Lecture 7

Microfabrication
– Wafer-Level Processes (V)

- Wafer-Level Processes

  - Wafer Bonding

    Direct Wafer Bonding of Silicon

      Direct Bonding

      SOI

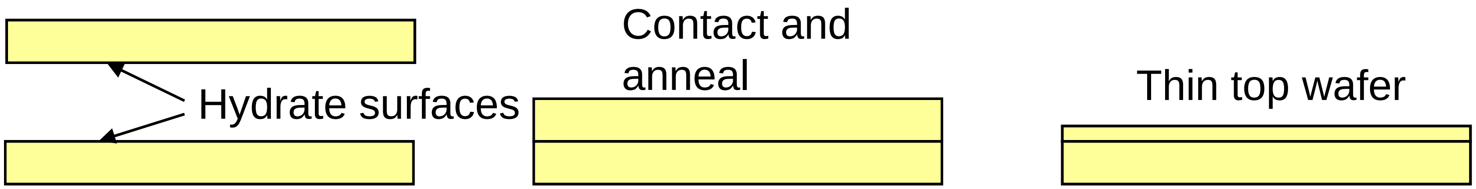
      Bonding on Patterned Wafer

    Anodic Bonding

    Bonding with an Intermediate Layer

Direct Wafer Bonding of Silicon

- The direct bonding of silicon wafers to one another requires high temperatures, on the order of 1000 ^{o}C.
- (1) The cleaning and hydration of the surfaces to be bonded.
- They must be smooth and completely particle-free.
- Contaminant particles create gaps which cause the bonding to fail locally.
- Hydration typically occurs during the wafer-cleaning operation.



Illustrating the direct fusion bonding of two silicon wafers

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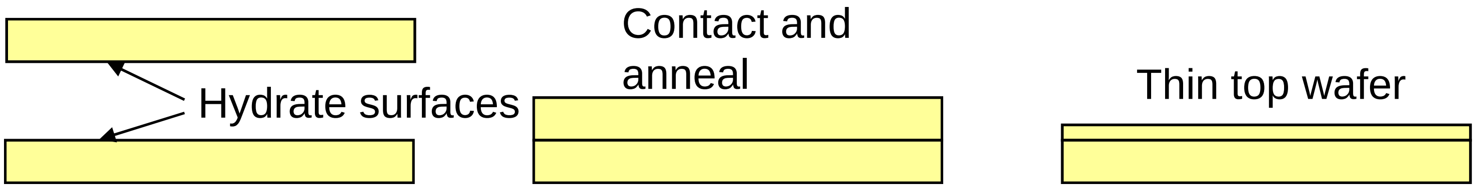
Direct Wafer Bonding of Silicon

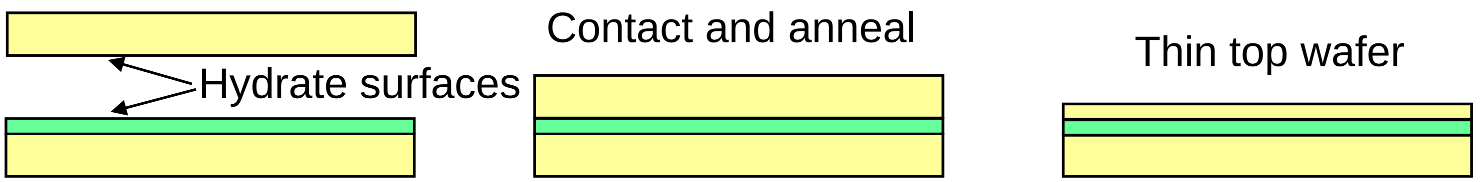
- (2) The surfaces to be bonded are contacted and pressed together, using hydration bonding of the hydrated surfaces to provide a modest degree of adhesion.
- The contacted pair is placed in a high-temperature furnace to fuse the two wafers together.
- The resulting bond is as strong as the silicon itself.
- (3) After bonding, the top wafer can be thinned by mechanical grinding and polishing, or by wet etching.



Illustrating the direct fusion bonding of two silicon wafers

Silicon-On-Insulator (SOI) Wafer

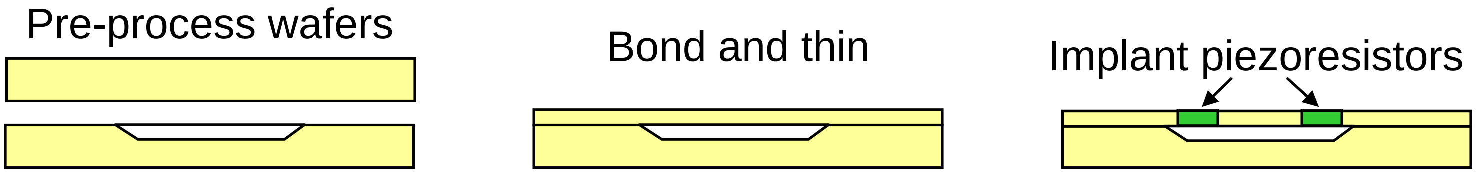
- The bottom wafer has a thermal oxide on it.
- The surfaces are cleaned and hydrated, then contacted and annealed, and the top wafer is thinned.
- The result is a layer of silicon on an insulating oxide, SOI wafer.
- BESOI: SOI structure is formed by bonding followed by etchback of the top layer.



When one of the wafers has an oxide on its surface, the resulting structure is a thin film of silicon on insulting oxide. This type of structure is called silicon-on-insulator, or SOI.

Bonding on Patterned Wafer

- One of the two wafers has cavity etched into it.
- After that, the surfaces are cleaned and hydrated, contacted, and annealed.
- The upper wafer is then thinned, leaving a thin silicon diaphragm over the cavity.
- Piezoresistors can then implanted into the diaphragm, making a pressure sensor.



Illustrating the fabrication of a piezoresistive pressure sensor using wafer bonding.

Sealed Cavity

- After bonding and thinning, the exterior of the wafer is virtually identical to a blank wafer.
- It can be used in a standard microelectronics fabrication line to build transistors on the regions next to the cavity.
- After the transistors are built, subsequent etch steps in the diaphragm region can be used to create movable microstructures on the same wafer as the circuitry.
- Depending on the ambient atmosphere in which the wafers are sealed, the sealed cavity may have residual gas in it.
- Oxygen in the cavity reacts with the walls during the high-temperature anneal, forming a thin oxide on the cavity walls.
- Nitrogen or other inert species remain.

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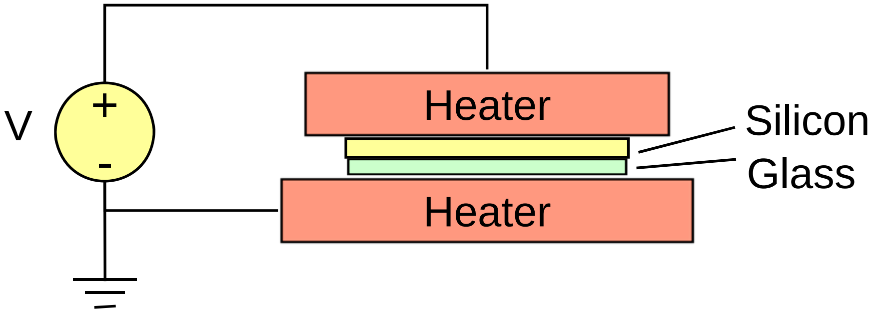
Sealed Cavity

- After the device is thinned, the diaphragm is potentially vulnerable to damage when heated, because the pressure increase of the residual gas in the cavity causes the thinned diaphragm to bend, and possibly break.
- By controlling the ambient gas composition during bonding, cavity pressure after bonding can be reduced to a safe zone.
- It is also possible, using commercially available equipment, to align already-patterned wafers to one another prior to bonding, with accuracies of a few microns.
- This makes possible microstructures that cannot be fabricated using a single wafer.

Anodic Bonding

- A method which is restricted to certain glasses bonded to conductors. The mechanism responsible for anodic bonding is the mobility of sodium ions in the glass.
- Pyrex 7740 glass, which has a thermal expansion close to that of silicon, is a good candidate.
- When the silicon wafer is placed on the glass, and the two are heated to temperatures on the order of 500 ^{o}C, a positive voltage (300 – 700V) applied to the silicon repels sodium ions from the glass surface, creating a net negative charge at the glass surface.



Apparatus for anodic bonding of silicon to glass

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Anodic Bonding

- The force of attraction between the positively charged silicon wafer and the negatively charged glass surface brings the two surfaces into intimate contact.
- At the elevated temperature, they can fuse together.
- Contact is typically initiated at a single point by applying a load, and as contact is established, it spreads out to cover the rest of the wafer.
- Bonding time ranges from seconds to minutes and can be monitored by measuring the current in the circuit.
- When the bonding is completed, this current drops to zero.

Bonding with an Intermediate Layer

- In the microelectronics, candidates for the role of the adhesive must meet the thermal and cleanliness requirements of microfabrication.
- Glass frits, which are powdered slurries of relatively low melting glasses, can be applied selectively to parts of the surface of one of the wafers using techniques such as screen printing.
- After a low-temperature bake to reduce the fluid content of the frit layer, the wafers are contacted and annealed, flowing the glass into a continuous layer that bonds the wafers together.
- Thermocompression bonding: To use gold layers and apply moderate pressure to the wafers at a temperature of about 300 ^{o}C.
- Using conventional solders, provided the mating surfaces have been pre-coated with a material which the solder can easily wet.
- Polymeric adhesives, such as polyimides, silicones, or epoxy resins, provided that the cleanliness and thermal requirements of the device are not compromised.