A new tool for aligned micro-embossing and nano-imprinting

T.Rogers & I.Malmros

Applied Microengineering Limited, Unit 8 Library Avenue, Didcot, Oxon.,OX11 0SG, UK

Abstract

A new multi-purpose MEMS fabrication tool is described. The tool enables in-situ aligned embossing and nano-imprinting, in addition to surface activation and aligned wafer bonding. De-embossing is also included in-situ via the use of vacuum chucks and chamber pressurisation. The multi-purpose tool enables the fabrication of bonded, embossed, multi-layer, micro-fluidic devices, for example PDMS structures on silicon, including the alignment of the embossed structure to any pre-existing patterning on the silicon. Examples are presented of various structures that have been made using the tool along with a description of the principles of operation.

Keywords: hot embossing, surface activation, MEMS, wafer bonding

1. Introduction

One of the factors that has inhibited the widespread commercialisation of MEMS has been the failure of silicon based manufacture to deliver the low costs that the early MEMS pioneers predicted. In particular, devices that require high aspect ratio micro-machining can incur high processing costs when solutions like LIGA and DRIE are used.

The use of polymers for MEMS fabrication offers cost reductions, but issues such as the machining of high aspect ratio structures, and alignment for the integration of other processes then need to be resolved.

This paper describes a tool that addresses the aligned micro-embossing / imprinting of polymer substrates. This tool is based on the AML AWB aligner –bonder platform and has similar specifications to that aligned wafer bonding equipment. In fact with suitable tooling the machines can be used in an in-situ aligned wafer bonding mode, or aligned embossing mode.

By utilising emboss stamps that have been fabricated using a high aspect ratio MEMS process such as silicon DRIE or LIGA, the high aspect ratio structures can be faithfully transferred into polymer substrates at low cost.

2. Emboss Tool – Description and Specifications

Hot embossing [1, 2] is a process in which a pattern on a stamp is replicated into, mainly polymer, substrates. In order to perform the replication process, both substrate and stamp are heated to a temperature at or above the glass transition temperature (Tg) of the substrate. The stamp is then pressed into the substrate (embossing force). The stamp and substrate are cooled down to a temperature below the Tg, the stamp is then pulled out of the substrate; this is the de-embossing step.

There are many commercial systems available for carrying out hot embossing of microstructures, but not with the in-situ ability for precise alignment of the embossed structure with pre-existing features on the substrate. Alignment is present on the tools that have been designed for nano-imprint lithography, but these machines tend to be much more expensive than the aligner-emboss / imprint tool described here.

The AML emboss tool is shown in Figure 1 and schematically in Figure 2.
functional wafer bonder so all processes that can be carried out on a stand-alone wafer bonder are also possible on the embosser.
The embosser comes equipped with an alignment feature that makes it easy to align the embossing to structures that already exist on the substrate. If the embossed polymers require a subsequent bonding step (eg for encapsulating microfluidic structures, then surface activation of the polymer can also be carried out in–situ. This process uses a novel RAD-tool [3], that works in a similar manner to plasma activation [4], to activate the substrate during the process. The RADical activation process is a feature that uses free radicals to activate surfaces and is also being investigated as a means of improving the anti-stiction properties of the stamp, thereby making the de-emboss process easier to perform.

Fig 1. Basic machine for in-situ aligned bonding and / or aligned embossing / imprinting

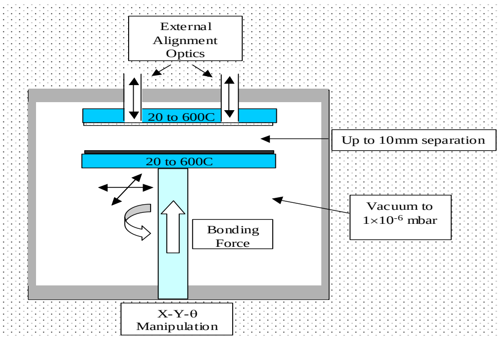


Fig 2. Schematic of process chamber

The tool utilises a process chamber that can either be evacuated or pressurised, a lower platen that is movable in X,Y,Z and Theta, and a fixed upper platen that includes apertures that allow optical split-field alignment via externally mounted lenses / cameras. In addition both platens can be independently heated, and a force of up to 15kN can be applied between them. For de-embossing the vacuum can be switched from the chamber to the platens (ie they then behave as vacuum chucks) whilst pressurising the chamber.

The vacuum chucks, and the ability to switch the applied vacuum from the chamber to the chucks, are two of the functions that have been added to convert the existing commercial tool, the AML Aligner Bonder, into a dual aligner bonder / embosser. One of the other important additions has been the modification of the Z-drive to reduce XY movement over a long stroke. For an aligner bonder, the "true Z" stroke only has to be ~10(m in order to enable the movement from the proximity separation, needed for the alignment process, to contact in order to enable wafer bonding. However, in order to be able to emboss high aspect ration structures, for example for a microfluidic device, much longer strokes are needed, and if micron scale precision is needed over the lateral dimensions, for the whole depth of the embossed structure, then the stroke has to be "true" to micron accuracy. The specifications for the tool are shown in Figure 3.

Wafer Sizes	3”, 100mm, 125mm, 150mm
Max emboss force	15kN
De-emboss force	630N
Max temperature of platens	560^{o}C
Platen temperature uniformity	+/-2.5^{o}C (100mm wafers) +/-3.5^{o}C (150mm wafers)
Z stroke	2mm
XY error over full Z stroke	1.4μm (NB XY error for shorter strokes is pro rata, ie 1.4nm for a 2μm stroke
Alignment accuracy	+/- 2μm

Fig 3. Emboss Tool Specifications

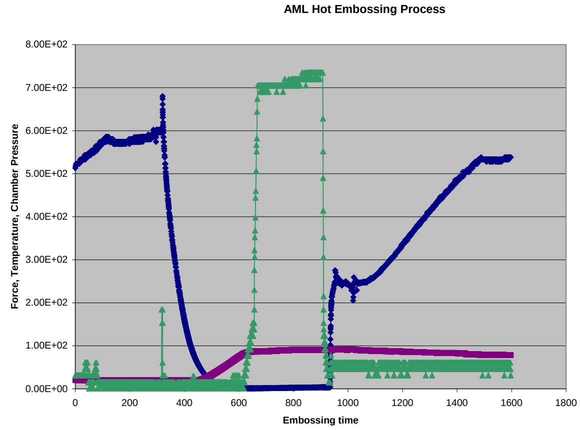
The emboss / print procedure is as follows:

- Mount wafers on platens
- Close lid
- Pump down chamber and simultaneously heat to process temperature (for embossing this is typically just above the glass transition temperature (Tg).
- Align stamp wafer with workpiece (for embossing this is typically a polymer wafer or polymer coating on carrier wafer)
- Align wafers
- Apply force for defined time
- Cool (using nitrogen) to defined de-emboss temperature (typically just below Tg)
- Separate (de-emboss) wafers – for this process the chamber is vented and pressurised to 2 Bar absolute. This enables the wafers to be secured via vacuum chucks.
- Vent to atmosphere, open lid and remove embossed wafer

In order to perform the alignment operation, the lower platen can be moved in X,Y,Z and θ, to enable precision contacting of the stamp with the workpiece. The alignment is achieved in a similar fashion to mask aligners, and the stamp / workpiece need to have alignment marks processed onto them. These marks are then imaged using externally mounted cameras. Either visible reflected light, or transmitted IR can be used depending on the optical characteristics of the materials being used.

The de-embossing process can be performed in-situ and uses the same precision z movement that is utilised to perform the high aspect ratio embossing. Thus there is no possibility of the precision of the embossed reproduction becoming degraded by the withdrawal of the stamp from the polymer. To perform this de-emboss function, the machine operator can switch the vacuum from the chamber and apply it to the platens on which the stamp and substrate (workpiece) are mounted. This then enables a separation force to be applied, and this force is amplified by pressurisation of the chamber. Note that during the embossing step the stamp is held by a special edge clamp thus removing the need for a vacuum chuck at that stage, and therefore allowing the embossing to be performed within a vacuum – which is beneficial in preventing any air trapping as the stamp is pressed into the polymer. The workpiece, during the emboss stage, sits on the lower platen under gravity.

An actual process run showing chamber pressure, platen temperature and applied force is shown below in Figure 4.



Emboss Force (N)
Substrate Temp. (^{o}C) (100^{o}C / div)
Chamber Pressure (mBar)

Fig 4. Data for a typical emboss process

3. Results

To date the tool has been used for embossing the following polymers, but many others are possible:

PDMS, PEEK, Polycarbonate, PMMA

Some examples of typical embossings, in this case in a spun-on layer of PDMS on a silicon substrate are shown below in figures 5 and 6.

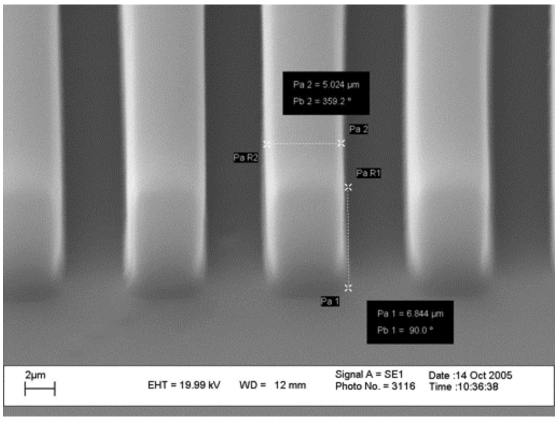


Fig 5. Vertical wall structures in PDMS on silicon

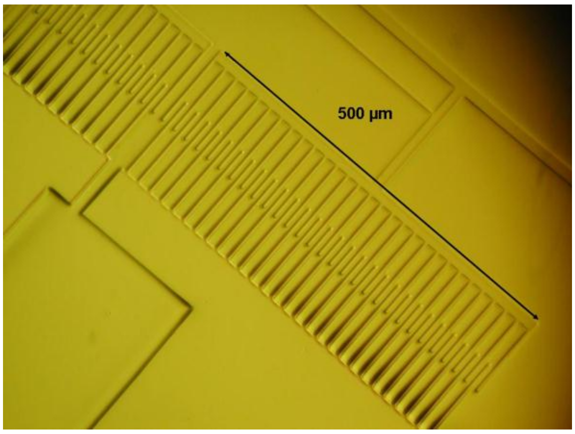


Fig 6. Embossing in PDMS layer on silicon

In addition to hot embossing, the tool has also been used to demonstrate nano-imprinting. Figure 7, below, shows an example of a nano-imprinted material in which 100nm lines are completely resolved.

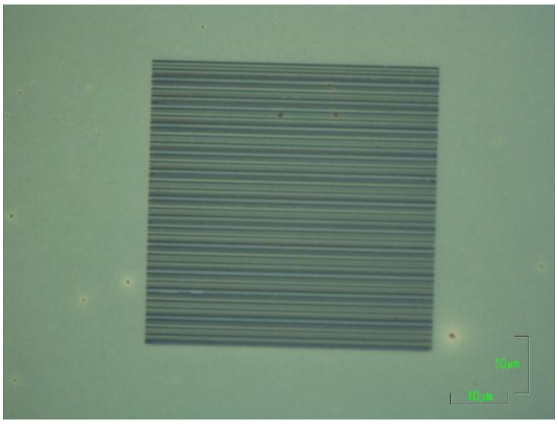


Fig 7.100nm printed lines in surface layer

If the stamp includes holes, that align with the apertures for the two split-field cameras that are used for the alignment process, then reflected, through-the-lens, visible light can be used for alignment. For standard silicon stamps, transmissive IR light can be used. This avoids having to machine through holes in the silicon. Figure 8 shows an image of the substrate wafer as seen through the in-situ alignment optics, when using transmissive IR illumination.

By including alignment marks on the stamp and on the substrate it is then possible to accurately align the embossed structure with pre-defined structure on the substrate. As with standard photolithography the overlay of a cross within another is the preferred alignment technique -See figure 9. A typical example whereby this alignment procedure would be used is the embossing of flow channels in a PDMS layer that has been spun onto a silicon wafer that has already been metallised and photolithographically patterned to include electrodes and bond pads.

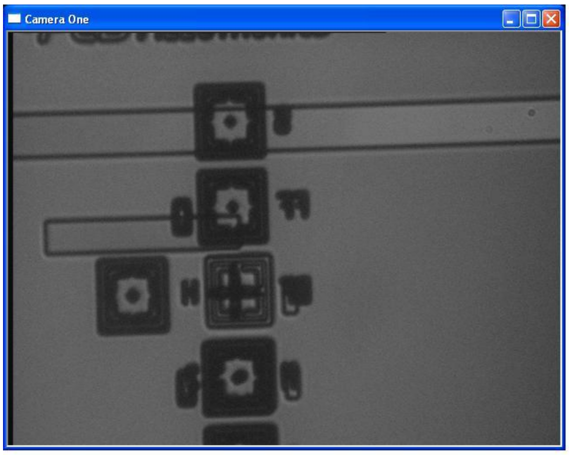


Figure 8. IR image of patterned substrate as seen through the in-situ alignment optics.

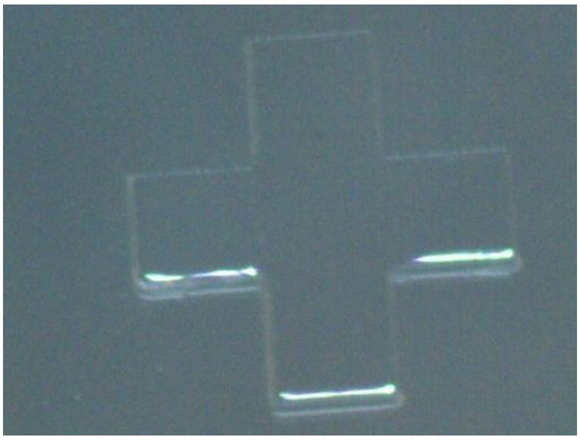


Fig 9. Overlaid crosses used for alignment of the embossing to pre-existing structures on the substrate. Magnification: 200X

The combined capabilities of embossing and bonding in the same machine have recently been exploited for the fabrication of a three-layer microfluidic polycarbonate structure, in which the through-embossing of the central layer is used to define flow channels. Two other substrates are also embossed such that when the three layers are subsequently bonded together, the embossings in the outer two layers form structured walls for the central flow channels. The bonded structure is shown schematically in Figure 10, and Figure 11 shows a photo of the structured wall at the end of one of the 100 micron deep flow channels.

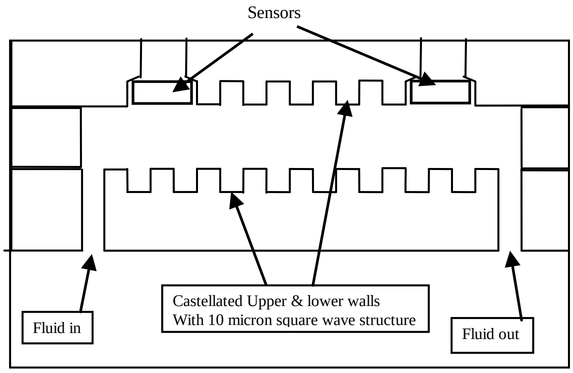


Fig 10. Schematic of three layer, embossed / bonded micro-fluidic device

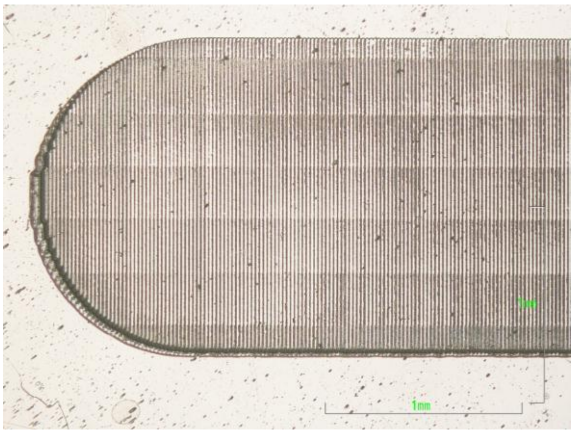


Fig 11. View of Structured polycarbonate surface forming the wall of a flow channel.

Figure 12 shows a close up of the 10 micron castellated structure that forms the channel upper and lower walls. The undulating edges are an artefact of the low cost acetate mask that was used for masking the silicon stamp during the DRIE fabrication. The undulating edges were then subsequently faithfully transferred in to the polycarbonate during the emboss step, thereby demonstrating the accuracy of the reproduction.

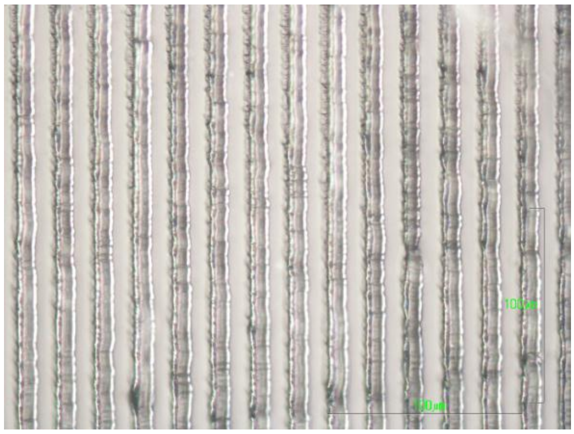


Fig 12. Close up of structured walls of the channels of a micro-fluidic device

4. Conclusions

The multi-purpose tool has been demonstrated to perform the following:

- Embossing of 100 micron high features
- Micron scale features with vertical walls and an aspect ratio of ~5:1
- 100nm printed lines / spaces
- In-situ alignment using transmissive infra-red illumination

These results are examples of structures that have been produced to date rather than representing the limit of the tool.

In addition to the above emboss / imprint processes, the tool has been demonstrated as being capable of a wide range of standard wafer bonding processes, also featuring in-situ alignment. In addition, in-situ surface activation using oxygen radicals can be used for polymer bonding.

The tool therefore provides a multi-purpose fabrication capability for MEMS devices.

5. References

[1] Chen C L and Jen F, Fabrication of Polymer Splitter by Micro Hot Embossing Technique. Tamkang Journal of Science and Engineering. Vol. 7, No. 1 pp 5–9, 2004.

[2] Malmros I,Hot Embossing of Polymers. MME2001. pp 7-10.

[3] Rogers T, Aitken N and Kowal J, Activation, Alignment and Bonding using Radical Activation. Ninth International Symposium on Semiconductor Wafer Bonding. 2006.

[4] Katzenberg F, Plasma-bonding of poly-(dimethylsiloxane) to glass. E-polymers 2005, No. 060. pp 1-5. ISSN 1618-7229.