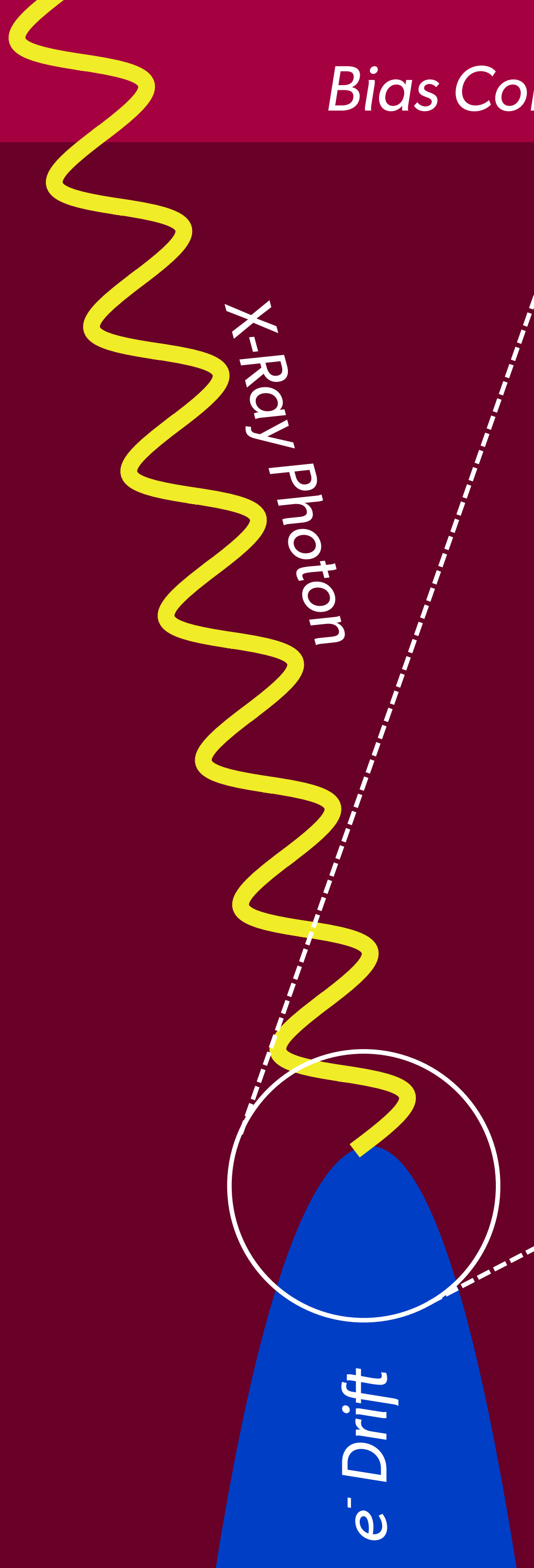
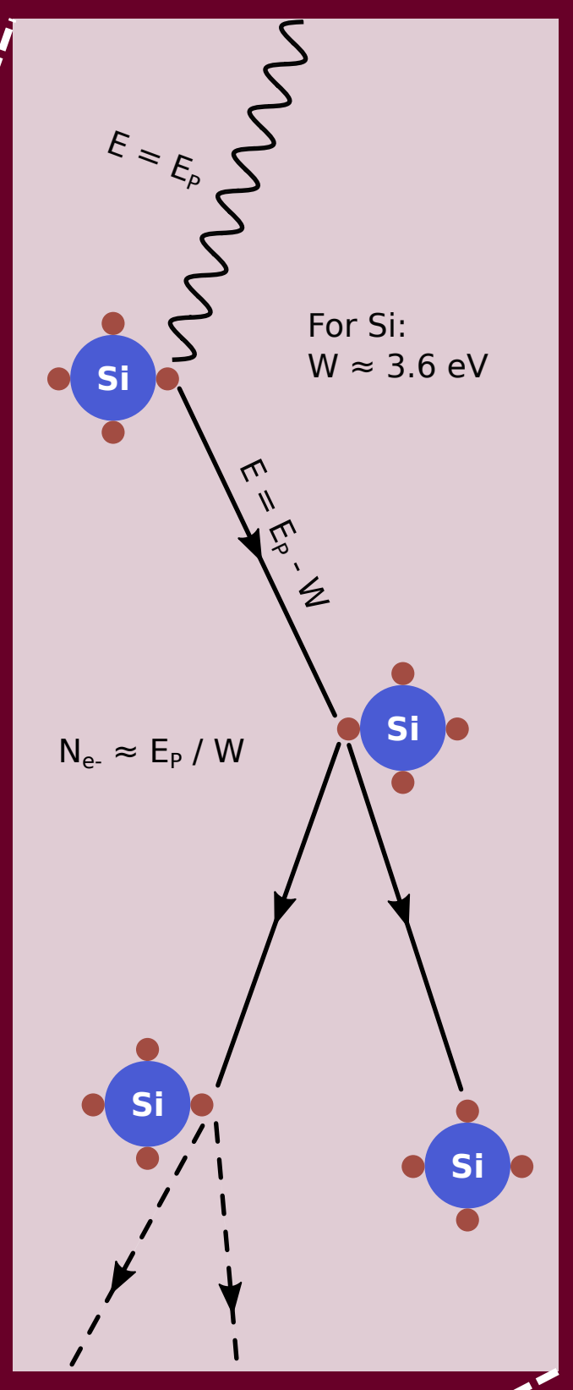
Bias Contact





Towards Novel Wafer-Wafer Bonded Pixel Detectors

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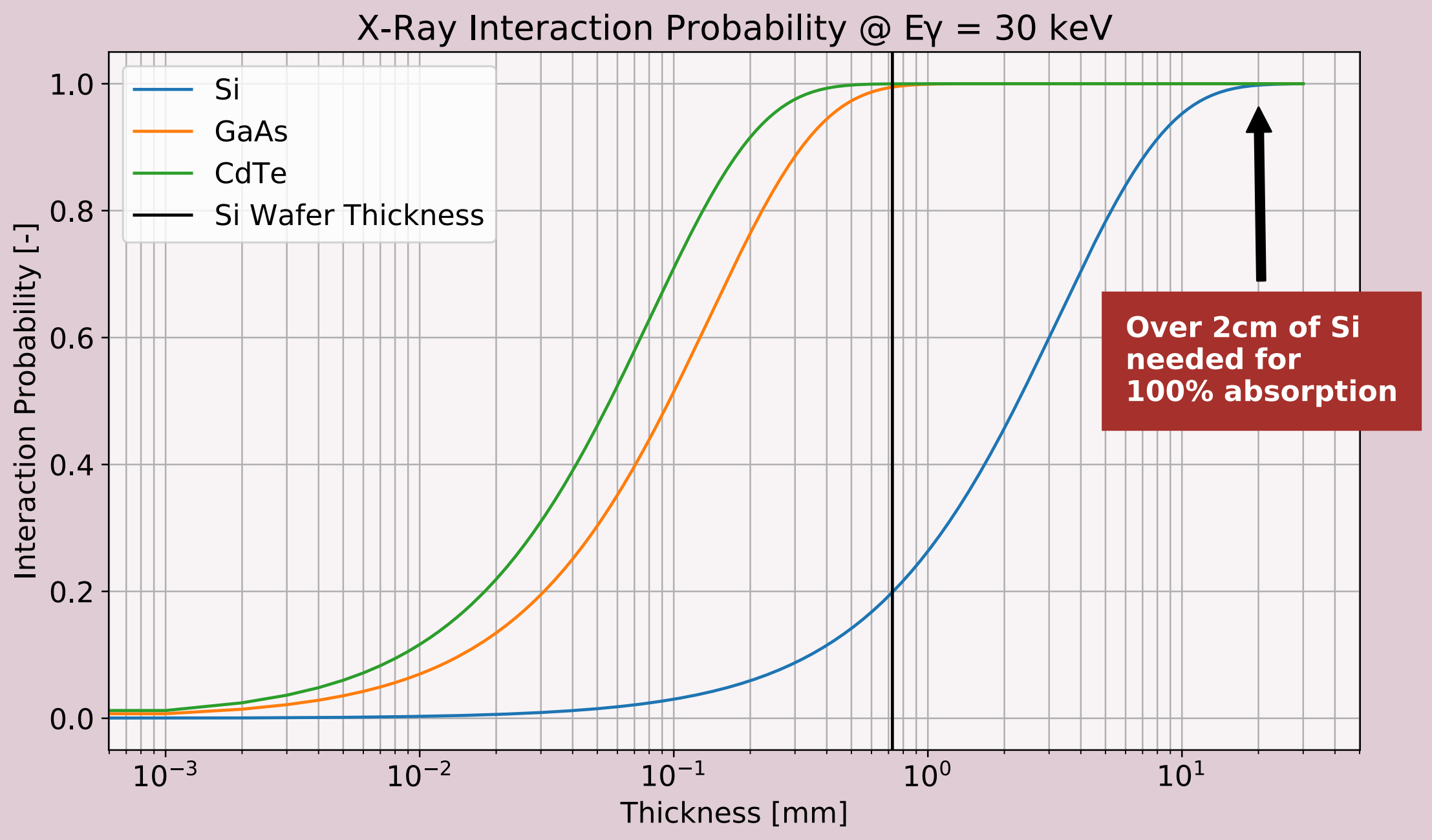
Motivation

- Low temperature covalent bonding enables the fusion of different semiconductor crystals without any additional material at the interface.
- In the ideal case, this would lead to an abrupt hetero-junction, which allows for transport of charges between the two materials.
- The bonding process used is similar to direct bonding, but is carried out at or near room temperature, without the need for a high temperature anneal.
- In the context of pixel detectors, this would allow to combine readout chips fabricated using a standard CMOS process, with a custom radiation absorbing material.
- This processing is carried out at a wafer level enabling mass processing.
  The operation principle would be similar to a depleted monolithic pixel detector.

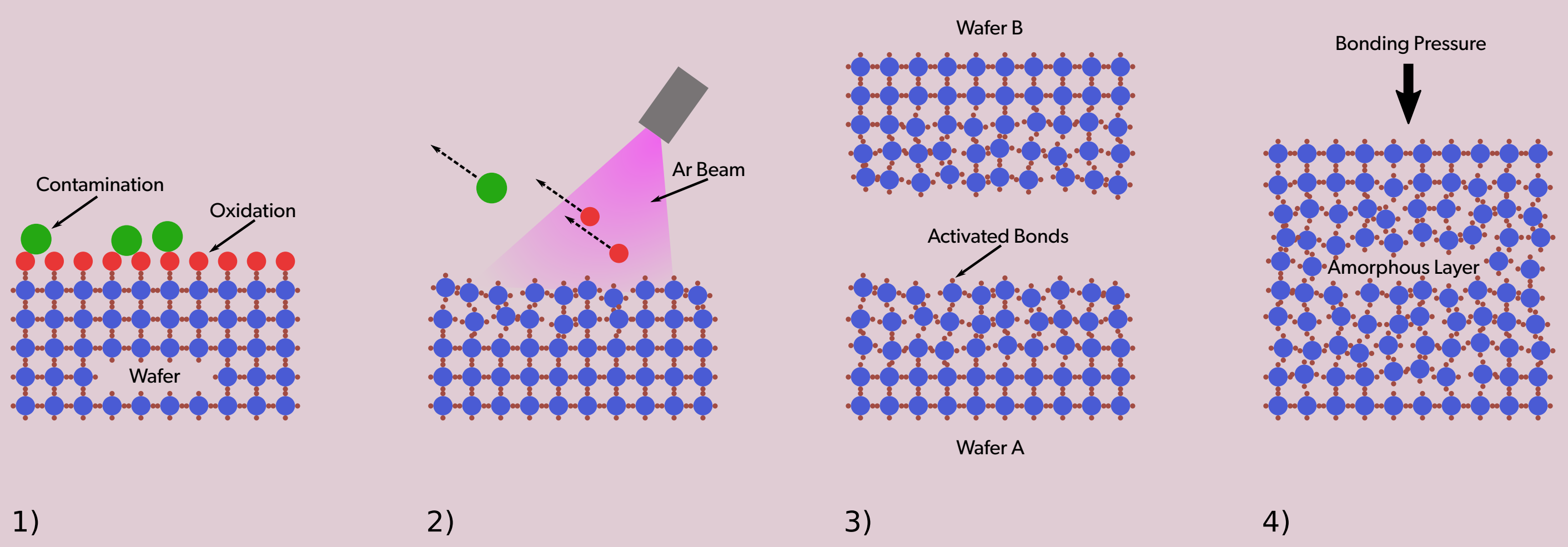


X-Ray Attenuation Coefficients from NIST

- When compared to silicon, High-Z materials (such as GaAs or CdTe) are highly efficient at absorbing X-Ray photons at low to moderate energies.
- Using such materials as an absorber for medical X-Ray imaging sensors could lead to near 100% detection efficiency within the detector.
- This in turn would allow to take X-Ray images with a lower total radiation dose for the patient, compared to when using a non-efficient X-Ray sensor.
- **Therefore medical X-Ray imaging would be a prime application for this novel type of radiation pixel detector!**

Low Temperature Covalent Wafer Bonding

First proposed in 1996 by H. Takagi et al. in [3]

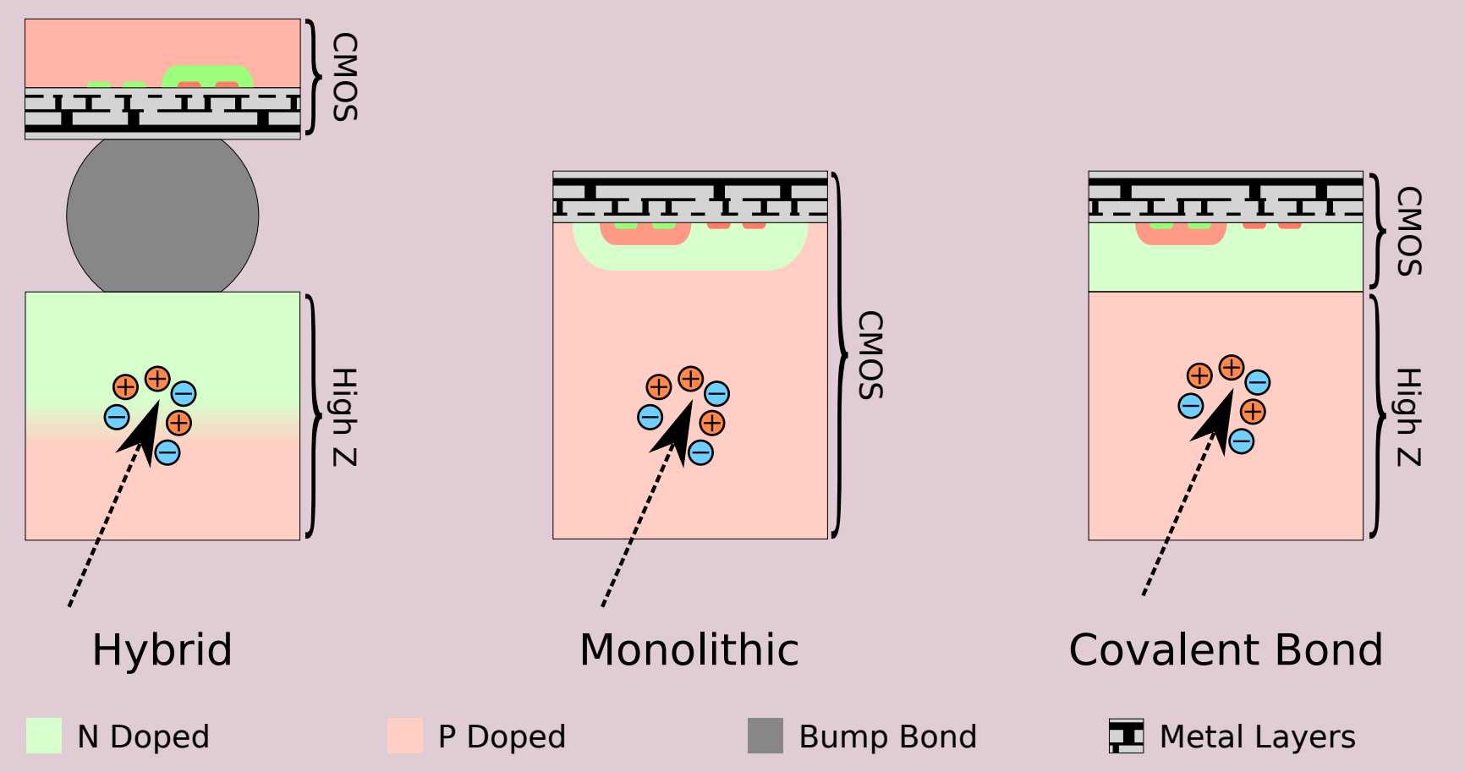


- Bonding is carried out in ultra-high vacuum ($p < 10^{-8}$ mbar).
- The wafer surfaces are cleaned using an argon plasma or an argon beam.
- This removes any oxidation and any surface contaminants and creates reactive (activated) crystal bonds at the wafer surface.
- Bonding happens spontaneously when the two wafers are brought into contact under (moderate) pressure.
- No high-temperature annealing is necessary to achieve a good bond.
- This allows to **bond fully processed CMOS wafers**.

Our Goals

- Electrical characterization of the covalent bonding interface.
- Focus on the transient behavior in the case of high substrate resistivities (as used in sensors).
- Initial focus on Si:Si interfaces with expansion to other materials later on.
- Characterization is enabled by the fabrication of custom test structures.

Comparison with Existing Detector Structures



- Hybrid detectors are limited by the size and yield of the bump bonds.
- Monolithic detectors do not allow any flexibility in the choice of the sensor material.

Influence of the Covalent Bonding Interface

- The covalent bonding process does not result in a perfect crystal interface.
- The activation by Ar beam leads to a (thin) amorphous layer at the interface. This layer, combined with a miss-alignment of the crystal, leads to bulk defects at the interface.
- The amorphous layer may have additional effects on electrical charges crossing the interface.
- In steady state applications (for example Solar Cells), the effects of the interface can be mitigated via high doping concentrations [2].
- The effect of the interface on transient charge pulses has yet to be fully investigated!
- In order to design efficient detectors, the behaviour of the covalent interface needs to be studied in detail.

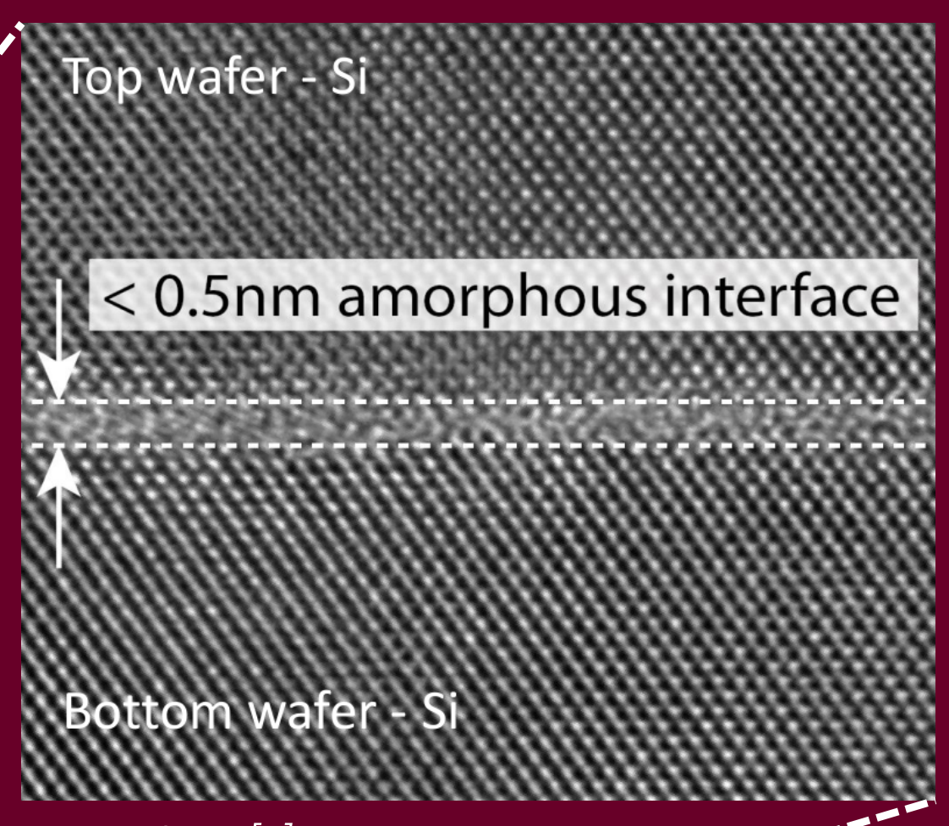


Image from [1]

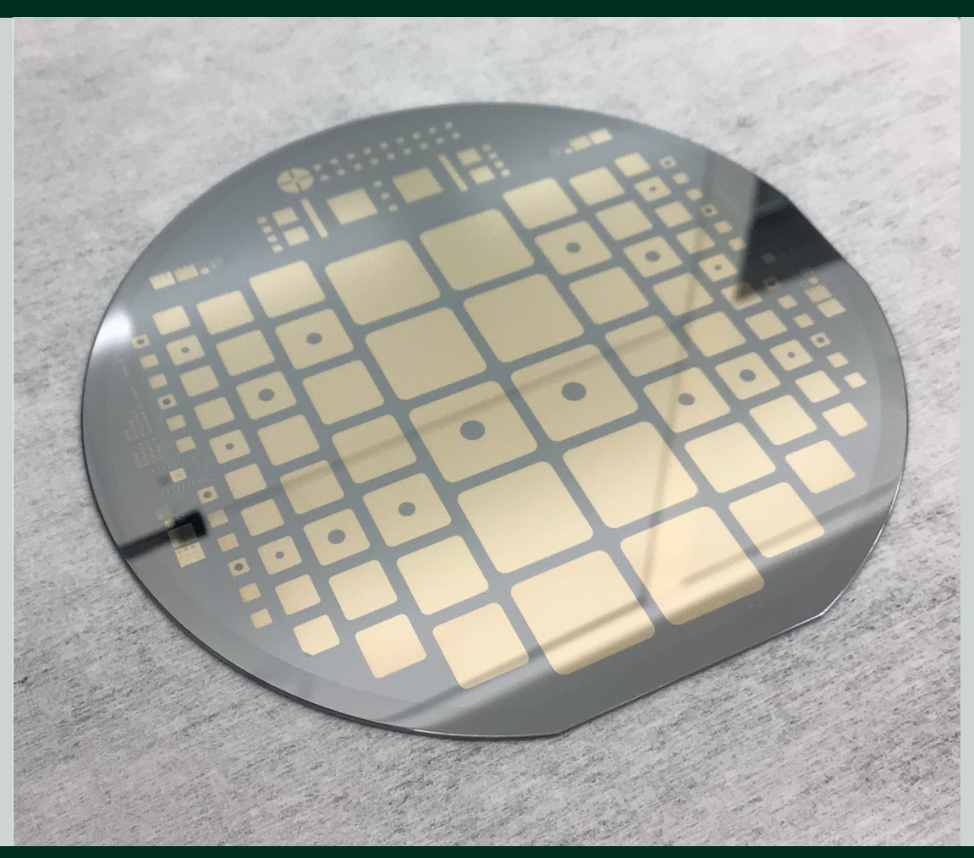
High-Z Absorber (i.e. GaAs)

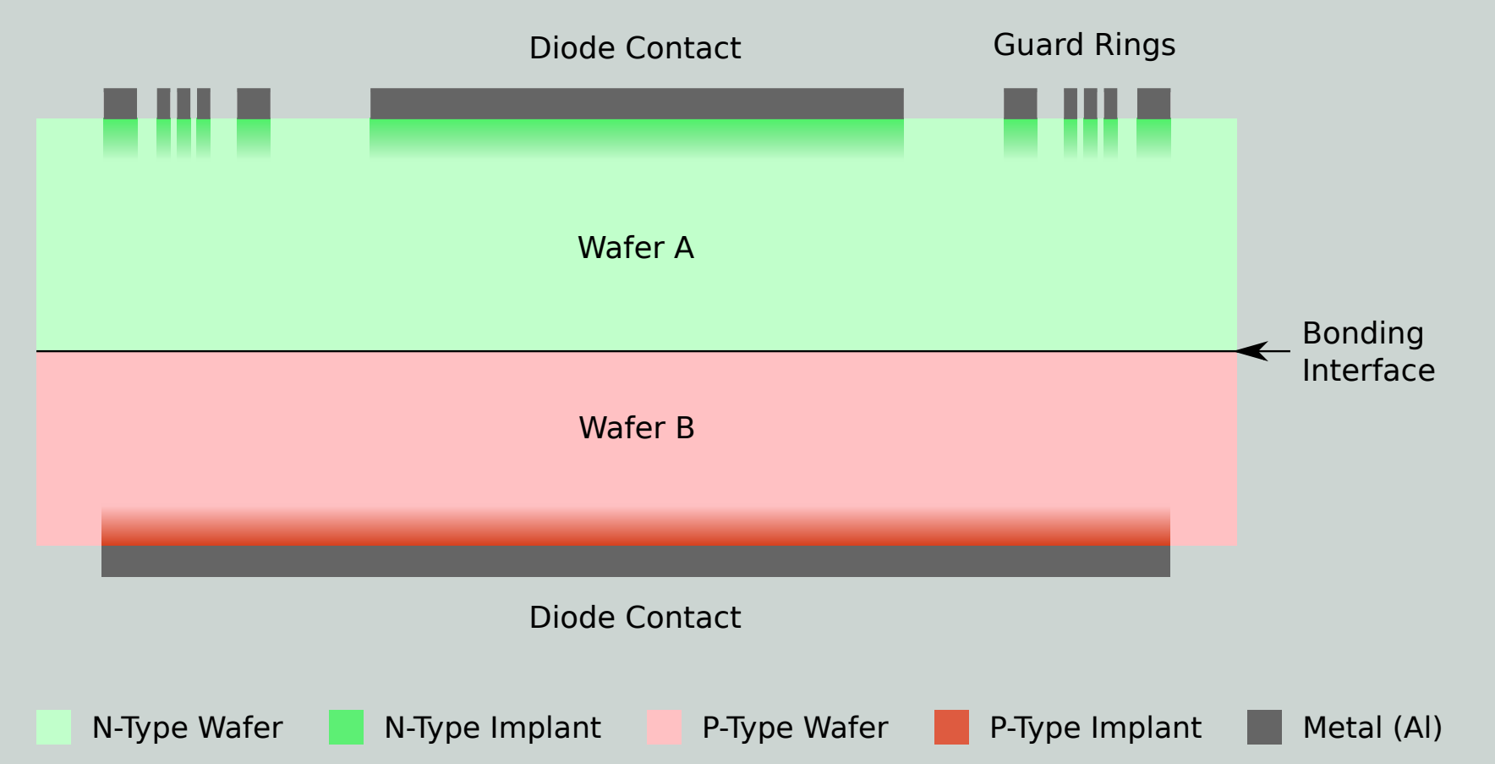
Bonding Interface

CMOS Readout

Processing of Custom Test Structures

- Manual processing in our university cleanroom.
- Fabrication of simple bonded diodes, to be used for electrical characterization.
- Process steps include:
  - Doping via ion beam implantation
  - Wafer polishing via CMP
  - Wafer-wafer bonding
  - Contact metallization via evaporation
  - Wafer dicing and wire bonding





References

[1] J. Neves, presented at the VCI2019, Vienna, Feb. 21, 2019.
[2] F. Predan et al., Apr. 2020, doi: 10.1117/12.2557979.
[3] H. Takagi et al., Apr. 1996, doi: 10.1063/1.115865.

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Readout Electronics

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