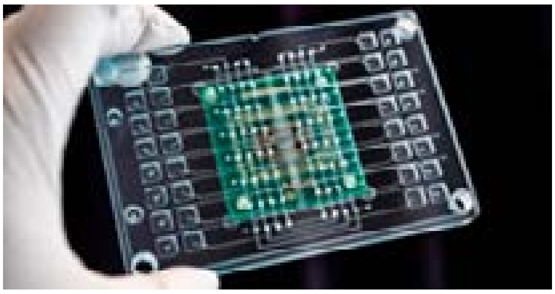
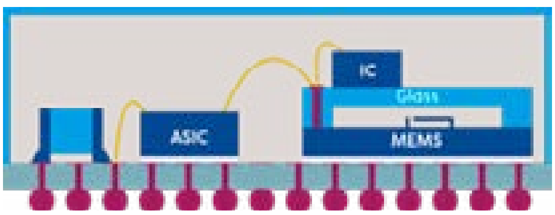
Hybrid bonding

a crucial technology in MEMS and microfluidics

Technical advancements ask for more complex devices. The complexity of devices is determined by the number of components that are incorporated. What solutions are being thought of to keep up with these developments? And what does this mean for the design of future devices?



Heterointegration: a microfluidic well plate fused with a high-density multi-electrode array (MEA) chip.



Heterointegration: wafer level capping (glass lid) in a SiP-application.

Heterointegration

Emerging trends in MEMS and microfluidics demand more intelligent and therefore more complex devices. On one hand this upscaling of devices can lead to a more intensified use of specific features (e.g. in high throughput analysis), on the other hand there is the trend of applications becoming more and more individualised.

All this calls for the integration of several techniques and components (or: units) into one 'package'. These components can consist of an individual die, MEMS device, sensor, actuator, passive component etc. All these choices and possibilities can be captured into one term: heterointegration.

Heterointegration is all about multi-chip packaging; the integration of various substrate materials into one package. A key process in heterointegration is bonding – a technology with a rapidly growing relevance in packaging on wafer level.

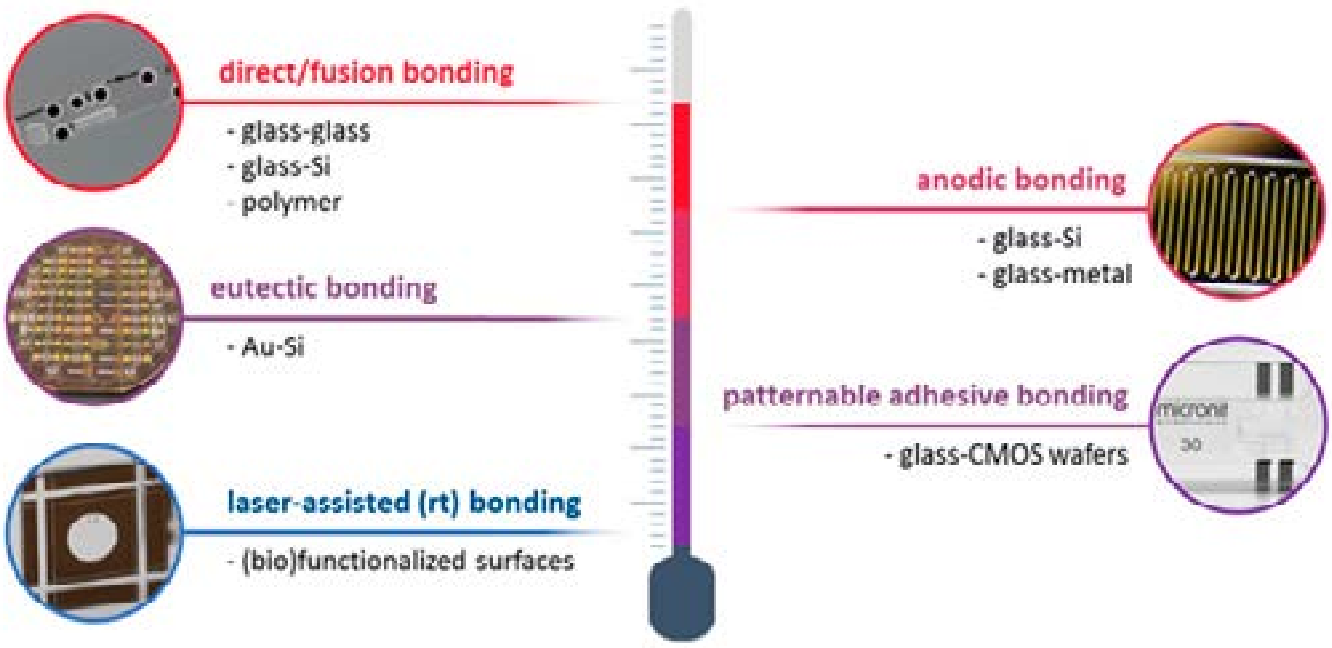
Wafer bonding and temperature

For numerous applications, bonding of two or more (structured) substrates is required. Often, the bonding process involves different types of materials. These hybrid material bonding processes bring their own challenges. Various solutions are available for hybrid bonding and for the integration of specific elements into the devices, like porous membranes, flexible films and (bio)sensors.

Most bonding processes require a typical working temperature. To be able to perform complex hybrid bonding and therefore having to reckon with the specific properties of various materials, it is necessary to have a wide range of bonding methods so in any case the most suitable method can be chosen.

Micronit currently provides five different bonding methods, including direct/fusion bonding, anodic bonding, eutectic bonding, (patternable) adhesive bonding and laser assisted room temperature bonding.

This portfolio gives way to numerous hybrid bonding possibilities for many materials and applications.



Five different substrate and wafer bonding methods.

Bonding methods

Direct/fusion bonding is a bonding process that requires no additional intermediate layers. The process is based on forming a direct chemical bond between two surfaces by annealing them at elevated temperatures.

The bonding process typically comprises of three steps:

1) wafer preprocessing/cleaning

2) establishing a pre-bond at room temperature

3) annealing at higher temperatures.

A prerequisite for direct or fusion bonding is that the wafer material is sufficiently clean, flat and smooth, and that there is no significant mismatch in coefficients of thermal expansion for the two materials to be joined. It is therefore mainly used in establishing glass-glass, glass-silicon and polymer compounds.

Technical Details

- *No intermediate layer*
- *Integration of electrodes possible*
- *High bond strength*
- *Aligned bonding*
- *Multi-stacks*

Applications

- *Microfluidics (microreactors/micromixers)*
- *Cover of microfluidic channels*
- *MEMS structures*
- *MEMS sensors*
- *Packaging*

Glass-glass bonded chips with integrated sensors.

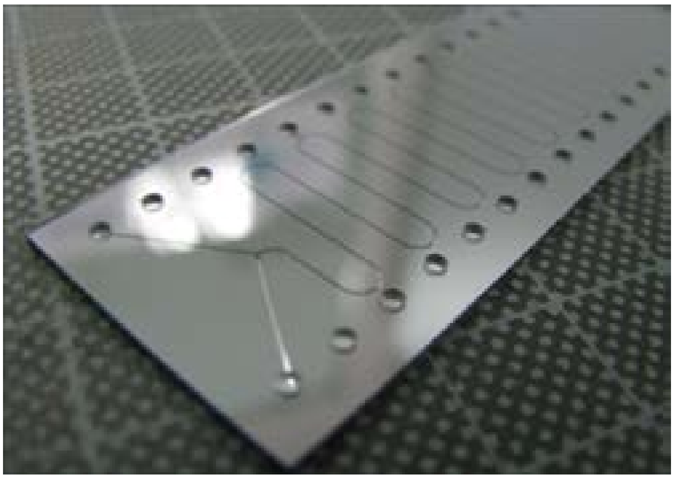
Anodic bonding seals glass to either silicon or metal, at lower temperatures than required for direct bonding. This is done by using a sufficiently powerful electrostatic field, which is used to generate a bond between the two substrates. In anodic bonding, there is no requirement for an intermediate layer. The only requirements are clean and even wafer surfaces and the use of borosilicate glass containing a high concentration of alkali ions to bond with the silicon or metal, since the process depends on the migration of these ions due to the applied electrical field. In this bonding process, the coefficient of thermal expansion (CTE) of the processed glass needs to be equal to that of the bonding partner. This technique can also be used for triple stack bonding (glass-silicon-glass).

Technical Details

- *Aligned bonding*
- *Vacuum bonding possible*
- *Integration of electrodes & biosensors possible*

Applications

- *MEMS structures*
- *MEMS sensors*
- *Packaging*
- *Lab-on-a-chip or point-of-care*



Anodic bonding: silicon-glass hybrid meander chip.

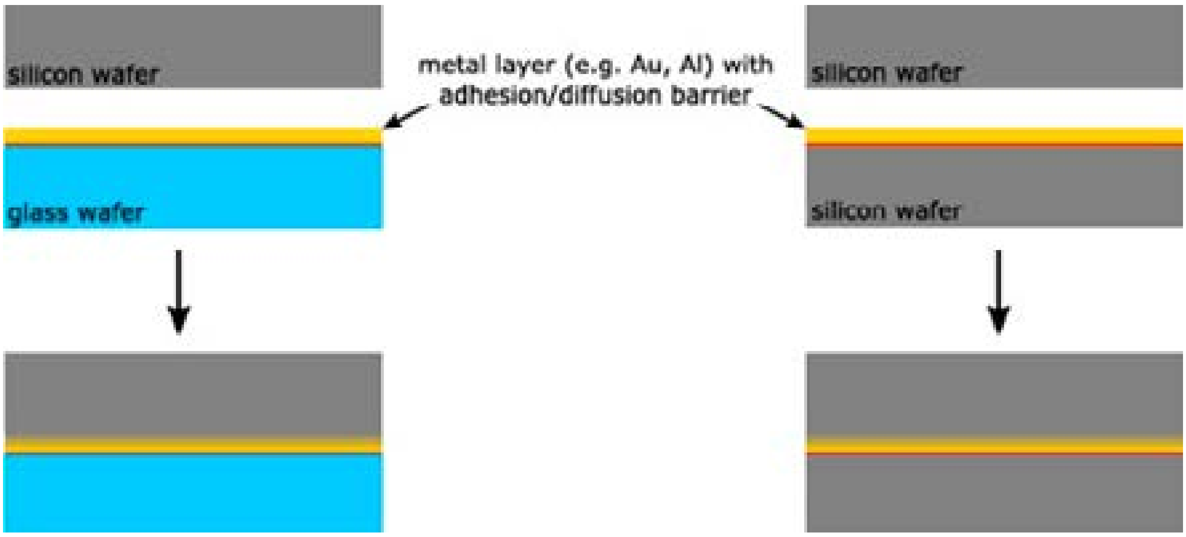
Eutectic bonding is based on the ability of silicon to form a eutectic system with certain metals. A eutectic system is an alloy of two or more substances (e.g. silicon and gold) that, as a homogeneous mixture, melts at a temperature that is lower than the melting point of either of the individual substances. The most commonly used eutectic formations are silicon and gold or silicon and aluminium. The bonding process itself takes place on a silicon or glass wafer that is coated with a (patterned) gold or aluminium layer. A silicon substrate is placed on top and heat as well as pressure are applied until the silicon forms a eutectic system with the alloy on its counterpart. This technique delivers hermetic bonds at lower process temperatures.

Technical Details

- *Metal intermediate layer with silicon*
- *Aligned bonding*

Applications

- *MEMS packaging*
- *3D Integration*
- *Microfluidics / Lab-on-a-chip*
- *Through-connection (via)*



Eutectic bonding of Si wafer to a glass (l) or silicon (r) wafer, coated with an Au or Al layer.

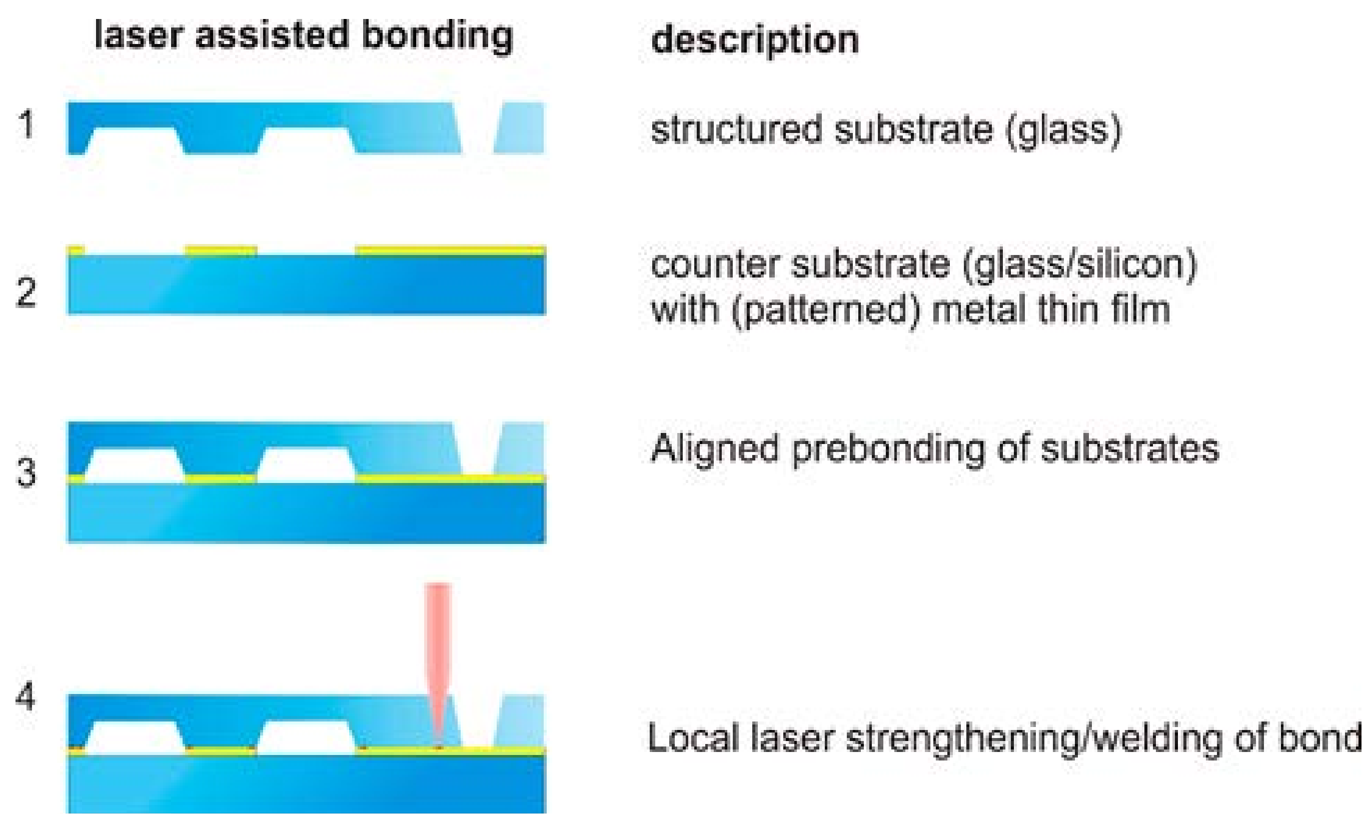
In adhesive bonding, substrates of different types of materials are connected by an intermediate layer. The intermediate adhesive layer can be organic or inorganic, possibly in the form of a glue, or for instance a photopatternable dry film resist/adhesive. Certain adhesives are especially suited for MEMS and/or other substrates with electronics. The adhesive layer can be deposited on one or both substrate surfaces. In this technique, bonding temperatures depend on the type of intermediate layer and the material of the bonding partners. When using a UV curable glue, the whole process can be done at room temperature. Other techniques may require a thermocompression bond step, but typically the temperatures involved are lower than in other bonding methods. This process also allows bonding of different substrates, e.g. silicon, glass, metals and other semiconductor materials. Bonds can be hermetic or not, depending on the type of adhesive used.

Technical Details

- *Controlled heating & cooling-off*
- *Integration of electrodes*
- *Integration of sensors*
- *Integration of functional layers*

Applications

- *Microfluidics / Lab-on-a-chip*
- *IC devices*
- *Isolating layers*
- *MEMS Packaging*



Schematic representation of the laser assisted bonding process: the through-hole on the right of the top substrate could be used to create an electrical connection to the chip.

Laser assisted room temperature bonding.

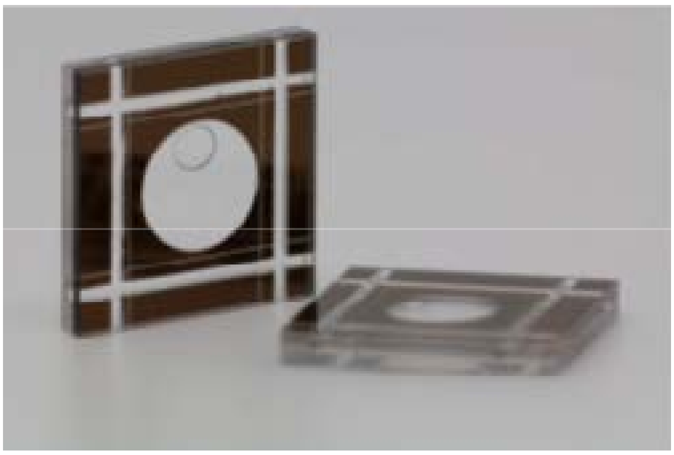
Micronit has developed a patented bonding process that can generate hermetic bonds, while only locally applying heat. In this technique, the initial step is to make a prebond using a light-absorbing (metal) interlayer. After this, the formed prebond is fortified by laser processing. A key advantage of the process is that, due to the prebond, there is no need to apply external pressure during the laser bonding phase. Overall, less laser power is needed to accomplish the final bond, which allows more precisely localised heating. Because of this, temperature-sensitive components, like biomaterials or liquids, can be part of the bonded stack. Usually, the substrates are of glass or silicon, or a hybrid combination of both. The metal interlayer can be any metal, as long as a prebond can be achieved with the counterwafer. Commonly used metals are chromium, tantalum, aluminium or titanium.

Technical Details

- *Low temperatures*
- *No external pressure during laser bonding*
- *Integration of electrodes*
- *Integration of biomaterials or liquids*

Applications

- *Lab-on-a-chip*
- *Biomedical devices*
- *IC devices*



Picture of a laser bonded chip, containing a cavity filled with water. A small residual air bubble can be observed due to incomplete filling.

Functionalities in device design

With all these techniques at hand, the opportunities to answer to the need for heterointegration are endless.

There are possibilities for solid high temperature bonds, but at the same time there is an increasing focus on bonding techniques that are performed at low temperatures. For example in cases that require protection of temperature-sensitive components, such as biomaterials, functional coatings or CMOS processed wafers. Low temperature bonding is also used to manage large differences in thermal properties between the bonded substrates.

For microfluidic devices, these developments mean that platforms can be made with active valves, pumps and sensors. In fact, with any element necessary to create a device that offers total integrated fluid management.

For microelectronics, it means an ongoing increase in possibilities for MEMS packaging, also with integrated elements. Multi-stacks up until 21 layers of glass can be produced at this moment. And as always, these numbers will be outdated any time soon. After all, the search for better, smaller, more never ends.

Micronit Microtechnologies

Micronit offers a broad range of bonding capabilities so that the requirements for specific applications and materials can be met.

Micronit Microtechnologies bv, founded in 1999, with development and manufacturing facilities in the Netherlands and Germany, provides innovative lab-on-a-chip and MEMS solutions using micro- and nanotechnologies. Solutions that help customers improve their products and research, contributing to the quality of life.

Micronit is ISO 9001 and ISO 13485 certified.

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