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## Fabrication of the monolithic polymer–metal microstructure by the backside exposure and electroforming technology

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**Abstract** Monolithic polymer–metal microstructures can be fabricated on the silicon or glass substrate using two kinds of photoresists and electroforming technologies for the inkjet and microfluidic application. However, it suffers from the high shrinkage problem of first SU8 resist after exposure and post exposure baking. This paper reports a novel approach to solve the shrinkage problem by introducing backside exposure of first SU8 resist for the fabrication of the monolithic polymer–metal microstructure. In combination with the light absorption layer coating on the unexposed SU8 resist, metal seed layer deposition, frontside exposure for second JSR resist on the seed layer and the nickel (Ni) electroforming together with release process, we have demonstrated a high physical resolution of 1,200 dpi monolithic Ni nozzle plate with negligible shrinkage. It also has the advantages of low cost and high resolution for the improvement of the traditional bonding of polymer and metal nozzle plate, which is generally in need of a complex alignment to stick the metal nozzle plate and dry film polymer on the heating chip together.

### 1 Introduction

The two-layer stacked microstructures by LIGA-like process have been widely used in the fields of inkjet printing, packaging, bio micro-arrays, microfluidic devices and so on. The conventional inkjet chip needs complicated alignment instrument and bonding technology to make the metal nozzle plate and heating chip together (Boeller et al. 1988). Some stacked

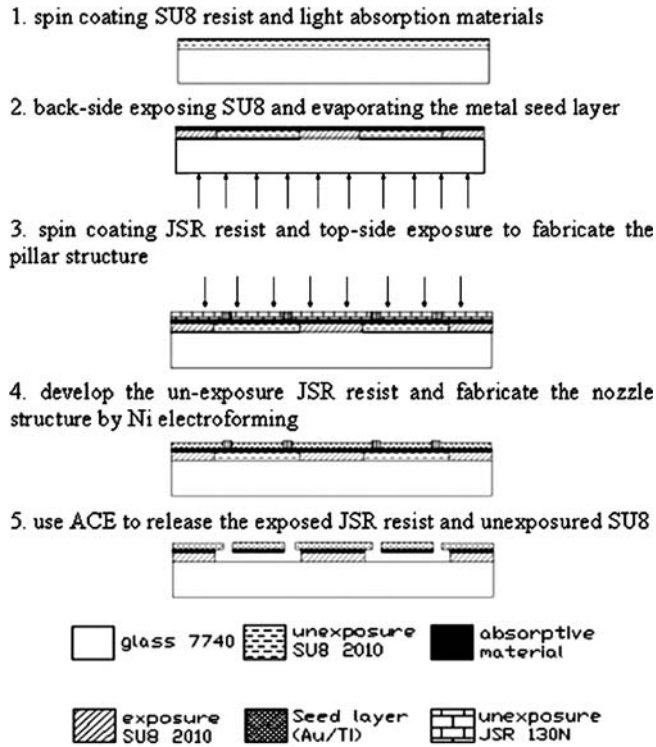
microstructures or buried channels, especially monolithic microstructures, fabricated by the MEMS technology have been proposed to simplify conventional process procedure, increase accuracy of alignment and reduce the process temperature and cost (Guerin et al. 1997; Francis et al. 2001; Kim et al. 2004; Chung et al. 2004a, b). Guerin et al. (1997) fabricated the embedded channel with different filling material to form SU8 buried channel. The roughness between the interface of exposed SU8 and unexposed SU8 would be produced by the SU8 polymerization. Francis et al. (2001) exposed the photoresist with the different doses of proton beam to fabricate the multi-layer structures in a single photoresist layer. Good performance of the layer-by-layer structures could be achieved, but the proton beam instrument is too expensive. Kim et al. (2004) used the backside exposure method to manufacture the micro-needle with over exposed method. Moreover, it is difficult to use the over exposed UV light dosage to control the precise profile of SU8 structure. Chung et al. (2004a, b) had proposed the two kinds of photoresist lithography and Ni electroforming process to fabricate the monolithic two-layer polymer–metal structure for inkjet application. However, all the above approaches related to the frontside SU8 exposure, they will suffer from the high shrinkage problem of exposed SU8 after post exposure baking (PEB) (Lorenz et al. 1997) to result in the non-uniformity of followed resist coating and process for the monolithic MEMS microstructure.

In this paper, we combine the backside exposure of the first SU8 resist with the CK 6020L light absorption layer coating, the frontside exposure of the second JSR resist and the Ni electroforming for the fabrication of monolithic polymer–metal microstructure with negligible shrinkage.

### 2 Experimental procedures

Figure 1 shows the schematic process flow of the monolithic polymer–metal microstructure using

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**Fig. 1** The schematic process flow of introducing backside exposure approach to the monolithic polymer–metal microstructure

backside exposure process for first SU8 resist, a light absorption layer coating, a metal seed layer deposition, frontside exposure for second JSR resist and the Ni electroforming. The details are described in the following steps.

1. Spin coat the negative tone SU8 about 35 μm photoresist on the Pyrex 7740 glass and followed by the light absorption material CK 6020L on SU8. The thick photoresist SU8 was used as structure material because of its superior properties (Lorenz et al. 1997, 1998). A light-absorbing polymer layer was coated to protect the SU-8 layer from overheating during the metal seed layer deposition and over-exposure of the backside exposed first SU8 resist and the frontside exposed second JSR resist during lithography process.
2. Pattern the first negative tone SU8 photoresist to fabricate the polymer chamber and channel by

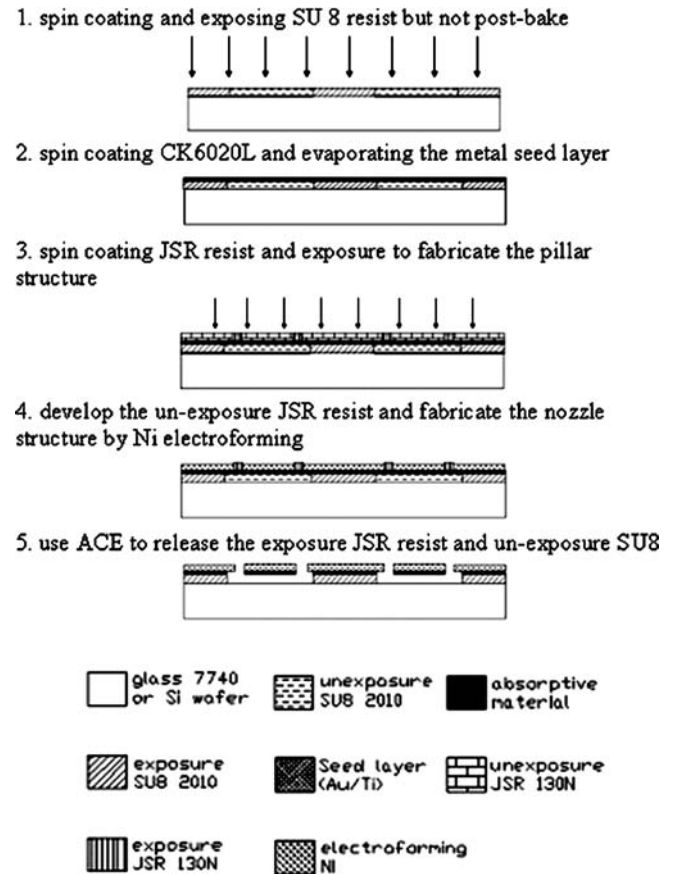
**Table 1** The solution compositions and operation condition in the nickel electroforming

Description	Concentrations or conditions
Nickel sulfate (g/l)	450
Nickel chloride (g/l)	4
Boric acid (g/l)	40
Wetting agent (ml/l)	5
pH	3.7
Temperature (°C)	45
Current density (A/dm <sup>2</sup> )	1–2.5

backside exposure technology. The UV-light dose was controlled at about 900 mJ/cm<sup>2</sup>. Then metal seed layer of the Titanium/Gold (Ti/Au 25 nm/250 nm) was evaporated by e-beam evaporator to fabricate metal structure by followed Ni electroforming. Multi-steps evaporation was used to decrease the temperature of polymer on the substrate and avoid the polymer to deteriorate or change the shape of photoresist patterned.

3. Spin coat the second negative tone JSR photoresist about 17.5 μm and followed by topside exposure method to fabricate the high resolution of pillar structure on the microchannel of polymer structure.
4. Develop the un-exposed JSR and fabricate the metal nozzle plate by Ni electroforming. The compositions of electroforming bath and the operating parameters are listed as follows Table 1.
5. Use acetone (ACE) etching solution to release the JSR exposed and the SU8 un-exposed structure to form the monolithic polymer–metal microstructure.

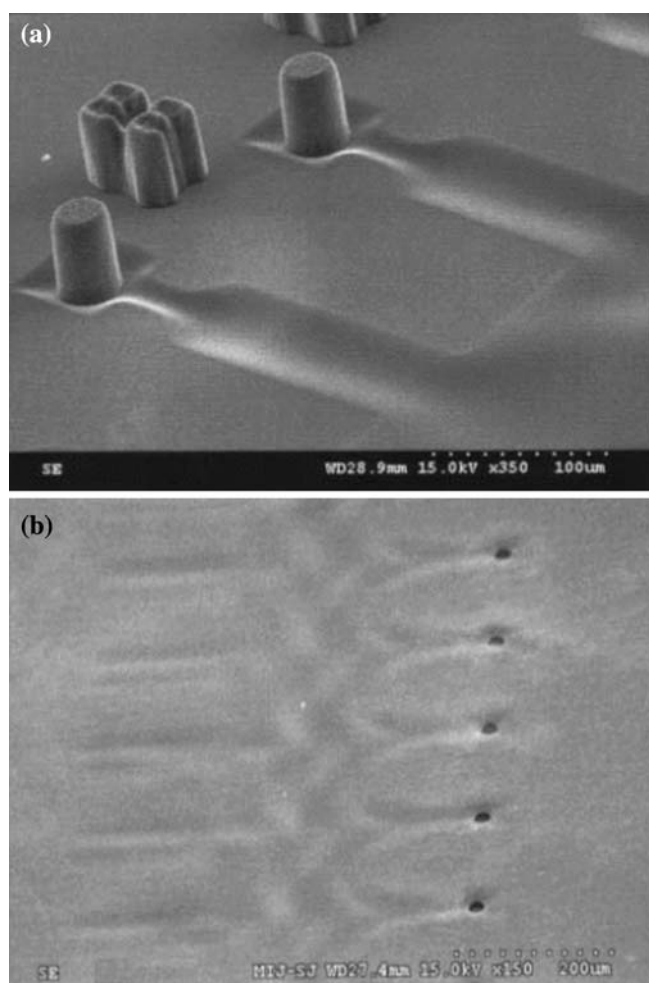
The quality of thick resist and electroformed Ni plate were examined by alpha-step profiler, optical microscopy (OM, Olympus BX-51, Japan) and scanning electron microscopy (SEM, JEOL JXA-840A, Japan).



**Fig. 2** The schematic process flow of only topside exposure approach to the monolithic polymer–metal microstructure

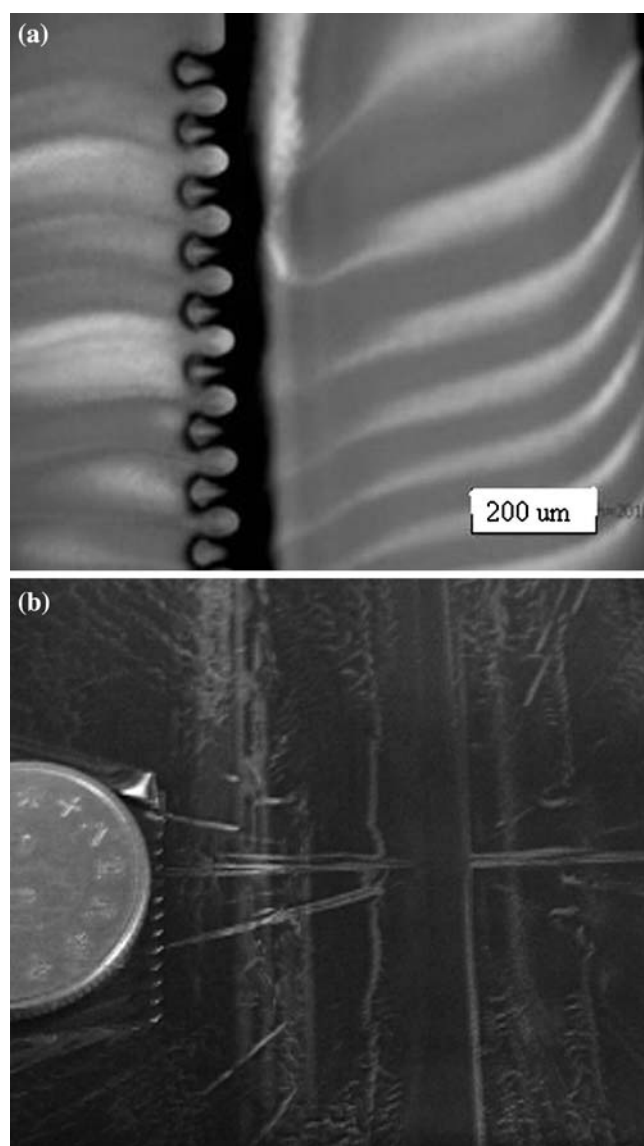
### 3 Results and discussion

Figure 2 shows the schematic process flow of the monolithic polymer–metal microstructure using only topside exposure technology. The first thick SU8 photoresist about 35  $\mu\text{m}$  is used for the polymer structure of ink channel and chamber. It is spin-coated and patterned on the substrate but not developing. The CK 6020L resist as a light absorption layer is following to coat on the top of SU8 and then evaporating the Ti/Au seed layer. The Ni nozzle plate is obtained by second thick JSR resist mold patterning, nickel electroforming and stripping the exposed JSR and unexposed SU8 resists. Figure 3a shows the mold of JSR resist on the top of undeveloped SU8 resist for nickel electroforming. After electroforming and stripping the remained resist, the Ni nozzle plate is achieved as shown in Fig. 3b. The shrinkage problem of the SU8 resist reflects to the followed process of second JSR resist mold coating, and

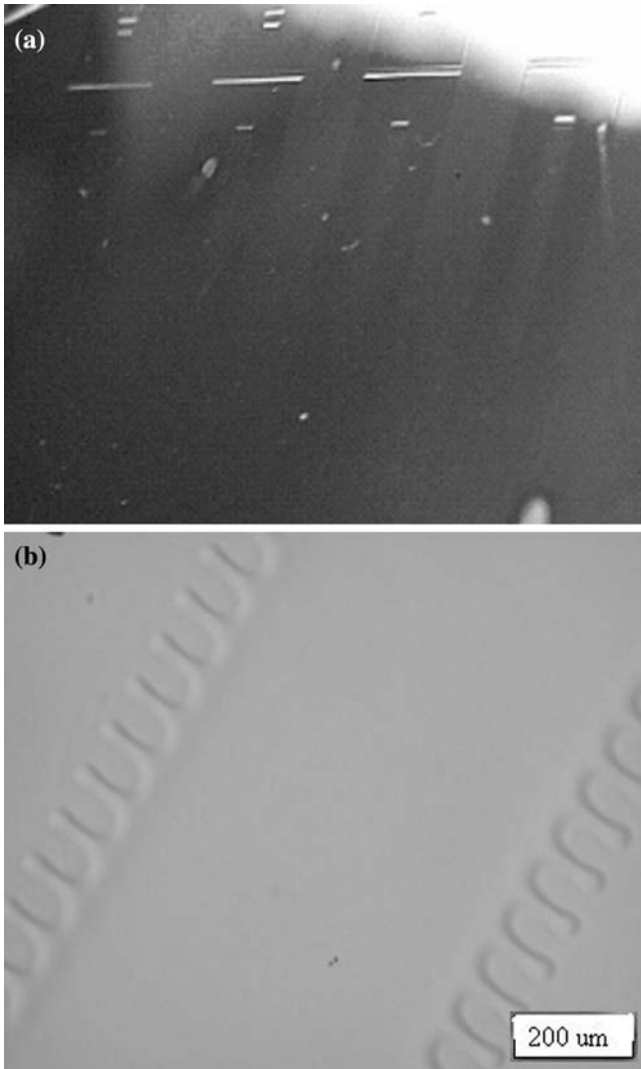


**Fig. 3** **a** The mold of JSR resist on the top of undeveloped SU8 resist for nickel electroforming, and **b** the Ni nozzle plate achieved after electroforming and stripping the remained resist. The shrinkage problem of the SU8 resist reflects to the followed process of JSR resist mold, and electroformed Ni nozzles plate

electroformed Ni nozzles plate. The JSR mold is located at the shrinkage area of SU8 and Ni nozzle plate duplicate the shrinkage area in the surface. It forms a concave area in the manifold due to SU8 performed by post exposure bake (PEB). If the shrinkage problem is severe after the cross-linking and solvent evaporation of SU8 with exposure and PEB, it will lead to a wrinkle surface with very large roughness (Fig. 4a) to affect the following CK 6020L resist coating in non-uniformity with irradiative lines (Fig. 4b). The irradiative phenomenon of CK 6020L is due to its material properties of low viscosity and quick-drying. It is important to reduce the SU8 shrinkage issue for a uniform coating of resist. So, we change the process sequence and introduce



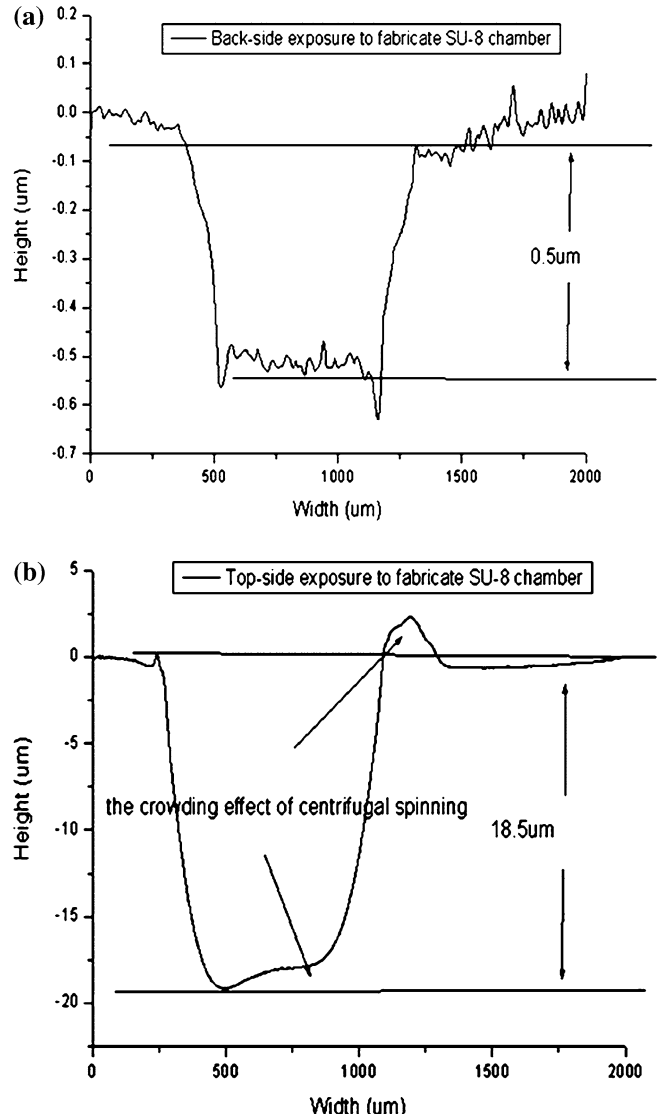
**Fig. 4** Optical micrographs of patterned first SU8 resist for the structure of ink channel and chamber with topside exposure technology: **a** severe shrinkage problem after SU8 exposure and PEB to result in a wrinkle surface with very large roughness, and **b** the followed CK 6020L resist coating in non-uniformity



**Fig. 5** **a** The optical micrograph of the un-exposed SU8 photoresist and followed black CK 6020L resist coating uniformly, and **b** using backside exposure technology to form the polymer structure of ink channel and chamber

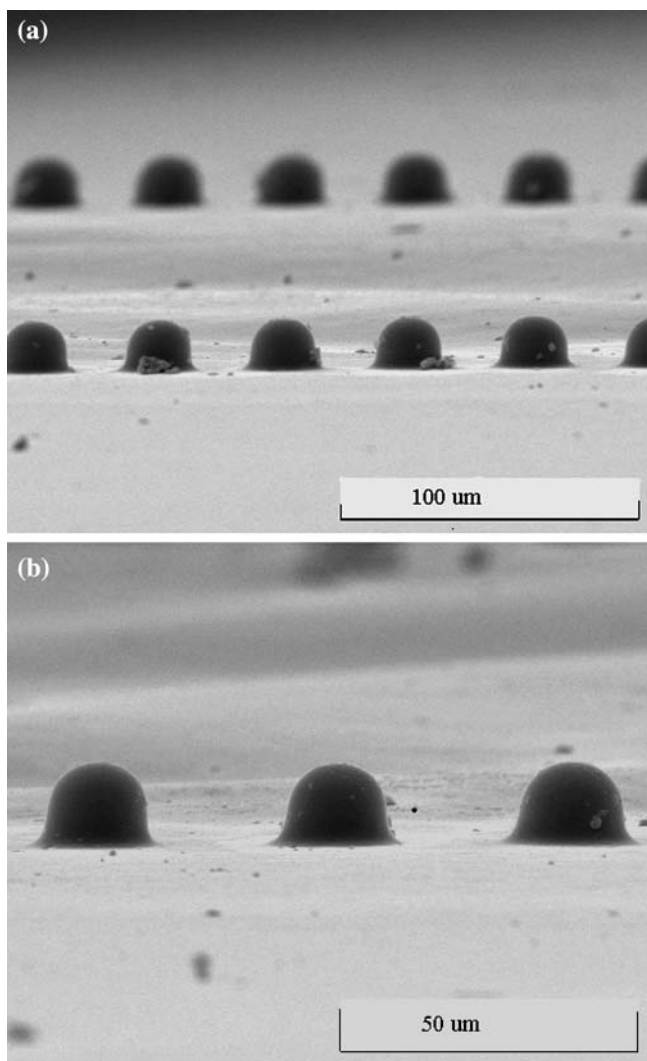
the backside exposure technology to solve this problem as shown in Fig. 1.

Figure 5a shows the optical micrograph of the un-exposed SU8 photoresist and followed black CK 6020L resist uniformly coating and then using backside exposure technology to form the polymer structure of ink channel and chamber as shown in Fig. 5b. The CK 6020L could be uniformly coated on the top of unexposed SU8 and the polymer structure with smooth surface and little shrinkage can be obtained after backside exposure. Figure 6a, b shows the alpha-step profiles of coating thick SU8 and CK 6020L resists and exposed by backside exposure and topside exposure technologies, respectively. The chamber profile by backside exposure exhibits the very small polymer shrinkage of about 0.5  $\mu\text{m}$ , but that by topside exposure has the polymer large shrinkage as high as 18.5  $\mu\text{m}$  and non-uniform. The



**Fig. 6** The alpha-step profiles of coating thick SU8 and black CK 6020L resists and exposure by: **a** backside exposure technology introduced, and **b** only topside exposure technology. The chamber profile by backside exposure exhibits a very small polymer shrinkage of about 0.5  $\mu\text{m}$ , but that by topside exposure has the polymer large shrinkage as high as 18.5  $\mu\text{m}$  and non-uniform

large shrinkage of SU8 photoresist results in the crowding effect of the centrifugal spinning by followed CK 6020L resist coating. A CK 6020L light-absorption polymer coated between SU8 resist and metal seed layer is used for protecting the SU-8 layer from overheating during the metal seed layer deposition and backside over-exposure of the first SU8 resist and topside over-exposure of the second JSR resist during lithography process. Figure 7a, b shows the SEM micrographs of the high-density pillar mold of the second JSR photoresist on the backside exposure substrate and its close-up, respectively. The physical resolution reaches to 1,200 dpi in two-column structures with alternate nozzles, and the thickness of JSR resist is about 17.5  $\mu\text{m}$ . If the physical

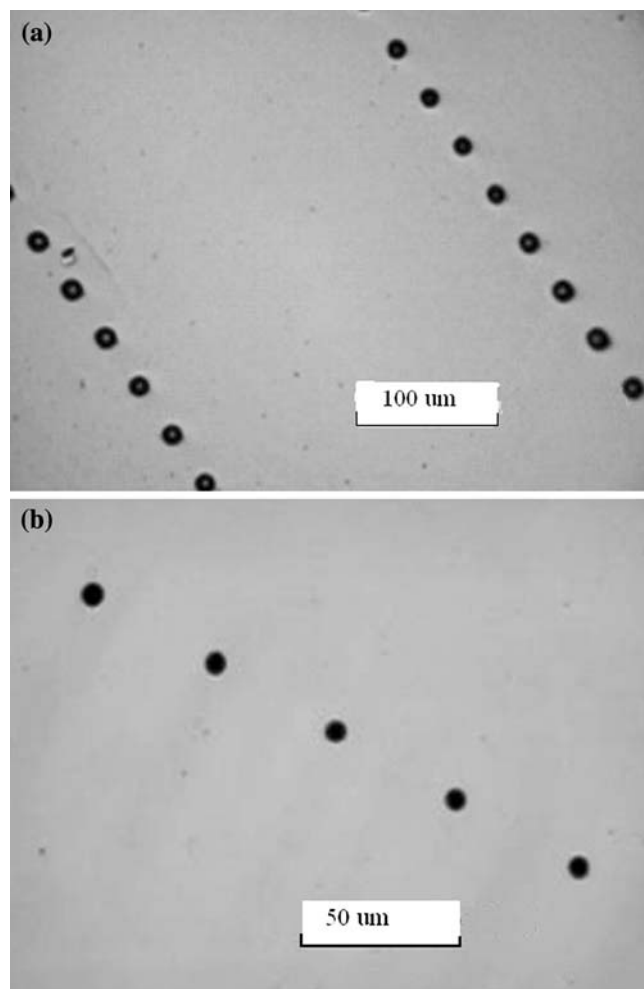


**Fig. 7** **a** The smooth JSR pillar mold on the top of ink chamber, and **b** its close-up picture using backside exposure technology

resolution is increased, the thickness and radius of the JSR photoresist pillar mold will be reduced. The reduced thickness and radius of JSR pillar mold will be more stable on the surface of patterned polymer photoresist but increase the release time longer. Followed by the Ni electroforming, the monolithic Ni nozzle plate with smooth morphology has been achieved by backside exposure method. Figure 8a, b shows the monolithic Ni nozzle plate with high resolution of 1,200 dpi and its close-up, respectively. The thickness of nickel nozzle plate is about 15  $\mu\text{m}$  and the lower current density of Ni electroforming could be used to obtain a better metal structure of the Ni nozzle plate as listed in Table 1.

#### 4 Conclusions

The monolithic polymer–metal microstructures can be fabricated using two kinds of photoresists and electroforming technologies for the inkjet and microfluidic



**Fig. 8** **a** The prototype of polymer–metal chip with the monolithic nickel nozzle plate of a 1,200 dpi physical resolution, and **b** its close-up picture using backside exposure technology

application. In the conventional integrated technology, only topside exposure is applied to different resists but it will suffer from the high shrinkage problem of exposed SU8 resist after PEB. This will lead to the followed resist coating in non-uniform and crowding effect at the interface of exposed and unexposed SU8 areas. It also duplicates the rough surface of SU8 due to shrinkage to the electroformed Ni nozzle plate. A novel technology by introducing the backside exposure method is proposed to solve the above problems during the fabrication of monolithic polymer–metal microstructures. The backside exposure technology can effectively improve the non-uniform surface of SU8 and CK 6020L resists coating. The CK 6020L light-absorption polymer is used for protecting the SU-8 layer from overheating during the metal seed layer deposition and backside over-exposure of the first SU8 resist and topside over-exposure of the second JSR resist during lithography process. Based on the above technology advantages, a high physical resolution of 1,200 dpi monolithic nozzle plate with negligible shrinkage has been demonstrated.

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## References

- Boeller CA, Carlin TJ, Roeller PM, Steinfield SW (1988) High-volume microassembly of color thermal inkjet printheads and cartridges. *J Hewlett Packard* 39:6–15
- Chung CK, Lin CJ, Chen CC, Fang YJ, Tsai MQ (2004a) Combination of thick resist and electroforming technologies for monolithic inkjet application. *Microsyst Technol* 10:462–466
- Chung CK, Lin CJ, Wu LH, Fang YJ, Hong YZ (2004b) Selection of mold materials for electroforming of monolithic two-layer microstructure. *Microsyst Technol* 10:467–471
- Francis EHT, Kan TA, Watt F, Choong WO (2001) A novel micro-machining method for the fabrication of thick-film SU-8 embedded micro-channels. *J Micromech Microeng* 11:27–32
- Guerin LJ, Bossel M, Demierre MS, Calmes S, Renaud Ph (1997) Simple and low cost fabrication of embedded micro-channels by using a new thick-film photoplastic. *Transducers* 97:1419–1422
- Kim K, Daniel S Park, Hong M Lu, Che W, Kim K, Lee J-B, Ahn CH (2004) A tapered hollow metallic microneedle array using back-side exposure of SU-8. *J Micromech Microeng* 14:597–603
- Lorenz H, Despont M, Fahrni N, LaBianca N, Renaud P, Vettiger P (1997) SU-8: a low-cost negative resist for MEMS. *J Micromech Microeng* 7:121–124
- Lorenz H, Despont M, Fahrni N, Brugger J, Vettiger P, Renaud P (1998) High-aspect-ratio ultrathick, negative-tone near-UV photoresist and its application to MEMS. *Sens Actuators A* 64:33–39