Self-assembly of MEMS Using Electrostatic Forces

Marcel Tondorf, Konstantinos Mouselimis, Yifei Gan, Jürgen Wilde
Albert-Ludwigs-Universität Freiburg, Institut für Mikrosystemtechnik (IMTEK)

Abstract
For micro-assembly often very expensive machines must be utilized, when an accuracy of placement below 10 µm is required. In this work, a method is presented, by which a component is self-aligned in an electrical field and the die attachment material is subsequently hardened in situ.

Introduction
The process cycle comprises three steps of adhesive dispensing (1), component placement and self-alignment (2) and hardening (3). On the top side of the mounting substrate and on the bottom of the device electrode pairs have been formed, which are electrically equivalent to two co-planar capacitors switched in a series. If a voltage is fed to the substrate electrodes, three-dimensional electrical fields will be generated, which also induce lateral in-plane forces in the electrodes. As the devices have been placed on a film of low-viscosity adhesive, they are movable. They will swim towards the center position where the electrode pairs overlap. In the last step, the UV-hardening adhesive will be exposed to radiation and the device is fixed in this way.
In this contribution we will first present the process sequence. The relevant influencing parameters of the process are analyzed and modeled. Furthermore structures for self-alignment as well as an experimental self-assembly bonding machine are exhibited and first application examples are shown.

Experimental setup and fabrication
The misplacement relative to the substrate should be less than a few micrometers. The structures must be supplied with an electrical potential via probing devices. The setup should also comprise a dispenser for liquid adhesives. It is essential to harden these in situ by photo-polymerization with UV-light avoiding sample shifting. A schematic representation of the specified self-assembly system is shown in fig. 1, a photograph in fig. 2.
A high-voltage source can provide DC or AC voltages up to 1 kV. The control signal with frequencies up to 20 MHz is formed by a function generator and is monitored with an oscilloscope.
The experiments are visualized with a stereo-microscope and a high resolution camera.

Fig. 2: Picture of the equipment configuration

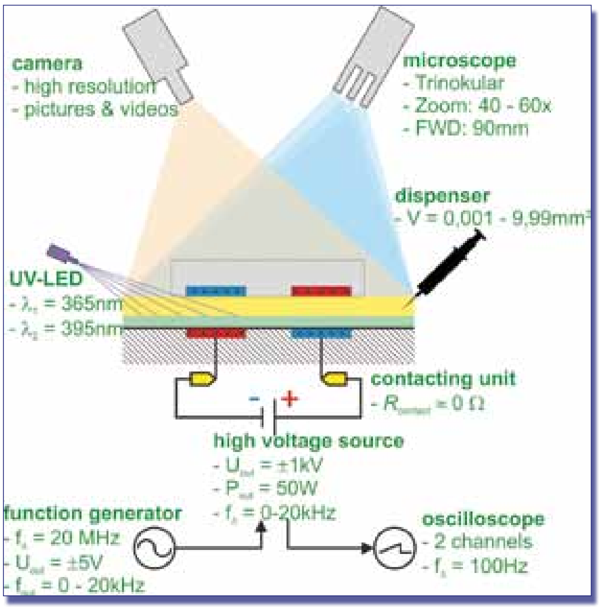

Fig. 1: Schematic of the self-assembly setup

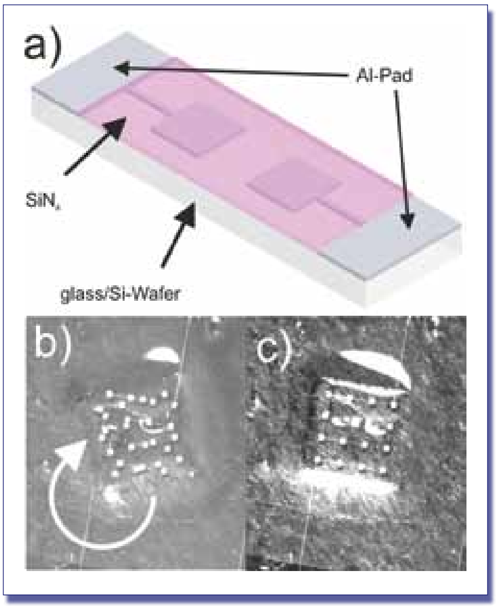

Fig. 3: (a) detail of the alignment structures (b) structure before assembly (c) structure after assembly

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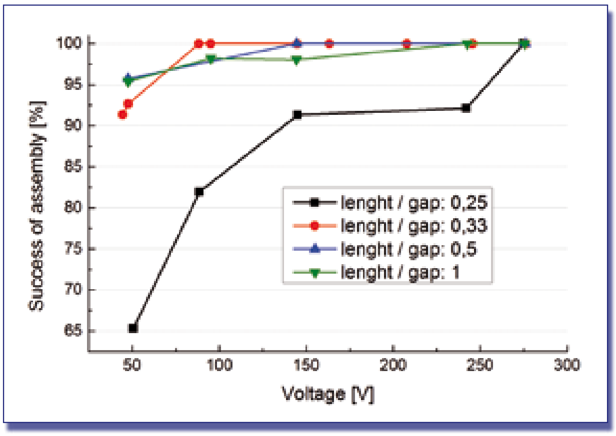
Fig. 4: Dependency of the success of assembly on the geometrical design of the chips



The coarse placement of the device chips is done manually. The hardening of the glue is induced by a LED-based UV-light system, which was specifically designed and assembled at IMTEK. A profile of the alignment structure can be seen in fig. 3. Aluminum pads are used to apply the voltage to the structure. A passivation layer of Si_xN_y was plasma-deposited all over the rest of the substrate in order to avoid short circuits.

Accuracy after self-positioning and hardening

Variables of the experiments are the profiles (square or hexagonal), the dimensions (20-200 µm) and the spacing between the pads (80-600 µm). To compare the different structures the ratio between pad size and gap width is used as an auxiliary parameter, fig. 4.
A structure was taken as successfully adjusted when the lateral mismatch was < 4 µm. Therefore alignment tests were repetitively performed. A correlation between the geometry and the applied voltage could be verified. If the applied voltage is > 270 V all geometries behave equivalent and all of the structures are assembled. Below this voltage significant differences appear. If the area portion of the active pad structures is small, the forces will be low. The consequences are structures which are not precisely aligned in some cases. Although higher voltages are generally better for the precision of positioning, all alignment tests with the appropriate structures were successful above voltages of 75 V, fig. 4. The time for self-aligning is around one second. Presently, typical accuracies of few micrometers and below are achieved. The hardening must be started immediately after the self-assembly. The sensitivity curve of the curing adhesive has been matched with the wavelength of the UV-LED in order to reach a most efficient hardening. The UV power density must be constant all over the chip. Otherwise the adhesive will be hardened unequally and a displacement of the chip due to hardening shrinkage might be the consequence. Presently, the research program is aimed at this point in order to analyze the influences on the hardening process and on position accuracy after UV-curing. Another aspect is how electrical interconnections between substrate and chip can be generated in situ.

Conclusion

A test system for the proof-of-concept of self-assembly with in situ hardening has been constructed. Cost-efficient LED-based illumination systems have been designed to harden the adhesive via UV light. After the self-assembly of the chips the accuracy lies in the range of a few micrometers. If the design of the structures is appropriate, successful alignment can be achieved with field voltages below than 100 V. Hence the principle of electrostatic self-assembly is practicable.
Possible fields of this process are the production of LEDs or RFIDs with bare-chip assembly. Elements with sensitive surface structures can be assembled and fixed with high precision without the need of touching them after the first placement. So, expensive high precision systems could be replaced by a cheaper alternative.

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Marcel Tondorf
Albert-Ludwigs-Universität Freiburg
IMTEK – Institut für Mikrosystemtechnik
Professur für Aufbau- und Verbindungstechnik
Georges-Köhler-Allee 103-01-105
D – 79110 Freiburg
Phone +49 (0)761 - 203 - 7294
Fax +49 (0)761 - 203 - 7292
Mail marcel.tondorf@imtek.de
Web www.imtek.de