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Study of Picosecond Photonic Impact Microdeposition of Active Micropillars with Negative Sidewall Inside Micromoulds

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ABSTRACT
Photonic impact induced or laser induced microdeposition using high power pulse laser is an emerging new technology that overcomes limitations on materials used over microelectroforming, the most popular way to produce micromoulds for microinjection molding. Forming deformable microfeatures inside micromoulds to enable active demolding is challenging due to limitations on deformation ratio of shape memory alloys. This study proposes a new method for producing micropillars inside micromoulds that makes large deformation of micropillars in low temperature phase possible. Success of this study would not only enable the fabrication of microfeatured biocompatible plastic product such as artificial skin, molecular filters, etc. with the lowest cost massively. It could also be used to produce other artificial products that mimicking plant in the nature such as artificial leaf that absorbs CO2 and produces O2.

Keywords - microdeposition, mechanical strength, photonic impact forward transfer, side-wall roughness

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I. INTRODUCTION

Photonic impact forward transfer deposition or laser impact forward transfer deposition is a new technology that shows great potential and has not yet been fully developed. Limitations of laser assisted deposition for producing microstructures mainly lie on the low mechanical strength caused by the dot by dot (for micropillars) or line by line (for microwalls) connection process, where the shapes of dots and lines are normally round. Jhavar et al [2] studied the development of a novel technique called micro-Plasma Transferred Arc (microPTA) for producing net-like metallic microstructures at IIT Indore, India. Jerby el al. [1] used Localized Microwave Heating (LMH) for melting bronze-based powder and its stepwise additive deposition to manufacture its rod using ceramic support a tungsten electrode. They also used iron-based powder for magnetic fixation to provide a contactless means to hold the deposition powder instead of ceramic support.

Simulation of multi-layer and multi-material deposition using finite element simulation (FES) to study and predict distribution of temperature and stress, effect of deposition process parameters on them and modification mechanism of properties of deposition materials had also been carried out. Zhao et al. [6] carried out a 3D transient heat transfer simulation and investigated the thermal characters and effects of deposition directions on the thermal process for multi-layer deposition weld-based rapid prototyping. They optimized the deposition parameters and deposition direction through simulation.

Previously, the fabrication of micromoulds for producing plastic microneedle arrays using pico-second laser machine was studied [4]. The forward transfer deposition of single dot [3] and microlines by connecting microdots using pico-second laser was also studied experimentally. The effects of deposition step-size on top surface roughness were studied and it was found that reducing spot size can reduce the surface roughness while the deposition thickness was also increased. Depositing metallic materials AgW on quartz using electroless deposition were also studied by the authors [6].

This paper presents the investigations on producing deformable micropillars using laser forward transfer method to enable large deformations of the tip of micropillars made of SMA, which can deform under pressure at lower temperature. The objective is to produce reverse cone like microcapsules with maximum surface areas on plastic products. This type of microfeatures can greatly enhance surface absorption capabilities that can be used to produce artificial skins, artificial leaves etc.

II. BENEFITS OF PRODUCING ACTIVE MICROPILLARS WITH NEGATIVE SIDE WALL IN MICROMOULDS

Negative side wall micropillars in micromoulds can be used to produce plastic products with microcapsules that can be used to trap specific molecules and measure molecular structures inside the capsules. It can also be used to produce artificial tissues with surfaces that can filter out large molecules. These applications demand the capability of producing microcavities with maximum inside surface area with fixed entrance diameter. These can be explained as follows.

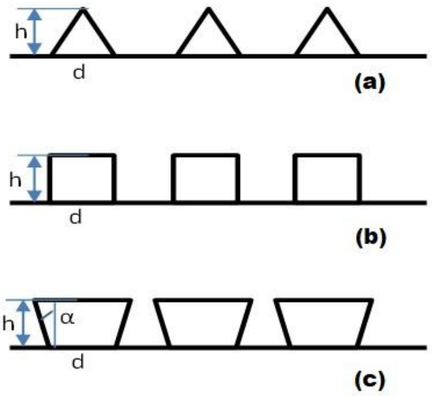

Fig.1 Illustration of 3 types of microcapsules with same entrance diameter d and depth h; (a) cone shaped microcapsules, (b) column shaped microcapsules, (c) reverse cone shaped microcapsules.

Surface areas of the 3 types of capsules as shown in Fig. 1 (a), (b) and (c) with identical entrance diameter d and depth h can be calculated by assuming angle $\alpha = 30^O$.

$$A_a = \frac{1}{2\pi}\int_0^h d(x)\pi dx = \int_0^h x\frac{d}{h}\pi dx = \frac{1}{2}hd\pi$$
(1)

$$A_b = hd\pi$$
(2)

$$A_c = \frac{1}{2\pi}\int_0^h d(x)\pi dx = \int_0^h (d + x\frac{(D-d)}{h})\pi dx = \int_0^h (d + x\frac{2}{\sqrt{3}})\pi dx = hd\pi + \frac{h^2}{\sqrt{3}}\pi$$
(3)

while d=200 µm , h/d=50,

Ratio $A_a=10^6\pi : A_b=2\times10^6\pi : A_c=59.7\times10^6\pi$

□ $A_c >> A_b$
(4)

where A_a, A_b and A_c are surface areas of the 3 types of microcapsules as shown in Fig.1. It is obvious that the reverse cone shaped microcapsules as shown in Fig.1(c) gives surface area much greater than the cone shaped and column shaped ones as shown in Fig.1 (a) and (b).

To produce reverse cone like microcapsules with maximum surface areas as shown in Fig.1(c) on a plastic product, a micromoulds with negative side wall micropillars that can deform in lower temperature and recover the original shape in higher temperature to reduce the resistance of demolding in the process of microinjection molding has to be produced. Such deformable micropillars that can deform by controlling the temperature and/or other parameters are called active micropillars.

III. ACTIVE MICROPILLARS TO REDUCE DEMOLDING RESISTANCE USING PHOTONIC IMPACT MICRODEPOSITION

One of the advantages of the proposed photonic impact microdeposition is that the new method can deposit almost any type of geometries by connecting lines or tapes together using photonic impact, unlike traditional material depositions that need to melt the powders first before allowing them to solidify.

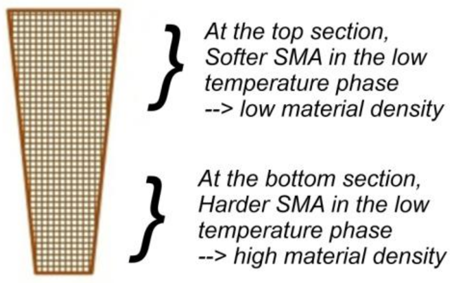

Fig.2 Illustration of hardness of deforming micropillars at different sections in lower temperature phase of SMA.

Is hardness proportional to material density? The answer is no, as materials can be deformed as a paper fan to fold the structures and unfold it. Therefore, the deformable micropillars to be produced that should deform by folding together to allow micromoulds to demold with much less demolding resistance.

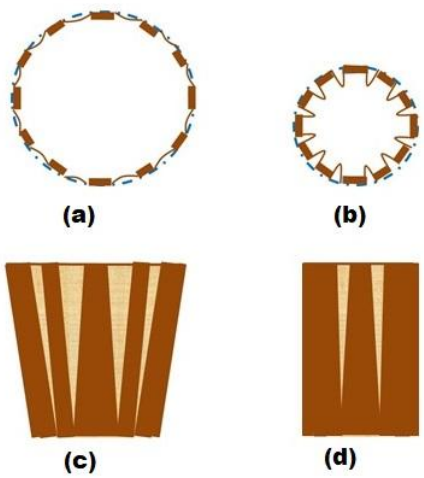

Fig.3 Illustration of active micropillars to be produced (a) Cross-section of micropillars in high temperature; (b) Cross-section of micropillars in low temperature; (c) Side view of micropillars in high temperature; (d) Side view of micropillars in low temperature

To form the side wall of the active micropillars, 2 types of microstructures: microbars and microfilms, are needed to deposit. A few rectangle cross-section microbars could be deposited firstly to form the main structure of the micropillar sidewall. Then the structure should be tilted to allow depositing films by winding microtapes around the microbars. An alternative way is to deposit reverse cone shaped microstructures by depositing microwires first, followed by depositing microbars inside the microwire structures. The advantages of using the first method are easier positioning, better sealing and higher material efficiency. The major disadvantage is that tilting of the target makes producing multiple micropillars difficult. Those micropillars produced one by one have to be put together by combining their bases, which is a bit tricky. Therefore the second method that combines microwire deposition with microtape deposition together is more suitable to produce micropillar arrays.

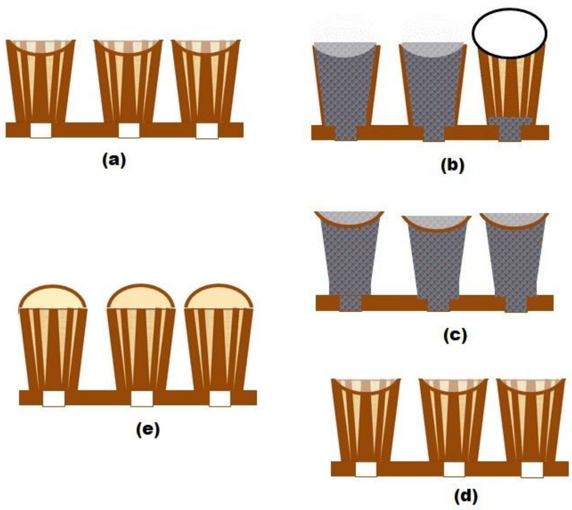

Fig.4 Illustration of micropillar arrays in processes; (a) shows the holes at the bottom of each pillar, (b) filling the micropillar cavity with removable materials to provide support; (c) depositing the top of micropillars; (d) micropillar arrays after supporting materials being removed, e) deposited tops of micro pillars, which can be pumped up using microneedles underneath

IV. CONCLUSION

In order to produce negative sidewall micropillar arrays on microinjection moulds to produce microfeatures on plastic surfaces for mimicking features of leaves and skins, this study proposed methods to deposit SMA lines and tapes by photonic impact deposition. In the design of micropillars, which could allow to deform more at the top and deform less at the bottom when transforming from higher temperature phase to lower temperature phase. Also, a type of pillar wall microstructures that would be folded rather than be shrunk in phase transition stage is introduced. This study could be helpful in producing artificial products with special functionalities.

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