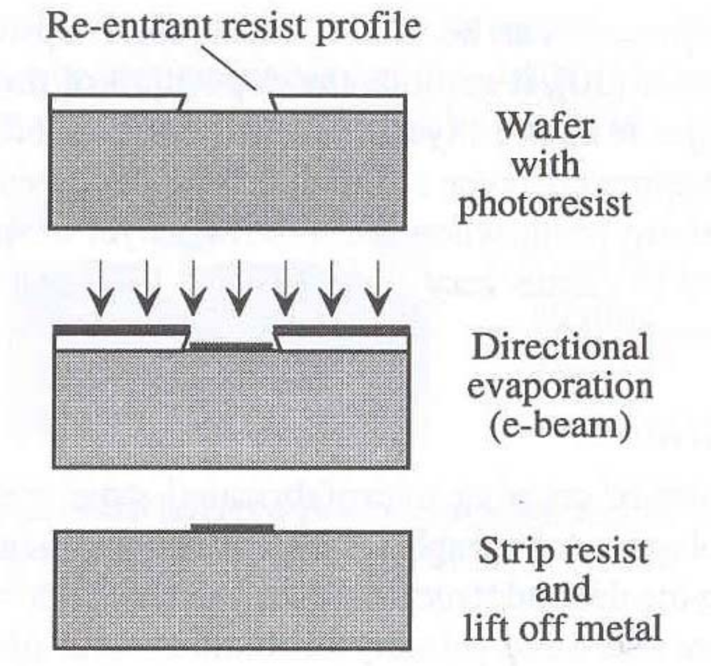
(1) A wafer is coated with a resist, and is exposed and developed so as to create a slightly re-entrant resist profile.

(2) The upper layer is patterned, and the second layer beneath is slightly undercut.

(3) When metal is evaporated from a directional source, such as an e-beam heated crucible, the resist profile shadows the side walls.

(4) Provided that the metal thickness is only a fraction of the resist thickness, discontinuous metal is deposited.

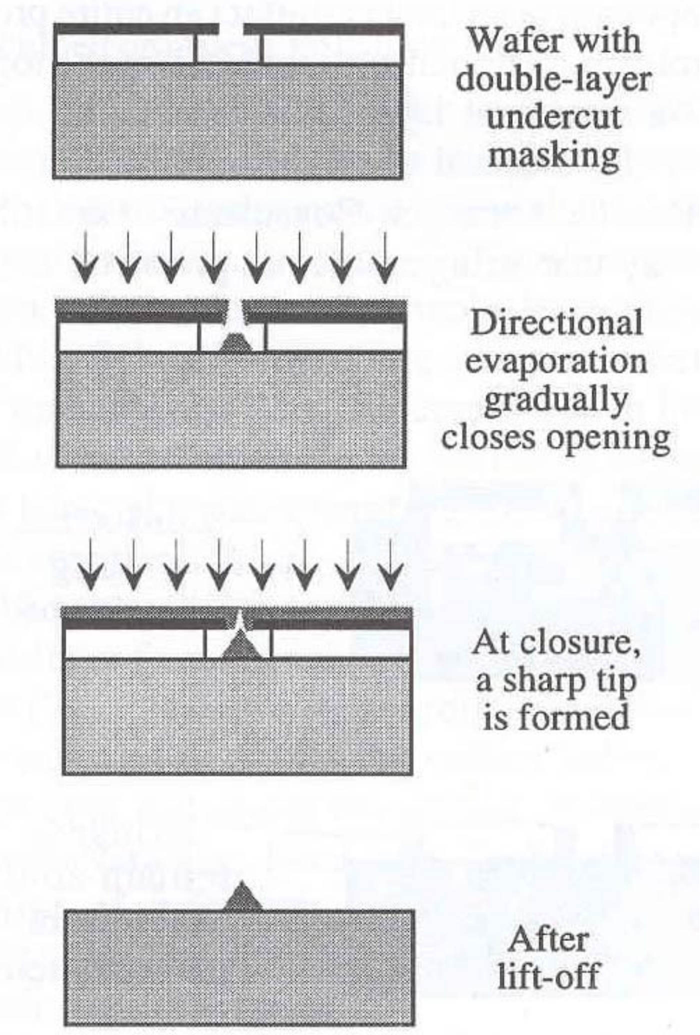
(4) When the resist is stripped, the metal on top of the resist is "lift-off", while the metal deposited directly into the opening of the resist remains.



Lift-off method for patterning evaporated metals

Spindt Process

- It exploits the deposition of the evaporated metal onto the edges of the masking layer, gradually closing off the opening.
- The evaporated layer at the substrate becomes conical in shape, finally reaching a sharp point when the masking layer closes off completely.
- This process is used to create very sharp tips for field-emission displays and vacuum-microelectronic devices.



Spindt process: The use of a modified lift-off process to create sharp tips.

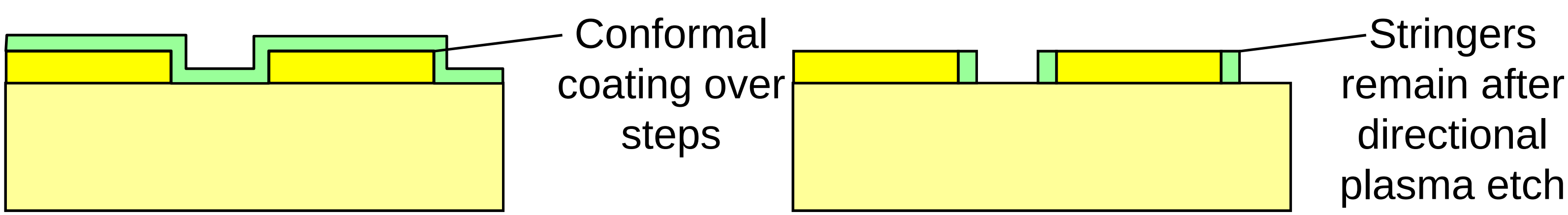
Planarization

- The initially flat wafer surface develops a topography.
- While topographical features may be essential to creating the desired structure, they can also interfere with successful process flow.
- There are three primary difficulties with non-planar surfaces:

  (1) Etching processes can leave behind unetched “stringers”
- (2) Non-planar wafers cannot be successfully bonded
- (3) Lithography is compromised,
- both by the difficulty of obtaining uniform resist deposition over non-planar surfaces and
- by the limited depth of focus of high-resolution lithographic exposure tools.

Stringers

- A thin film is deposited over a topographic feature, such as a portion of a sacrificial layer.
- When this film is patterned, it can be difficult to remove the material on the sidewall of the lower layer.
- This remaining thin slice is called a stringer.
- Considerable care is required to design processes in such a way that stringers are not produced at some point in the process sequence.

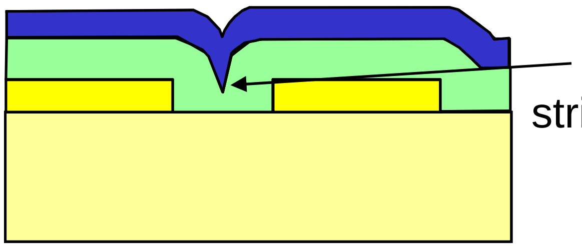


(continued)

Stringers

- A particularly difficult place for stringer formation occurs when a sacrificial layer is deposited over topographical features with a thickness comparable to the sacrificial-layer thickness.

When a sacrificial layer is deposited over topographical feature, a cusp is formed. If another structural is deposited over this cusp, the cusp region is extremely difficult to clear in a subsequent etch, so a stringer remains after etching.



- Because it is difficult to remove stringers, it is best to design the topography of the device so that they are prevented.
- One good method for doing this is to planarize the surface before depositing structural layers.
- There are two widely used planarization methods:

  (1) chemical mechanical polishing

  (2) resist etchback.

Chemical Mechanical Polishing

- Wafer polishing is a process in which the wafer is pressed against a rotating platen on which an abrasive slurry is provided.
- When this slurry includes chemicals that help dissolve material, the process is referred to as chemical mechanical polishing(CMP).
- Successive dielectric layers are planarized before performing the patterning step of opening vias to permit connection to lower layers.
- The vias are then filled with metal, after which, the next layer of conductor is deposited and patterned.
- By using planarized layers, extremely accurate lithography can be performed over complex substrate topography.

CMP in MEMS

- In MEMS, one important use is to prevent stringer formation during surface micromachining processes.
- If the intermediate sacrificial layer is made thick enough, it can be polished back to a flat surface before depositing the upper layer, removing the cusp that causes the stringer.
- A second use is to create flat surfaces prior to wafer bonding.
- Because wafer bonding requires intimate surface contact, remnants of surface topography can prevent good bond formation.
- A third use, like that in integrated circuits, is to provide a good planar surface for lithographic definition of features.

Pattern and Material Dependence

- CMP is primarily a mechanical polishing.
- Therefore, the rate of material removal depends on the local force applied to the surface.
- This force, and how it is distributed, depends in detail on the local topography.
- A flat smooth surface will much slower than a surface with a few peaks on it.
- This means that polishing rates exhibit a strong *pattern dependence*.
- As a result, the so-called "field regions" of a wafer, with no features, will polish at a different rate than regions that have local topography.
- Dummy structures can be placed in the field region to achieve uniform polishing rates across the wafer.
- Different materials polish at different rates, even with the same applied force.
- It is sometimes necessary to add thin polish-stop layers(for example, silicon nitride) over features that need to be revealed by a polishing step, but which should not themselves become thinner during polishing.

Planarization with Polymers

- Spin-cast polymers tend to planarize substrate topographies.
- There is an analogy to varnishing a floor.
- During application, the surface tension creates a flat surface.
- As solvent is lost, the film becomes thinner.
- When the viscosity becomes high enough that the polymer can no longer flow in response to surface force, the drying film develops topography that mirrors the underlying topography, but is less pronounced.
- To get a more planar surface, one applies more than one coating of polymer just as one applies multiple coats of varnish to get a perfectly smooth floor.

Planarization with Polyimides or SU-8

- Polyimides are often used for planarization.
- Because these materials can function at temperature above 300^{o}C, they can remain as part of the structure.
- But if the structure has mechanical loads applied to it, the response of the polyimide may vary with ambient humidity because it tends to absorb moisture.
- When it does, the residual stress in the polymer changes, and this can affect the mechanical behavior of the structure.
- SU-8 permits formation of extremely thick layers that can planarize large topographical features in a single application.
- The resist is based on epoxy-resin chemistry, and once hardened at 200^{o}C, is difficult to etch or remove.
- It can be used as a structural component of devices intended for low-temperature use (below the hardening temperature).

Resist Etchback

- Planarization by a polymer can be exploited to planarize an oxide layer over which the polymer is deposited.
- Photoresist is deposited over oxide topography so as to planarize that topography.
- Wafer is then plasma etched with an etch recipe that etches the photoresist at about the same rate as the underlying oxide.
- This results in a much more planar oxide surface.