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A Study of Pulse by Pulse Microscale Patch Transfer Using Picosecond Laser

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ABSTRACT
The shape restoring capability of Ti/Ni has potential to overcome the shrinkage of polymer in mould cavity, which has potential of solving the demoulding problems and helps dimension accuracy in micro/nano injection molding. However, the deposition of Ti/Ni film precisely and securely on specific location of the micro mould cavity present difficulties with conventional deposition methods. In this paper, the use of photonic impact forward transfer method to deposit Ti/Ni film patches on specific locations of a substrate is demonstrate using a picosecond laser. Pulse by pulse deposition control parameters affecting position accuracy and spot size were studied in this paper. It was found that although laser power, and distance between donor films and the substrate all influence the spot sizes of pulse by pulse deposited patches, adjusting spot size by changing laser power is better than changing distance due to separated particles being found around the deposited film patches. Results of this study proved the feasibility of depositing Ti/Ni film patches on specific location using pico-second laser with high position accuracy. The potential of using photonic impact forward transfer as a complementing method to laser powder 3D printing of difficult to process material to produce better surface quality microproducts such as micro moulds for micro-injection molding is tremendous.
Keywords: Shape memory alloy, photonic impact forward transfer, demoulding, titanium, nickel

I. INTRODUCTION

Micro injection moulding is a promising technique that offers high dimensional replication accuracy. The increasing demand for micro polymer-based devices and the continuous decrease of the structure size down to micro/nano range exemplifies the challenges. Most difficulties in polymer micro injection moulding are not caused by the filling of the mould, but by demoulding[1][2][3]. The main reason for polymer structures or parts of the wall profile being ripped away or deformed during demoulding is the high residual stress accumulated at the base of the features. The residual stress mostly comes from the shrinkage of the polymer relative to the mould cavity, which happens both in thermal and UV curing molding, either due to thermal compression, or reorientation of polymer chains, or cross-linking.

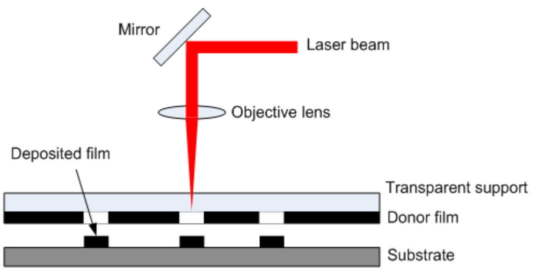
There are process conditions that affect micro injection moulding of polymer parts with micron-sized features, including the sidewall roughness of the mould inserts, sidewall angles, the chemical interface between mould and polymer, and thermal stresses, etc. Therefore, low surface energy materials should be used to coat the surface of the micro mould inserts to reduce sidewall friction. Current convectional release agents will induce a loss of mould shape, because the release agent coating thickness is comparatively large to the micro-features. If the release agent coating is made thinner, it may lose its effectiveness. Since demoulding in molding high aspect ratio features is an unsolved problem, many scientists suggested that it needs a completely revolutionized molding concept that is compatible with the production requirements instead of incremental improvements.

Metallic smart materials such as shape memory alloys (SMA) showing excellent features are emerging [4]. Ti/Ni shows large Young's modulus difference between two phases and great force for restoring original shape when transforming from martensite to austenite temperature [5]. The demoulding temperature can be fine tuned to satisfy different polymers by choosing an alloy that is compatible with the polymer's Tg. Recently, some scientists [4] have proposed a method of using SMA to actively compensate for errors in the forming process. It was predicted that SMAs may be used for enhancing the accuracy of micro molding. These smart materials can be deposited by thin film deposition methods such as, thermal evaporation, physical vapour deposition, chemical vapour deposition, magnetron sputtering, electroless deposition[6] etc. but these methods require specific combinations of material and environment, they can not deposit micro sized films on specific locations directly.

On the other hand, with the development of laser micromachining techniques, a new deposition technique is introduced recently, which is known as laser induced forward transfer[7] or photonic impact forward transfer. It employs laser radiation to transfer a thin film target from an optically transparent support onto a substrate placed next to it. In this paper, we demonstrated using photonic impact forward transfer technique to deposit Ti/Ni shape memory alloy in a specific location of the substrate. Factors affecting spot size of deposited film patches under different process conditions are studied. Results illustrated the feasibility of a new method to create SMA based active micromould with high accuracy for micro/nano moulding that enables the mass production of higher precision micro/nano products at low cost.

II. EQUIPMENT AND EXPERIMENTS

The schematic diagram of laser forward transfer process is shown in FIGS.1. With glass microscope slide as the transparent support, the Ti/Ni alloy donor film is produced by magnetic sputtering at and with thickness of about 400nm. Once the donor substrates are prepared, they are inverted and placed above the receiver substrate (glass microscope slide or silicon wafer), and a picosecond laser (3D MICROSYSTEM, Germany) is employed to perform photonic impact forward transfer experiments with them. The picosecond laser system is a solid-state Nd: YVO_4 laser (τ=9 ps) with 4 wavelengths from 1064nm to 266nm and adjustable repetition rate from 10 kHz to 1000 kHz. This laser system also equipped with galvanometric scan head, which can alter scan speed, marking location and marking pattern in a flexible manner. In our investigations, we used 1064nm wavelength to process donor materials.



FIGS.1 The schematic diagram of laser forward transfer process

A rectangle frame with dimension of 20mm×10mm is designed for investigating the photonic impact forward transfer deposition properties to enable pulse by pulse deposition of film patches with controllable spot size. Detailed process conditions are shown in following tables.

2.1. Laser Power Adjustment

Table.1 Laser process conditions with different average power (Attenuator cont =500 means about 50% full power, attenuator cont=1000 means about 30% full power)

	Attenuator cont	Repetition rate	Distance
1	0	10 kHz	<100μm
2	500	10 kHz	<100μm
3	1000	10 kHz	<100μm

2.2. Adjusting the distance between donor film and substrate

Table.2 Laser process conditions with different distance

	Distance	Repetition rate	Attenuator cont
1	<100μm	10 kHz	0
2	200μm	10 kHz	0
3	300μm	10 kHz	0
4	400μm	10 kHz	0

The dimensions of deposited and irradiated areas are measured by microscope (LEICA DM4000 M, Germany), to evaluate and analysis the process condition affect on transfer properties. The compositions of the deposition of 1000 repeated patches at same place were examined through EDS testing, to evaluate the compositions of deposited film.

III. RESULTS AND DISCUSSION

FIGS.2 and FIGS.3 show the optical microscope images of deposition transferred with different process conditions.

Fig. 2 (a)(b)(c) show results of using different laser power (FIGS.2). Fig.3(a)(b)(c) show results of using different distance between donor and the substrate (FIGS.3). Fig. 4 and Fig.5 illustrated the relation between pulse power and spot size deposited and the relation between donor-substrate distance and spot size deposited.

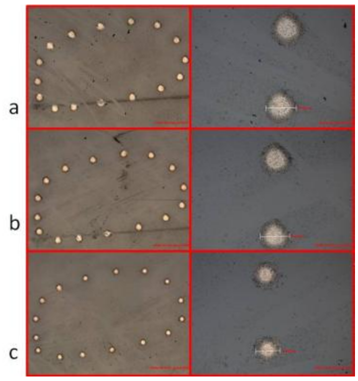


FIG.2 Optical microscope images of deposition transferred with different attenuator cont from 0 (a) to 1000 (d). Left: enlargement of deposited areas

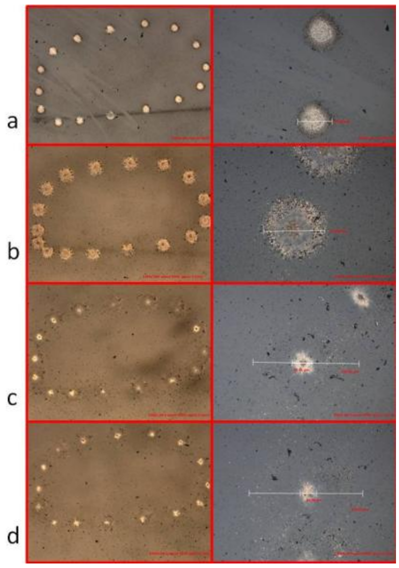


FIG.3 Optical microscope images of deposition transferred with different distance from <100 μm (a) to 400 μm (d). Left: enlargement of deposited areas

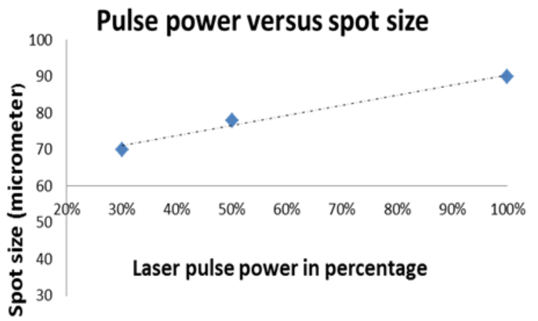


FIG.4 Relation between laser pulse power and spot sizes of deposited Ti/Ni micro-partches

FIG.5 Relation between donor film-substrate distance and spot sizes of deposited Ti/Ni micro-partches

3.1 Effects of laser power on spot size of deposited materials

Fig. 4 showed the dimension of spot size deposited was reduced from 90 μm to 70 μm with the reduction of average power, which directly resulted in reduction of pulse energy. The power to spot size relation was approximately linear.

3.2 Effects of donor substrate distance on spot size of deposited materials

Fig. 5 showed the relation between distance and spot size was non-linear. The spot size of deposited patches increased with the increase of the distance between donor and receiver, when the distance was between 100 μm and 200 μm. When the distance was greater than 300 μm, the spot size decreased with the increase of distance. However, there were particles found around the deposited center area when the distance was greater as shown in FIGS.3 c and d. This might be caused by not enough environmental gas pressure, allowing the separation of part of the patches on the edge when travelling longer distances under non-uniform pushing energy from laser photons. Fig. 6 illustrated the mechanisms of the effects of distance. There were materials on the edges fly further away from the main patch when distance increased.

Fig. 7 showed the results of EDS testing of 1000 repeated pulse forward transfer, proving the materials being transferred with similar composition of the coated film.

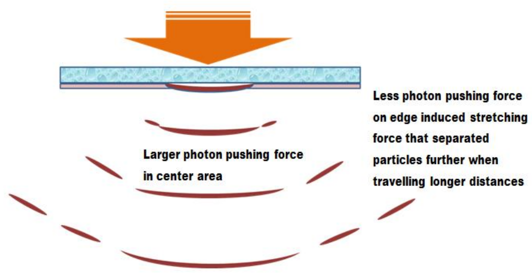


FIG. 6 Illustration of micro patches transfer under photonic impact force. Particles at edge go further away from the center micro patch when the distance between film and receiving substrate increases.

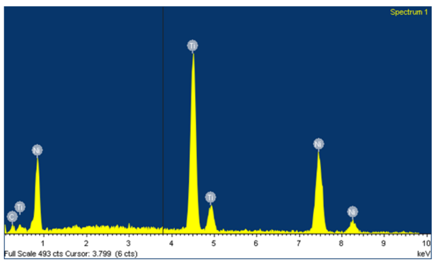


FIG. 7 EDS results of 1000 repeated pulse depositions of Ti and Ni on an area

3.3 Study of Deposition Accuracy

As the experiments were carried out by using the scanning function of the laser machine with very high scanning speed for the purpose of separating the spots generated by different pulses, the position accuracy of deposited materials was not ideal. Therefore, for the purpose of depositing with photonic impact forward transfer with high position accuracy, we are going to keep the machine optics steady and move the position of samples back and forth and up and down using a sample holding system with less than 1 micro-meter repetition accuracy.

IV. CONCLUSION

In this paper, we demonstrated using LIFT technique to deposit Ti/Ni shape memory alloy on a specific location of a substrate. The control parameters affecting spot size of deposited micro patches mainly laser power and distance between donor films and the substrate were studied. Results show that the relation between spot size and the distance between donor films and the substrate is non-linear. The spot size increased with the increase of film-to-substrate distance initially. When the distance exceeded certain level, spot size decreased with the increase of the distance. There were particles found around the deposited area, which could jeopardize deposition accuracy. On the other hand the relation between laser pulse power and the spot size was approximately linear. With the combination of these process conditions, the deposition features and size can be easily selected. From investigations, a new method is created to advance the accuracy of micro/nano moulding that enables the mass production of higher precision micro/nano products at low cost.

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