The Application of Surface Mount Technology to Multi-Scale Process Intensification

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ABSTRACT

Microtechnology-based Energy and Chemical Systems (MECS) are multi-scale microsystems, which rely on embedded nano and micro-scale features to process bulk amounts of fluids in applications ranging from man-portable heat pumps, distributed fuel reforming and in-situ waste remediation. Microlamination is a well-known process architecture for fabricating the massively parallel, high aspect ratio microchannel arrays needed within these devices. While the promise of MECS technology is exciting, the dissemination of MECS technology is greatly dependent upon economical fabrication. This paper explores the application of surface mount technology (SMT) from the electronics industry to the microlamination of microchannel arrays. An economic analysis shows the impact that SMT could have on the cost of MECS technology. Experimental results show that the fabrication of high-aspect-ratio microchannels is indeed feasible.

Keywords: microchannel arrays, high aspect ratio, surface mount technology, soldering, process intensification

INTRODUCTION

Microtechnology-based Energy and Chemical Systems (MECS) are multi-scale fluidic devices, which rely on embedded micro-scale features to process bulk amounts of fluids in applications ranging from man-portable heat pumps, distributed fuel reforming and in-situ waste remediation. Many MECS devices are fabricated using a process architecture known as microlamination. Microlamination involves three steps: (1) lamina patterning, (2) laminae registration and (3) laminae bonding.[1] Lamina patterning involves surface machining, or through cutting, thin sheets of material, or laminae, with the appropriate patterns necessary to produce the overall desired structure. The laminae are shims or films of a base material (metal, polymer, etc.) having desirable mechanical, thermal and chemical properties important to the functioning of the final device. Eventually the laminae are registered relative to each other and bonded together in a stack.

Many bonding techniques have been used in the past for producing MECS devices. Electron beam welding was used by Beir[2] to join the laminae of a microchannel heat exchanger. This is a very expensive and time-consuming process. Diffusion bonding (DB) has been widely used in microlamination.[3,4] This method is also time consuming and requires high temperature and pressure. Such extreme conditions can produce unwanted warpage and residual stress in materials leading to geometric variations and misalignment between laminae. Other techniques used for bonding have included diffusion soldering and brazing.[4] All of these methods require extreme operating parameters, vacuum conditions and/or long cycle times. Under these bonding regimes, it has been found that the bonding process not only controls the amount of shape variation within microchannels but it also dominates the cost in microlamination.[5]

A key impediment to the proliferation of MECS applications will be its economical production. It is expected that with the diversity of MECS products that will be developed, there will be a similar diversity with regards to how they are made. One class of MECS devices with current appeal are portable and distributed heat-actuated thermal management systems. In particular, characteristics of the man-portable devices are that they be lightweight and made from materials with high thermal conductivity. Materials must be inert to working fluids and refrigerants such as LiBr, water and ammonia and generally operating conditions do not exceed several atmospheres and 250°C (other than combustors).

One promising avenue for addressing economical production in these types of devices is the application of surface mount technology (SMT). SMT is the practice and method of attaching leaded and non-leaded electrical components to the surface of conductive patterns in the electronic assembly industry. In the electronic industry, SMT enabled the trend toward electronic assemblies that have greater functionality, smaller size, less weight and less cost. In addition to being an efficient, economical platform for production, SMT also provides a platform for integrating electronics into MECS devices. This factor may become more critical as the need to integrate sensors and actuators within MECS devices grows. The bonding process in SMT requires a low temperature of about 300° C

and occurs at atmospheric pressure. The reflow process takes 2-3 minutes, which is negligible when compared to techniques like diffusion bonding which takes hours to bond laminae. The printing and reflow processes can be easily automated as well.

It is also proposed that low fabrication temperature and pressure, prevents warpage and residual stress in materials leading to more stable geometry and alignment. These devices when produced in high volume will have shorter production and throughput times. This will cut down the cost of the end product drastically. As shown in Figure 1, SMT can bring down the individual device cost by more than 50%.[6] Figure 1 shows how the unit cost of MECS devices goes down when SMT is used for bonding as compared to diffusion bonding (DB) with photochemical machining (PCM) and blanking (BLK) as the patterning processes. This is mainly due to the decreased cycle time costs associated with the bonding process. The purpose of this paper is to see if SMT is viable for the production of microchannel devices.

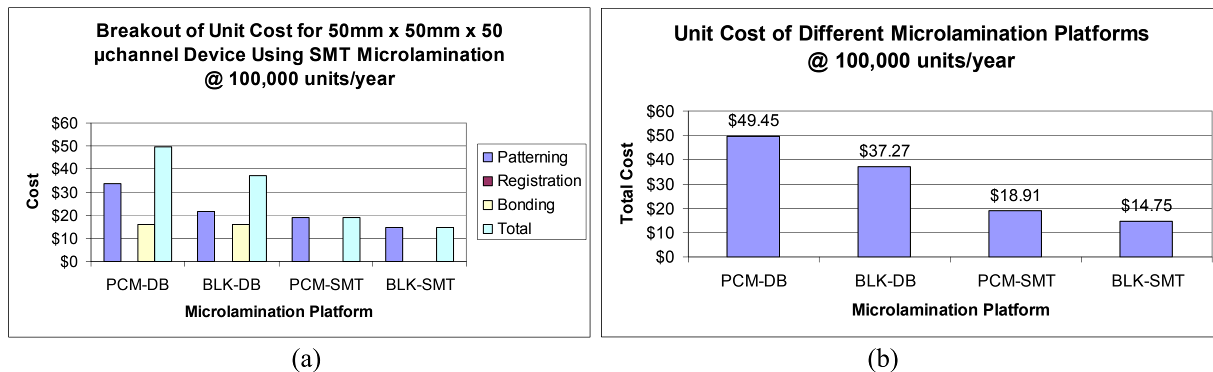


Figure 1: (a). Unit cost when separated into patterning, registration and bonding at a production rate of 100,000 units/year for four different platforms. (b). Unit cost for four different platforms.

MATERIALS AND METHODS

The substrate material chosen for this proof-of-concept experiment was Cu mainly due to the excellent wettability of Cu with standard solder paster. Cu shim stock approximately 200 µm (0.008 inch) in thickness was used for the experiments. The solder paste used for the tests is eutectic SnPb solder (Sn63-Pb37). Also, low residue no-clean flux is used for localized wetting of the Cu in some places where the solder paste is not applied.

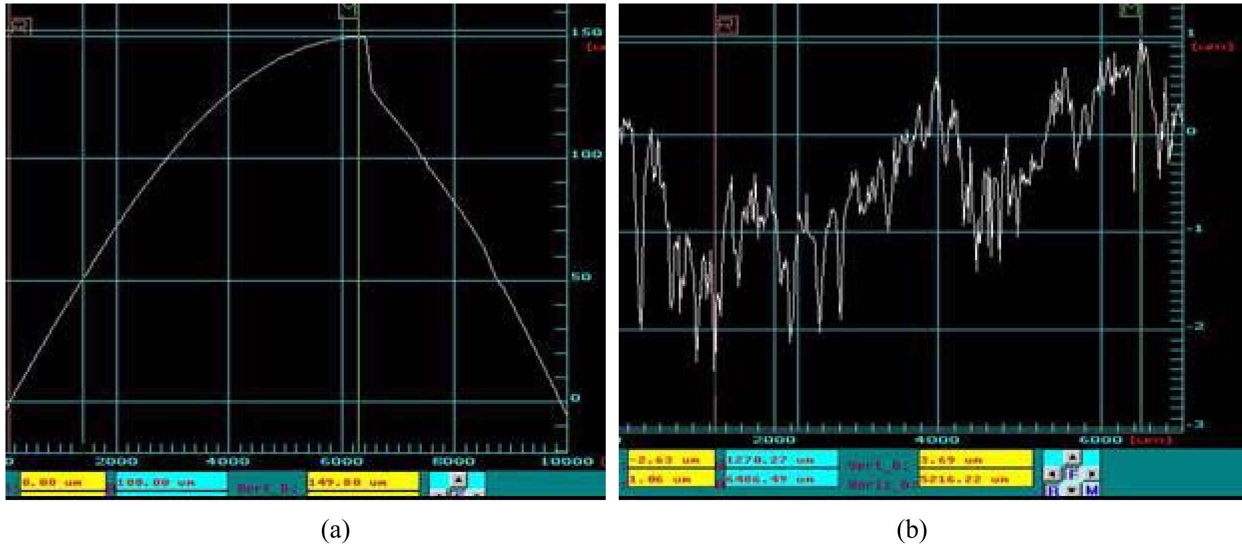
The substrate obtained from the vendor was first cut into the required geometry using a Nd:YAG 355 nm laser mounted on an ESI 4420 laser micromachining system. To form a single microchannel, laminae with three different patterns were cut. The bottom plate was a flat Cu substrate with dimensions 4.4 x 1.9 cm. A Cu rectangular spacer with a rectangular window was used to form the channel. The outer dimensions of the spacer were 4.4 x 1.9 cm and the inner dimensions were 3.68 x 1.14 cm. The top inlet plate had dimensions of 4.4 x 1.9 cm with a small diameter hole of 0.18 cm at the center for leakage testing. All of these laminae were deburred using Scotch Brite after being cut on the laser. These deburred laminae were then flattened in the hot press at a temperature of 500°C and a pressure of 36.75 bars.

Solder paste (Sn63-Pn37) was printed on each lamina using a Semi-Automatic Ekra screen printer. Low residue no-clean flux was applied at the tie-bar areas where the solder pasted is required after reflow. These solder printed laminae were stacked on the top of each other in the desired pattern and then reflowed through the Quad ZCR convection based four zone reflow oven. The device was pressure tested for leakage at 1.72 bar with the help of a fixture.

RESULTS

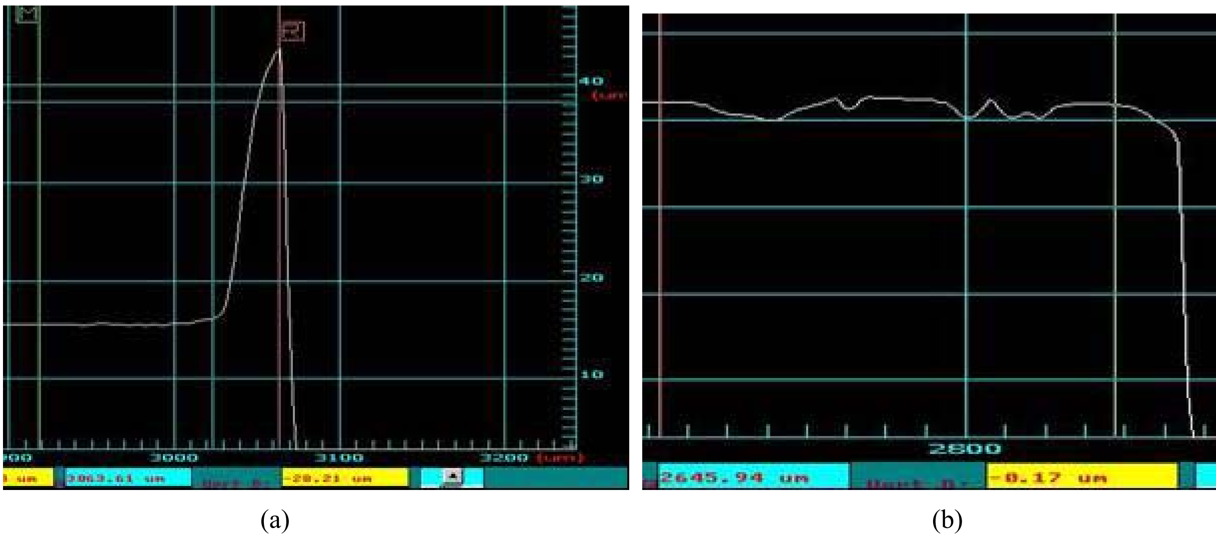
The flattening procedure on the hot press for the Cu substrate showed significant improvement in the flatness and roughness of the laminae. This was critical for proper solder paste printing. The fresh shim stock received from the vendor had a mean flatness of 99.9 ± 32.9 µm. After treating the laminae on the hot press, the flatness obtained had a mean of 4.73 ± 1.14 µm. Figure 2 shows the flatness profiles obtained before and after treatment with the hot

press. Further, as shown in Figure 3, the burrs produced by the laser were greatly reduced by using the mechanical deburring technique going from a mean of 19.1 ± 8.5 µm to 2.93 ± 2.3 µm.



(a) (b)

Figure 2: (a). Flatness variation of a fresh Cu shim obtained from vendor. (b). Flatness variation of a treated Cu shim.



(a) (b)

Figure 3: (a) Profile obtained from laser burr on the Cu shim. (b) Profile obtained after deburring the Cu shim.

Figure 4 shows the single microchannel made by application of SMT. A channel height of 334.3 ± 3.14 µm was obtained using this process. This indicates a channel uniformity of less than one percent which is currently unattainable in diffusion bonding based processes. Also the device successfully passed the leakage test when tested at a pressure of 1.72 bars. More recently a leak proof (pressure tested at 1.72 bar) four-channel microchannel device was also made using the same technique.

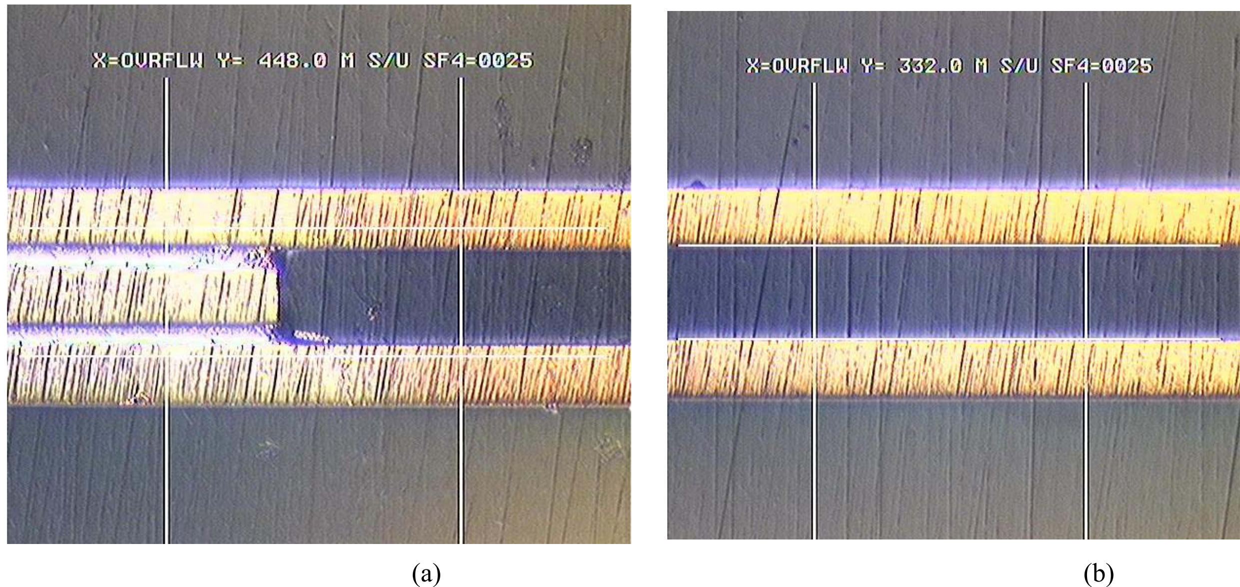


Figure 4: (a) The spacer with the solder layer and the channel. Solder joints are approximately 65 µm in height. (b) Picture of the midsection of the channel showing excellent uniformity. Overall channel height was 332 µm with a channel aspect ratio of 34:1.

CONCLUSIONS

The results obtained show that SMT can be successfully used to produce high aspect ratio microchannels. The use of low bonding temperatures (in the range of 300°C) and pressures results in well aligned, parallel channels with extremely low levels of warpage. Also, the surface flattening procedure using the hot process, resulted in significant reduction in the surface roughness of the laminae. Economic analyses indicate that this process will be favorable over existing diffusion bonding-based processes. While this material and process combination will not meet all of the requirements for future MECS devices, it has shown the potential to use solder pastes in the formation of microchannels. Future efforts will be focused on understanding the physics involved with controlling microchannel height in multi-channel arrays as well as the development of new solder paste/substrate material combinations acceptable for manportable MECS applications.

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