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M. Wagner / S. Böhm / K. Dilger

Adhesive bonding of MEMS and MOEMS with support of substrate inherent functional structures

Design of a fault-tolerant adhesive bonding technique for microsystem technology by use of component integrated micro structured bonding aids

Introduction

The progressive miniaturization in the field of microsystem technology makes consistently higher demands on techniques to join parts. Besides complex monolithic structures and traditional wire bonding techniques the adhesive bonding technology achieves an increasing acceptation. The permanent request to obtain a higher integration level, multi-functionality and reliability leads to the demand for joining technologies being able to join such heterogeneous systems mechanically as well as functionally. Adhesive bonding technology with its broad applicability and flexibility is particularly suitable to meet these needs [1].

With structure sizes smaller than one millimeter the established adhesive bonding techniques are starting to reach their limits. The specific physical properties of adhesives and the technological characteristics of the dosage and automation technology inhibit an unlimited downscaling to the micrometer or nanometer dimensions.

Typical resulting problems are over or under dosage by volume variation as a matter of principle as well as a contamination of the substrate by the adhesive beyond the designated joining area. Difficulties resulting from handling such small parts and demands for higher quality at lower tolerances are side effects. Apart from the joining accuracy the curing process affects the resulting joint as well. A short curing time with an early achievement of handling strength is advantageous for automated processes. The selection of suitable adhesives can solve the problem.

The presented results of the latest research show an interesting approach to a fault-tolerant adhesive bonding technique by use of component integrated micro structured bonding aids. The main objectives are improvements of the joining behavior of the parts, increased tolerance against wrong dosage and better reproducibility of the joint.

To attain this goal, suitable structures integrated in the substrates to be joined were designed and manufactured. The chosen material for the research is silicon, because it is very common in microsystem technology and a broad range of techniques for structuring is available. Topics included are as follows:

- Research of different parameters for the quality of the adhesive joint,
- Choice of suitable adhesive bonding systems and adhesives,
- Choice of suitable micro structuring methods for the substrates to bond,
- Design of the geometry of the part integrated bonding aids,
- Specification and selection of suitable measurement methods.

One important factor is the shape of the joining zone [2]. To reach a high precision, it is helpful to separate the different functions in positioning and adhesive bonding by design. The adhesive bonding function is to ensure the correct distance between the parts to be joined, to guarantee the expedient wettability of the surface and to cope with a wrong dosage of adhesive. To support these functions a specially designed structure with a defined gap to the other substrate and a spill trench was developed. Another important parameter is the selection of the right adhesive according to the substrate's material and the intended application with its technical demands. To reach exact positioning, all these parameters must be under control.

Motivation

It is very common to build microelectrical or micromechanical systems as a hybrid system and to assemble the different structures with joining technologies such as adhesive bonding. For best results, a precise, reproducible joining technology is required. Other requirements include the integration of the joining process into other production processes or the possibility for automating the entire process. Up to now, the use of adhesive bonding in microjoining was limited (see [1] p. 522 for details) by:

- Unsuitable choice of adhesive,
- Incorrect dosage,
- Bad curing,
- Poor positioning.

Very often time/pressure dispensers are applied for the dosage of the adhesive. Timed release of a set air pressure controls the amount of adhesive released through a syringe. For various reasons the adhesive may not be dispensed to the desired amount.

This can cause a contamination of the joining area or joint weakness in case of an under dosage. The uncontrolled spreading of the adhesive over the substrate after application can also be a problem. Spreading can cause a contamination beyond the joining area. Due to the long time some curing processes need, adhesive joining is often inefficient or produces poor results. During the curing stage after part release, displacement, rotation or sinking of the parts can all affect the part's position of the resulting joint (Figure 1). An automated assembly improves the position accuracy when compared to a manual assembly, but the result is dependent on the curing state at the release time and the properties of the adhesive.

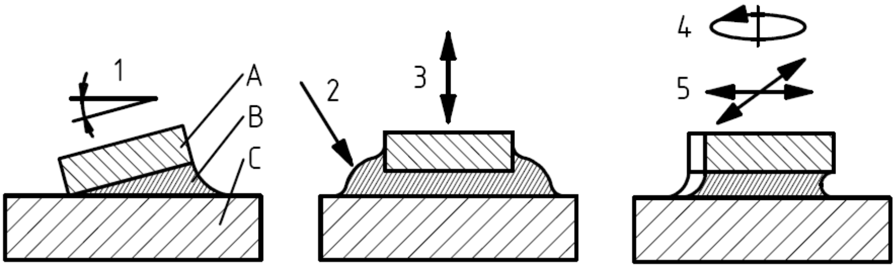

Figure 1: 1 Tilting, 2 Squeezed adhesive, 3 Lowering, 4 Rotation and 5 Displacement are typical movements of parts (A) bonded with adhesive (B) to a substrate (C)

The idea of the project was to overcome the described limitations and to develop and design a fault-tolerant adhesive bonding technique for microsystem technology using component integrated microstructured bonding aids. The primary objectives were:

- The ability to produce integrated joining aids using established microstructuring processes – ideally as part of the production process,
- Robustness to dispensing variations,
- The ability to be integrated into common assembling processes.

Choice of adhesives

The analysis and selection of suitable adhesives were main parts of the work. Due to sensitivity limitations of the used microassembling unit and the non-transparency of the used substrate material, only certain types of adhesive were usable. Additional, for eventual industrial application, it was important to choose adhesives with a short curing time. Examples for these kinds of adhesives are cyanoacrylates (CA), UV or light curing adhesives as well as two-component systems with a short working life. Finally, cationic epoxy adhesives were selected. Particularly noteworthy is that specially conditioned cationic epoxy has the ability to be pre-activated. This means that photonic activation energy starts the chemical reaction. The light might then be blocked but the chemical reaction continues. This allows parts to be bonded together a short time after activation. An important fact in the research was that analytically determined curing parameters, suitable for normal applications are strongly different from the necessary parameters for adhesive microbonding. Further investigations show that the development of exothermal heat by the curing process has a lower influence on the curing progress compared to macro bonds because of the relatively stronger heat sink by the substrate and the lower quantities of adhesive. This causes a need for a longer exposure time.

Development of test structures

To achieve a high joint precision, it is helpful to separate the different functions into positioning and adhesive bonding during the design phase. The adhesive bonding function itself can be divided into:

- Ensuring the correct distance between joined parts,
- Guaranteeing the expedient wettability of the surface,
- Checking for correct adhesive dosage.

To support these functions, a specially designed structure was developed. It has a defined gap between part and substrate and a spill trench (Figure 2).

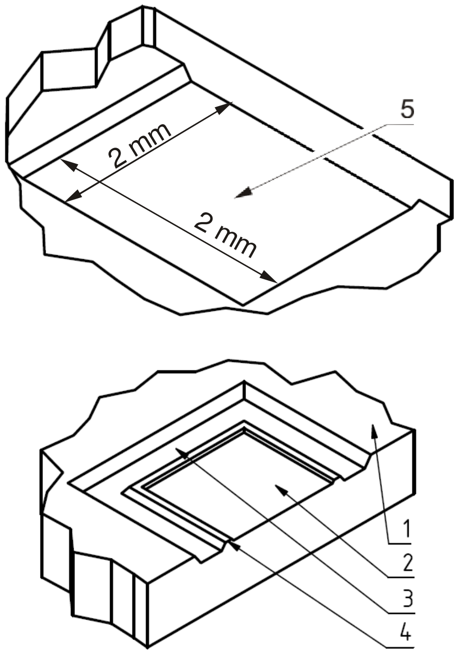

Figure 2: Above: Functional area of the part to be joined; Beneath: Structured profile of the substrate with (1) Joining area, (2) Plateau for the application of the adhesive, (3) Ditch for the assimilation of excessive adhesive (spill trench), (4) Aiding structures; (5) Joining area of the part

A major challenge was the prevention of uncontrolled spreading of the adhesive. To address this issue, some areas can be made either hydrophobic or hydrophilic. One such process is described in [3]. Another method is to make use of the adhesives' rheological behavior of the fluidic adhesive as described in [4]. Edges can stop, guide or accelerate the spreading of the adhesive (see Figure 3). Such edge breaks are useful for the assembly process, since minor over dosages do not cause a contamination of the joining area. An adjustable adhesive bank is helpful particularly to bridge larger gaps between the substrates.

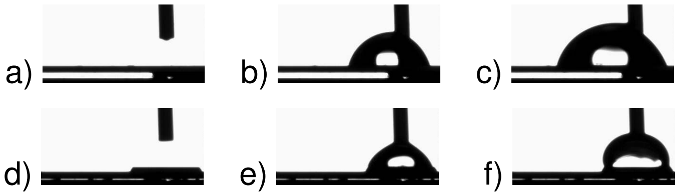

Figure 3: a) to c): Spreading of a liquid applied to a planar substrate; d) to f): Spreading of a liquid applied to a substrate area (plateau) with edges

The material chosen for the tests was silicon, which is very common in microsystem technology. For structuring, a broad range of techniques are available. Anisotropic etching with potassium hydroxide (KOH) was used for the specimen production. This standard technology is widely available and has a good reproducibility.

The main joining area was defined in dimensions of 1 mm x 1 mm (Figure 4). The surrounding trench is 300 µm wide and the defined gaps are respectively 30 µm or 50 µm according to the adhesive specifications.

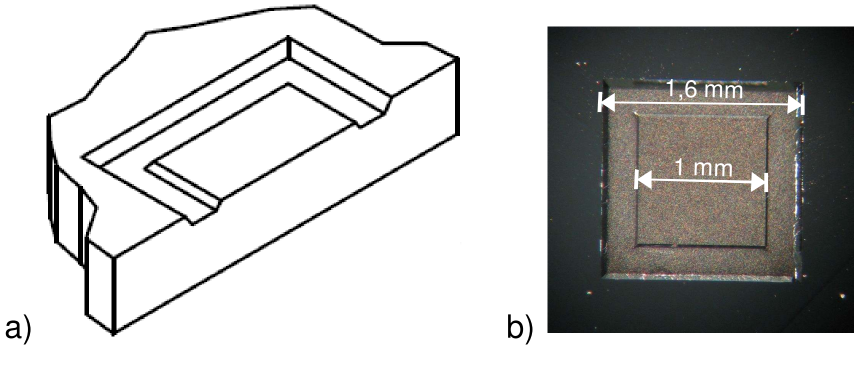

Figure 4: Structured substrate with plateau and trench; a) Sectional drawing; b) Etched silicon structure

The dimensions are a compromise between the minimization and the reproducible application of adhesive with time/pressure dispensers as well as the possibility to design small structures using the chosen etching processes. During the research various aiding structures were analyzed (Figure 5).

Apart from the different structures and gaps, the following parameters were changed:

- Type of adhesive used (various adhesives and viscosities),
- Assembly pressing force to the part,
- Quantity of dispensed adhesive.

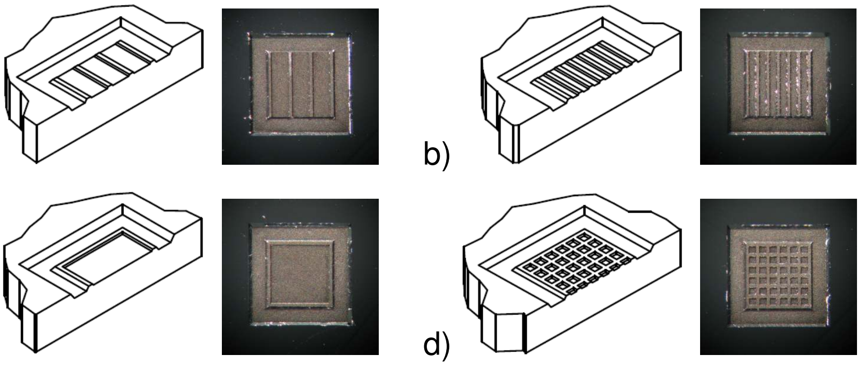

Figure 5: Different structured substrates; a) Ditches and barriers with a wide distance; b) Ditches and barriers with a narrow distance; c) Surrounding wall; d) Waffle pattern

Experimental process

As described previously, both parts need to be assembled with the joining areas face to face and have a geometrically exact designed region with a defined quantity of adhesive. Excessive adhesive can drain into a spare cavity to prevent the contamination of unwanted regions. The normal adhesive dosage is between 30 nl and 60 nl, depending on the width of the gap between the assembling part and the substrate. The trench cavity is approximately 100 nl. Figure 6 shows a sectional view of two adhesively bonded parts with the normal quantity of dispensed adhesive.

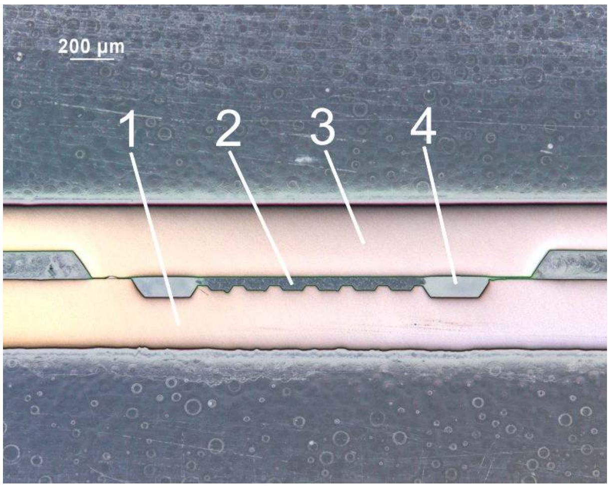

Figure 6: Polished micrograph section of a adhesive joint under incident light; 1 Substrate, 2 Adhesive, 3 Part, 4 Trench

First, substrates without any structure were used as a reference. Second, even plateaus, as shown in Figure 4, were tested with two different gap sizes. Third, research was conducted on ditches and barriers as shown in Figure 5. And finally structures with walls and waffle pattern (Figure 5) were examined to see if an increase of the bonding force occurred.
For assembling of the parts, a microassembling unit was utilized (description in [5]). It is made up of an assembly robot with flexible clamping and grasping systems, force measurement equipment, an optical measurement system (explanation in [6]) for locally gauging movements and curing devices for the adhesive. A detailed description of the complete setup is published in [7].

Measurements

An important feature of the experimental setup was a continuous in-situ measurement of position and orientation of part and substrate with a specially designed optical measurement system. A measurement of the pressing force made it possible to assemble the parts under constant conditions. After age hardening, a shear test was applied to the specimens. The testing unit used is described in [8].

Results and discussion

Figure 7 shows an exemplarily result of the displacement of an part after release. In this example the displacement is approximately 11,5 µm with a time to approach this value of 60 seconds. With the chosen parameters this time is typical for the selected preactivating process with cationic epoxies and even substrates.

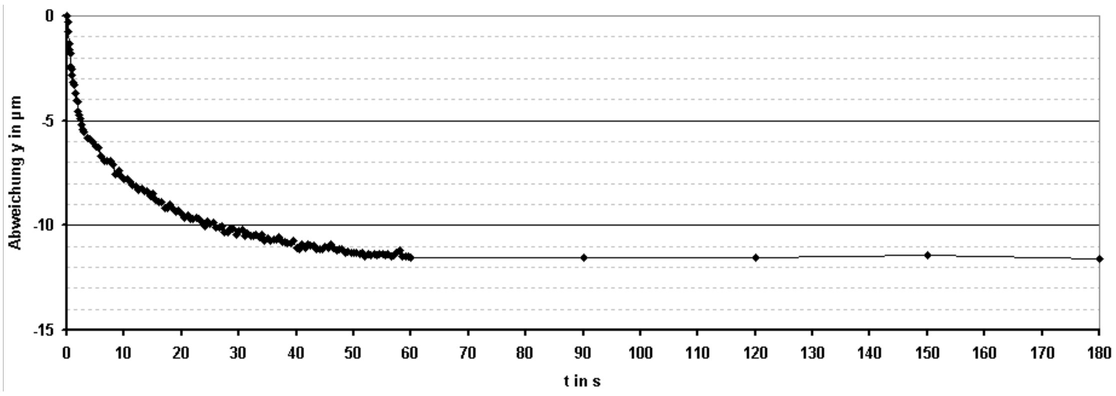

Figure 7: Displacement in Y direction over the time for a part bonded with *Delo Katiobond 4552* to a substrate without microstructured aids; Normative quantity of adhesive; Joined with a pressing force of 0.6 N

The experiments prove the assumption that the point in time is crucial for the accuracy of the assembled component. Experiments with joined parts after release and before adhesive curing show a displacement in time depending on the chosen adhesive, viscosity and joining pressure. The determination of displacement indicates that substrates without additional microstructures have a larger offset than samples with the new designed integrated aids. Figure 7 shows this difference.

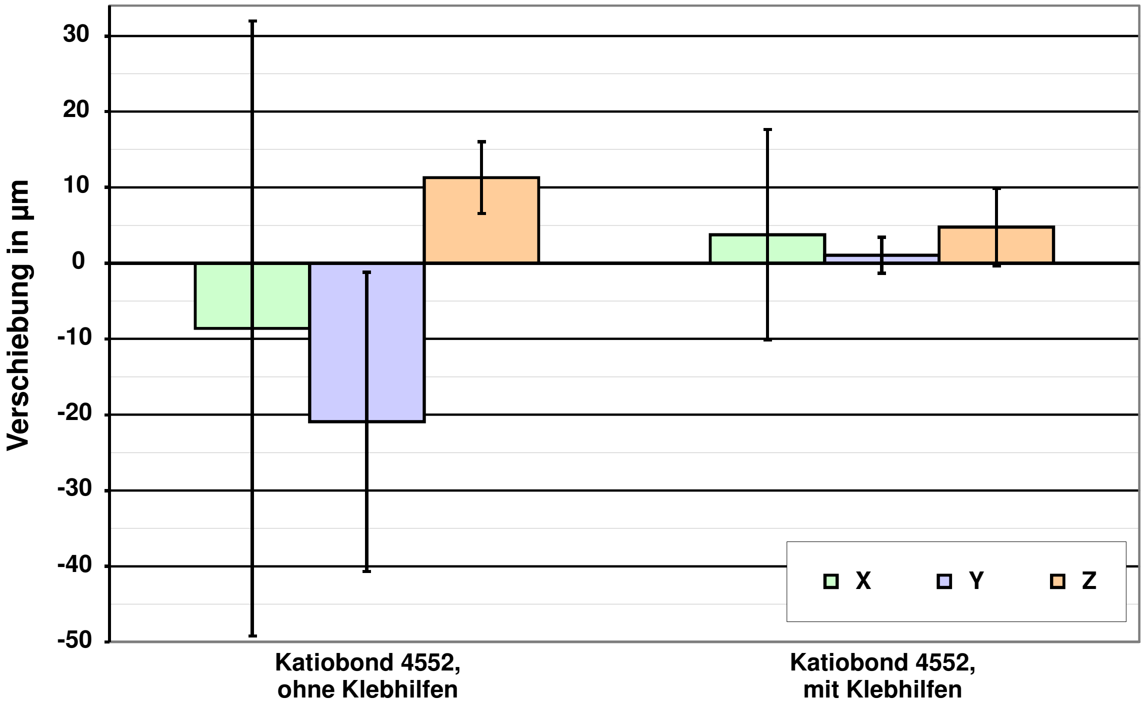

Figure 8: Average displacement for the adhesive *Delo Katiobond 4552* in different directions after accomplishing handling resistance, left: without bonding aids, right: with bonding aids

A further improvement of assembling accuracy is shown by the reduction of the statistic spread of the results. Over dosage can be widely compensated by use of a trench. But the results are worse if the trench is completely filled.

Conclusions

The analyzed solution with integrated aiding structures is able to improve the positioning accuracy of the assembled parts. Suitable fields of application are sensor devices, assembly of optical components or lab-on-a-chip applications. It is possible to create these structures with established processes. In principal, the solution is independent from the material and the concrete geometry of the substrates. The results of the research show that it is possible to shorten the assembling time at higher assembling accuracy with an acceptable effort.

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