How wafer direct bonding mechanism enables die-to-wafer technology.

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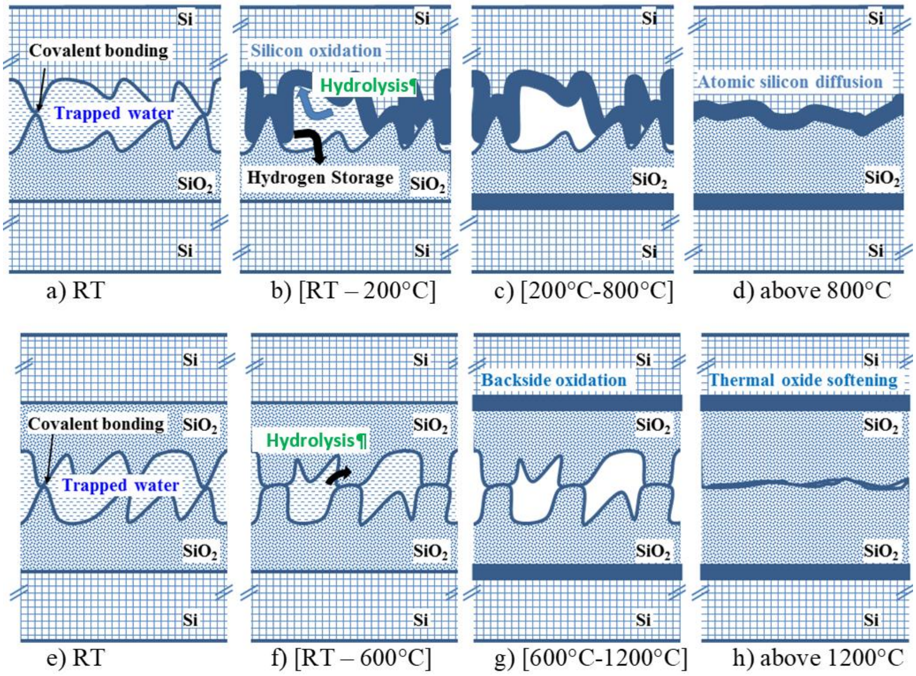
Direct bonding, of which hydrophilic molecular bonding is now the most widespread type, is currently used in mass production in the microelectronics industry. After a brief introduction to direct bonding, we will focus on this specific subtype. We will analyse the origin of its adhesion energy, which enables the bonding to self-propagate, as well as the consequences in terms of defectivity when the Joule–Thomson coefficient of the bonding atmosphere is positive.

After bonding, although covalent bonds are already present at room temperature, adherence generally remains weak. A thermal annealing step is therefore required to increase the density of these bonds until complete sealing of the interface is achieved. To shed light on the physicochemical mechanisms responsible for this increase in adherence using silicon dioxide material (cf. Fig. *1*), we will briefly discuss results obtained from other types of direct bonding. This comparison will highlight the central role of interfacial water and its influence on the mechanics of silica asperities. In particular, we will see that chemical catalysts can be used to drastically enhance adherence at low annealing temperatures (cf. Fig. *2*). These chemical bonding energy boosters can replace the standard plasma treatment to obtain plasma free direct bonding.



a) RT b) [RT – 200°C] c) [200°C-800°C] d) above 800°C

e) RT f) [RT – 600°C] g) [600°C-1200°C] h) above 1200°C

Fig. 1 : Mechanism for silicon and silicon dioxide molecular direct bonding [*1*].

Of course, changing the bonded material will drastically impact the bonding mechanism to explain the adherence evolution. Usually, the adhesion energy and the direct bonding propagation is not impacted by the bonded material. As an example, copper/copper bonding mechanism will be discussed. This opens the way to hybrid bonding as this bonding uses two hybrid surfaces made of copper and SiO_2.

Wafer-to-wafer bonding, using wafer diameter up to 300mm, presents many advantages in terms of large bonded area, availability of advanced CMOS wafer and compatibility to any microelectronic classical process. However, many materials of interest, such as InP and GaAs, which are commonly used in photonic applications, are not available in large wafer sizes. Moreover, in 3D applications, the bottom and top chips do not have, in general, the same sizes. And even if they have the same size, it is highly advantageous for overall yield to bond only functional chips onto functional chips. This approach cannot be implemented using wafer-to-wafer bonding.

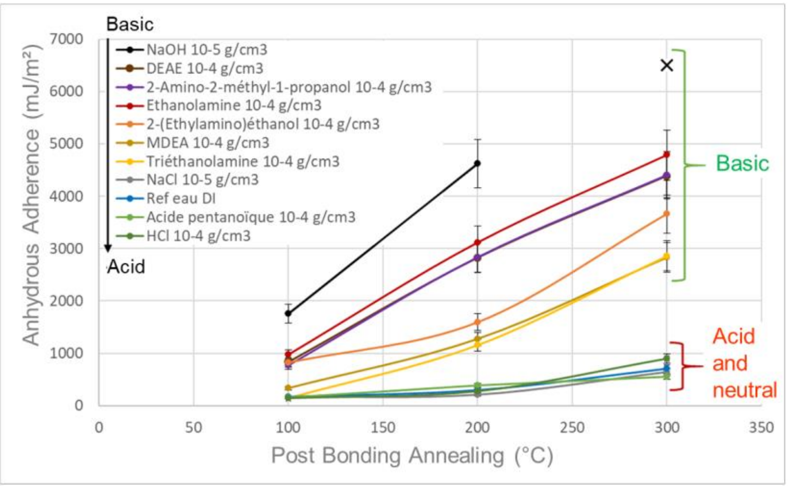
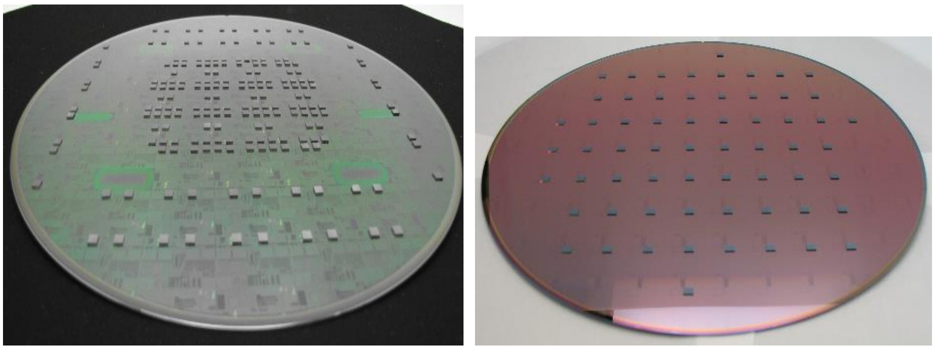


Fig. 2 : Chemical bonding energy boosters for $SiO_2//SiO_2$ direct bonding [2].

Die-to-wafer bonding, which maintains the advantages of a direct bonding interface, offers significant potential for integrating different materials or enabling pre-bond functional testing of dies. Even if the fundamental direct bonding mechanisms are not changed, some specific features have to be taken into account for die bonding. For instance, edge effects during and after the bonding or annealing, significantly impact both bonding energy and interface defectivity. To reduce interface defectivity, a specific bonding technique using liquid water could be employed only in die-to-wafer bonding. If all these specific features are under control, then, very innovative structures could be obtained. It is possible for instance to bond small 3 mm*3 mm InP dies onto a 200 mm silicon photonic wafers as shown on Fig. 3a [3]. Moreover, hybrid bonding interface could be also obtained between 6 mm*4 mm dies and a 300 mm wafer as shown on Fig. 3b. For hybrid bonding, precise alignment is mandatory. This can be achieved using die-to-wafer bonder, but innovative technologies such as capillary-assisted self-assembly could also be highly beneficial [4,5].



a) b)

Fig. 3 : a) *InP dies directly bonded on a photonic SOI wafer. b) Die-to-wafer hybrid bonding example.*

References

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