Development of highly precise bonding procedures for structured polyimide films on silicon substrates

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Abstract

Established bubble-jet printheads consist of a three layer assembly. The aim of the presented work was to simplify the setup of bubble-jet printheads by bonding a three-dimensional laser-structured polyimide nozzle plate onto a 1/3 inch standard printhead substrate with an alignment accuracy of <5µm. Main challenges are the prevention of blocking the 20µm deep fluidic channels in the polyimide with 10µm minimal lateral dimensions and a minimum pitch of 15µm.

In total, three bonding techniques, with and without additional adhesion layers, were developed and evaluated. One method applies a 4µm thick layer of Epotec 353ND (Polytec), a standard two-component epoxy, in a specifically adapted rolling manner onto the film that is subsequently aligned to the silicon chip using a flip-chip-bonder. Screen-printing and dispensing processes of adhesives were investigated but failed due to insufficient structural resolution. The second method uses photolithographic processes to produce structured adhesion preforms in SU-8 resist. With a layer thickness of 3µm and an adapted curing schedule, promising results concerning resolution and contour accuracy were obtained. Thirdly, bonding without additional adhesion layers was achieved in a micro-sealing process that takes advantage of the highly defined thermoplastic softening of polyimide KJ (DuPont).

The different processes were compared regarding to yield, printing behavior of the assembled printheads and applicability to high volume productions.

Keywords: polyimide, micro-sealing, adhesion preforms, print-head

1. Introduction

Conventional, highly integrated ink-jet nozzle plates consist of a three-layer system. This paper reports on the assembly of a new highly integrated 1/3 inch thermal bubble jet printhead as a two layer system with reduced assembly complexity. Therefore, a three dimensionally structured polyimide film with integrated fluidic channels and nozzles (Fig. 1) is applied to a CMOS substrate. The polyimide film was structured using an excimer laser at Boehringer Ingelheim microParts GmbH. Various groups are working on the development of bonding and manufacturing techniques for similar structures [1-3]. In this paper, three different assembly methods are developed and evaluated, as there are a rolling technique to apply adhesive, the photolithographic realisation of adhesion preforms in SU-8 and a direct heat-sealing which avoids the use of additional bonding layers.

A main challenge that had to be overcome was a fluidical sealing bond of channel structures measuring 11µm in width and 10µm in depth without clogging single channels. Proper sealing of fluidic areas comprising heaters and ink support structures against the integrated electronic structures with a topology of up to 1µm was claimed. Furthermore, temperature resistance of up to 200°C, chemical resistance to ink and an alignment accuracy over the whole structure of <5µm had to be guaranteed.

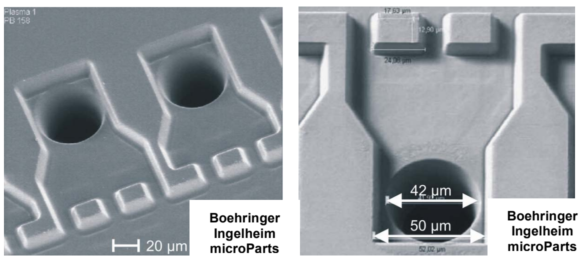

Fig. 1: Laser-structured 3D nozzle plate.

2. Micro-adhesion process

2.1. Process development

To apply the polyimide nozzle plate onto the substrate, a micro-adhesion process was developed. Best results were obtained with the two-component epoxy Epotek 353 ND of Polytec, Waldbronn/Germany, applied by a roller transfer technique (Fig. 2).

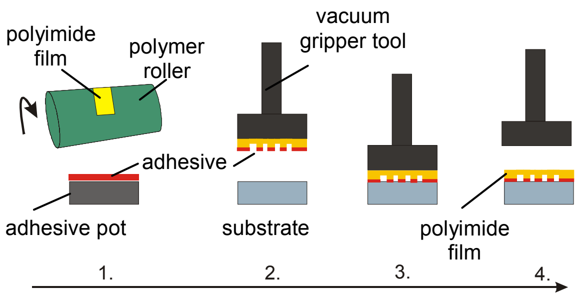

Fig. 2: Sketch of the micro-adhesion process.

To achieve a homogeneous adhesive transfer, the polyimide needs to be cleaned properly. This was achieved by low power ultrasonic cleaning first in acetone and then in isopropanol. A subsequent exposure to an oxygen plasma created free bonds at the surface of the polyimide film, increasing the surface activity and thus its affinity to the adhesive. The adhesive was filled into a 5µm deep RIE-etched silicon pot and leveled out by a wiper. Using a polymer roller, the structured polyimide nozzle plate was subsequently coated with adhesive. Once leveled, the adhesive can be used for a maximum of 15 minutes due to an increase in adhesive viscosity. The reason for this rapid increase in viscosity in thin layers relates to the evaporation of not reacted hardener. A flip-chip-bonder from FineTech GmbH, Berlin/Germany, was used to transfer the coated polyimide film onto the printhead substrate with an alignment accuracy of <5µm. Fig. 3 gives an example of a polyimide nozzle plate coated with adhesive. The open nozzles can be seen clearly as white spots.

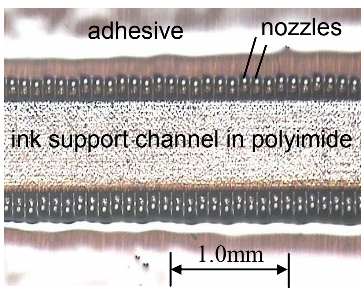

Fig. 3: Nozzle plate coated with adhesive.

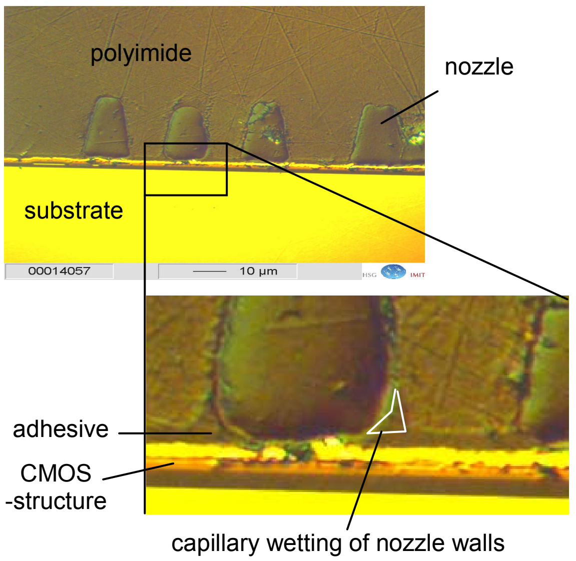

Fig. 4: Cross section through bonded printhead.

Fig. 4 shows the cross section of a bonded printhead. Capillary effects led to wetting of the nozzle walls with adhesive. Photographs of assembled printheads are given in Fig. 5. On the left side, empty nozzles can be seen, the right shows a 100% capillary filling of the nozzles with dark ink.

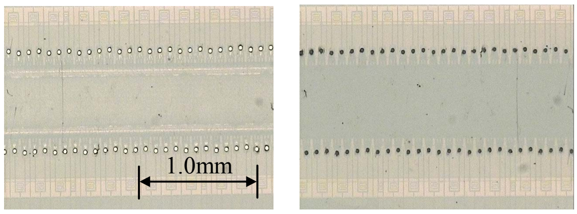

Fig. 5: Photographs of assembled printheads.

2.2. Evaluation

Printheads assembled with the micro-adhesion process were fluidical addressed to evaluate the applicability of the process. Fig. 6 shows the results of dispensed droplet volumes from different nozzles. The adhesion process proved to have negligible effects on the dosing behavior as the dispensed volumes corresponded very well to theoretically calculated volumes. Several aging tests were performed to prove the long-term stability of the printheads. Cyclic temperature changes between -20°C and +80°C for 53h (according to DIN IEC 68214), storing at 85°C and 85% humidity for 53h and storing in ink for two weeks could not harm the printheads. Changes in dispensed volumes before and after these tests added up to less than 5pl which is tolerable for ink-jet applications (Fig. 7).

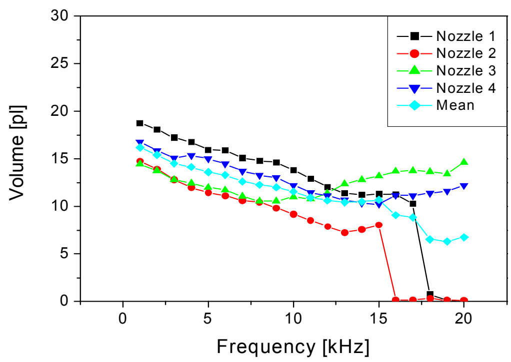

Fig. 6: Dispensed droplet volumes from a printhead assembled by the micro-adhesion process.

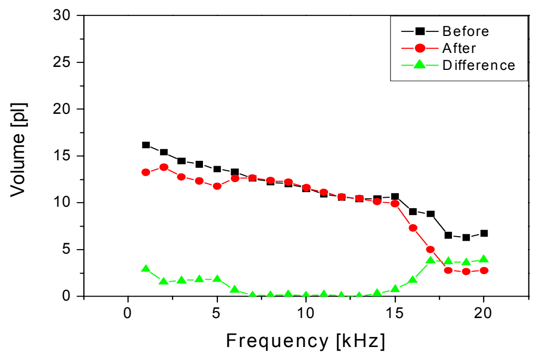

Fig. 7: Dispensed droplet volumes before and after aging tests.

3. Structured adhesion preforms in SU-8

Another method uses photolithographic processes to produce structured adhesion preforms in SU-8 resist. In this application, the negative resist NANO™ SU-8-2000 from Microchem Inc., which is suited for a layer thickness of 2 to 4µm, was used. This material is distinguished for very high chemical and thermal resistance and is applied to flat substrates by spin-coating. After a thermal softbake, a subsequent exposure to UV-light through a mask changes the chemical structure in those areas exposed to light. During a post exposure bake (PEB) the exposed areas polymerize while the not exposed areas can be removed in a developer bath [4,5]. When using this SU-8 resist as an adhesion layer, care has to be taken that the polymerization of the structurized resist is not complete. After developing the exposed areas, the SU-8 channel structure was aligned to the substrate using a flip-chip bonder and the hardbake was completed in a further curing step with raised contact pressure. Best results were obtained at 150°C for 300s, applying a contact pressure of 4,5MPa. With a layer thickness of 3µm and an adapted curing schedule, promising results concerning resolution and contour accuracy of 5µm were obtained. Fig. 8 shows a cross section of a fluidic channel, measuring 3µm in height and 80µm in width.

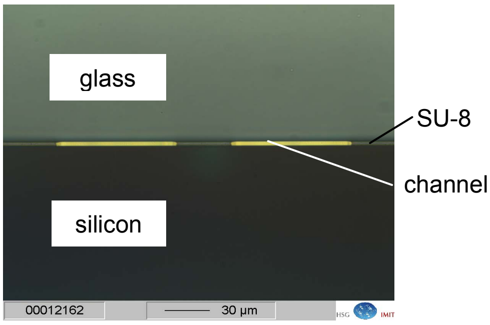

Fig. 8: Cross section through channels in SU-8, covered by glass.

Fig. 9 shows channels in SU-8 covered by unstructured polyimide. For reasons of visualization and proof of the fluidic sealing, the channels have been filled with ink by capillary forces.

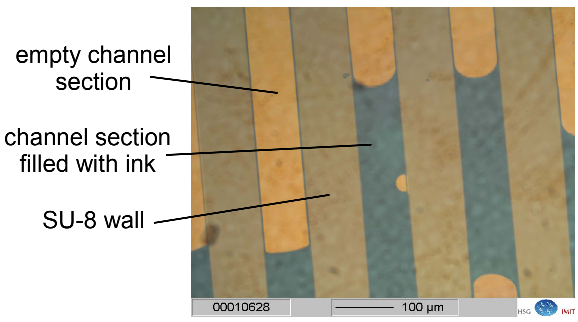

Fig. 9: Channels in SU-8 covered by polyimide and filled with dark ink.

4. Heat-sealing process

Lamination processes represent a smart bonding technique, with no need of an additional adhesion layer [6]. Alternatively to the other presented processes, a heat-sealing process was developed for the current application. The fluidic structures were realized in Kapton® KJ (DuPont) by laser-machining at Boehringer Ingelheim microParts GmbH. Due to its thermoplastic behavior, this polyimide is heat-sealable. The chemical and thermal resistance is comparable to Kapton® HN. Excellent adhesion can be maintained above the glass transition temperature. The process presented here uses a film with a thickness of 75µm. Main challenges were to be seen in a proper cleaning and pretreatment of the structures and adhesion of the polyimide to the surface materials of the CMOS-substrate, as there are Al, Ta, SiC, Si and SiO_2. Furthermore, changes of the cross sections of the channels had to be limited.

4.1. Cleaning and Pretreatment

The excimer-laser process contaminates the KJ film. Clean and chemically active surfaces are a requirement for reproducible and uniform bonds. Low power ultrasonic cleaning of the polyimide film was performed first in acetone, subsequently in isopropanol. Remaining contaminations were removed by a subsequent exposure to an oxygen plasma.

Polyimide tends to absorb water that will evaporate during the heat-sealing process and which leads to imperfections in the bond due to vapour bubbles. This can be avoided by dehydration at 170°C for several hours (Fig. 10).

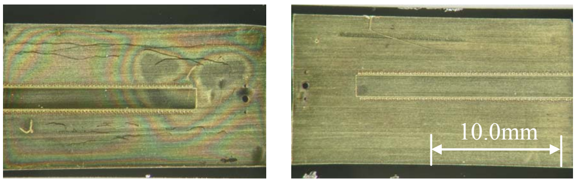

Fig. 10: Heat-sealed Kapton® KJ on silicon.
Left side: imperfections due to evaporated water during the process.
Right side: homogeneous results due to dehydration.

4.2. Heat-sealing and evaluation

The heat-sealing process was performed using a flip chip bonder from FineTech GmbH, Berlin / Germany. Using individually designed gripper tools, both bonding partners can be aligned to each other, heated and pressed together in a very defined manner.

Kapton®KJ showed well adhesion to all contact materials (see above). Pull tests at 8 coincidentally chosen samples showed breaking tensions of 15,0MPa (average value).

The temporary softening of the Kapton®KJ during the bond process helps to compensate the topology of the CMOS-substrate. A reverse effect is that the structural resolution decreases due to deformation effects. Fig. 11 shows strongly deformed (originally round) nozzles after a sealing process with raised temperature and pressure.

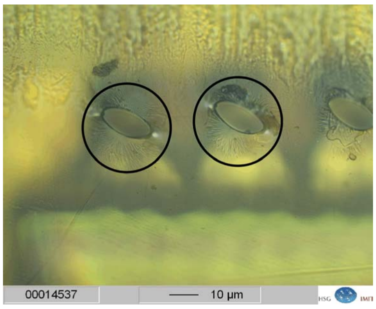

Fig. 11: Originally round nozzles, deformed during a heat-sealing process with unsatisfactorily adapted process parameters.

Best results were obtained at 333°C and a bonding pressure of 0,63MPa for a time of 120s.

4.3. Further evaluation

To evaluate the deformation of the polyimide film during heat-sealing in a more detailed manner, unstructured Kapton®KJ was bonded on channels in silicon with 80µm in width and 30µm in depth. Fig. 10 shows cross sections of such channels, both sealed with 0,94MPa at 300°C and 370°C, respectively. The higher the temperature and the higher the pressure, the higher is the deflection of the polyimide into the channels. As can be seen at 370°C, the channel is completely clogged by polyimide. On the right side of Fig. 12, cracks in the silicon due to the high pressure are visible.

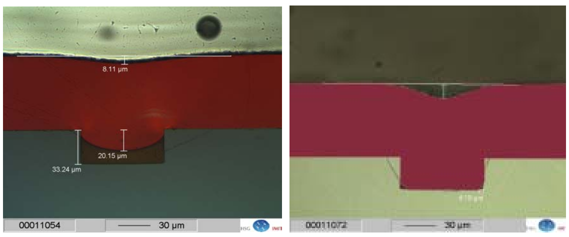

Fig. 12: Heat-sealing of unstructured Kapton®KJ on channels in silicon.
Left side: sealing temperature 300°C.
Right side: 370°C.

Fig. 13 shows the influence of the sealing pressure when the sealing temperature and the process time are kept constantly at 300 °C and 180 s, respectively.

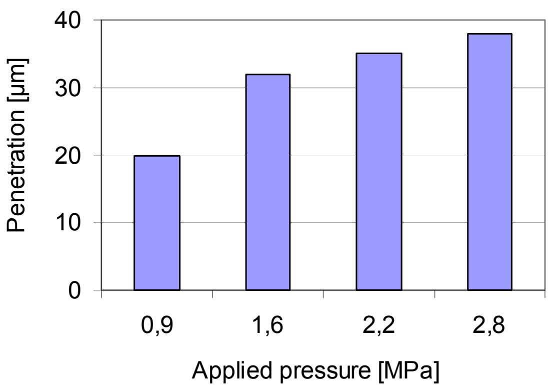

Fig. 13: Influence of sealing pressure.

5. Conclusion

Three different methods for the application of 3D-laser-structured polyimide films onto CMOS print-head substrates were developed and evaluated.

The application of epoxy adhesive using a roller transfer technique showed promising results. A lateral assembly accuracy of <5µm with a layer thickness of only 4µm was achieved. The necessity to comply with a narrow window of process parameters proved to be unfavourable. Process parameters are the viscosity of the adhesive, the layer thickness, the bonding pressure and the curing schedule.

The process based on structured adhesion pre-forms in SU-8 showed promising results but could not be applied to the available print-head substrates on chip level as the coating of the print-head substrates needs to be done at wafer level.

Once the appropriate process parameters are established, heat-sealing is a very simple and fast process to bond Kapton® KJ films onto a multitude of substrate materials. Due to considerable deformation of the geometries, this process is not applicable in the given application.

Acknowledgement

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References

[1] S. Li et al. Fabrication of micronozzles using low-temperature wafer-level bonding with SU-8. Journal of Micromechanics and Microengineering, Vol. 13 (2003) 732-738

[2] L.J. Guerin, et al. Simple and low cost fabrication of embedded micro-channels by using a new thick-film photoplastic. Transducers'97 (1997) 1419-1421

[3] A.P. Gadre et al. Fabrication of an epoxy based multi-layer bio-fluidic dermal patch. Transducers '03 (2003) 806-809

[4] Ruddy, C. Anwendungsspezifische Prozess-optimierung zum selektiven Bonden mit SU-8. Master Thesis, HSG-IMIT, Germany, 2003

[5] K. Jiang et al. An ultrathick SU-8 process using UV-lithography. Polytronic. Montreux (2003) 45-49

[6] Paul, B.K. et al. Microlamination for micro-technology-based energy, chemical, and biological systems. ASME IMECE. Nashville, Tennessee, USA (1999)