System of Thermal Micro/Nano Printing and its Application in Metallic Glass

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Abstract. A micro/nano thermal printing system was developed in this paper. The system has the characteristics of high resolution, large imprinting areas, convenient operation and low cost. Some experiments on metallic glass (La-Co-Al) were carried out by the system. The results indicated that this system has the elegant performance and the metallic glass is one of the best materials to fabricate the microstructures.

1. Introduction:
With the development of nanotechnology, the demand for processing microstructures is great needed. Nowadays there are several methods dealing with it. Among them, LIGA [1] technology under Synchrotron Radiation Light source is an effective way to get high aspect ratio microstructure [2] but with low precision (larger than 1um) and high cost-effectiveness [3]. Electron Beam Lithography (EBL) [4] or Focused-Ion-Beam (FIB) [5, 6] is another one which takes over the disadvantages of LIGA by increasing the precision [7-10] (less than hundred nanometers even tens nanometers) using electron or ion instead of light, but still with high cost as well as LIGA. A relatively cheaper method with inexpensive machine and simple process is Ultra-Violet lithography, whereas its precision is low approximately micrometer or hundred nanometers. Nevertheless, all of the methods mentioned above can’t yield large area microstructure. So, it is necessary to develop new methods which can convenient manufacture micro/nano structures with large area, high precision and low cost. Here we presented a micro/nano thermal printing method to address these issues. The basic concept and controlling system of the micro/nano thermal printing were introduced, and some experiments were carried out with the thin metallic glasses films.

2. Working principle and operating methods of the system
This system was automatic controlled by computer. With inputting control parameters at first, the system can implement the fabricating procedure automatically. The working principle and operating method is shown in Figure 1.
This system consists of five parts: temperature control circuit, protective circuit, zero circuit, circuit, and anti-oxidation air source. Some parameters need to be input before the system begins working. The sample needs to be heated to the preset value. During the heating process, the protective circuit must be open to protect piezoelectric ceramics (PZT) to a higher temperature. Once the sample is heated to the appointed value, the zero circuit starts to work. The zero circuit adjusts the system to a zero position where the press on the sample results in the sample's deformation. Next, the system begins to work with arithmetic. All the follow-up work is automatically finished by the system.

3. System Design

3.1. Mechanical design

A vertical pressure transmission structure was applied in the machinery, which exerts pressure on the system from top to bottom. Compared with horizontal pressure transmission structures, the sample can be avoided from being asymmetrical due to the obliquity of the pressure. The mechanical design of the system is shown in Fig. 2. It was mainly composed of 6 parts. They were stepping motor, loading block, pressure sensor, PZT, pressure heads, and sample stage in turns. Component 1 was the stepping motor, playing a key role in adjusting the system's position to a proper altitude especially during the zero circuit. The loading block (component 2) made a difference to adjust the system's operating distance as well as helping easily adjust the zero position of the pressure. Due to the different sensitivity of the pressure sensor in its measuring range, the loading block assists to adjust the pressure sensor to work in its most sensitive range.
Component 3 was pressure sensor, playing a part as monitor and feedback source. It monitored the press of system vertically meanwhile gave feedback to the computer across all periods especially in zero circuit and work circuit. The key part of the system was PZT component 4 in Fig.2, acting as the power source of the system by pressurizing high pressure on the sample. The pressure was operated by computer arithmetic. Component 5 was a pressure head, serving as transmitters and balancer of pressure between PZT and sample. Component 6 was sample stage.

3.2. Control system
The control part is the kernel of the system. It helps the individual section working together systematically. The control principle was shown in Fig. 3. The five parts in Fig.3 from top to bottom were corresponding to zero circuit, working circuit, protection circuit, gas protection and temperature control circuit in Fig.1, respectively. Zero circuit including stepping motor, pressure sensor and computer, was on the top of the system far away from the sample. By the way of zero algorithm, the stepping motor forwards and backwards until reach zero position.

The working circuit was blew zero circuit by sharing the pressure sensor with each other. The PZT forwards and backwards with the method of algorithm as the system running. Protected circuit situated in the head of PZT where the temperature can be reduced directly. Due to the protected circuit, the PZT can remain safe temperature, otherwise, the PZT can’t work regularly. In practice, the protected circuit was continuous working until the end of the process. Gas protection was in the heat chamber to prevent the sample from oxygenizing and continuous working as well as protected circuit. Specifically, the noble gas is pumped in at low position while the air is pumped out at high position. Compared to vacuum chamber, it was more convenient and effective way with low cost.

The temperature circuit situating at the bottom of the system was to uniformly heat the sample to its softening temperature. An integral PID was used in temperature control algorithm where the current temperature, direct temperature and total power were taken into account to work out the current power.
2.3 Software and Algorithm

The system was controlled by the computer where several parameters were input in advance. Compared with traditional instrument, more parameters can be monitored to established database for future research and data analytics. Algorithms were displayed in Figure 4-1 and Figure 4-2.

Figure 4-1 is zero algorithm. Although the zero position refers to a condition that the pressure on sample happens to result in sample’s deformation, it is judged by analyzing the value of pressure sensor in reality. Specifically, assuming the pressure before zero position changes slowly rather than abruptly, it is judged by pressure’s first-order derivative and second-order derivative. In practice, the computer starts to monitor the pressure’s first-order derivative until it is abruptly changing, and then to
monitor the pressure’s second-order derivative. Usually, the pressure’s second-order derivative is slowly decreasing until the value turned to be a constant, i.e., the zero setting is finished.

Figure 4-2 is working algorithm. There are two work algorithms classified by displacement and pressure. One method was to control the voltage to make the PZT forwarding nearly linear. However, due to the nonlinearity and hysteresis effect of PZT (as shown in Fig. 4-3), the distance cannot be directly controlled by just linear increasing the voltage of PZT. So, linear interpolating was used in rising curve in Fig. 4-3 to get sufficient points and then filtrating all these points to select linear change points. Another way was to control pressure to put the PZT forwarding by a specific pressure curve. Specifically, if the pressure value is superior to the curve, the PZT will forward smaller, stop forwarding or backwards until the pressure nearly approaches the curve; if the pressure value is inferior, the PZT will forward larger to approaches the curve. Practically, mode two is more in common use, because pressure makes direct and large contribution to the final result.

Figure 4-3 PZT hysteresis curve

4. Experiments and Applications in Metallic Glass Film
Some experiments were carried out by using this printing system with Thin-Film of metallic glasses [11, 12] (TFMGs). TFMGs are characterized by an absence of size effect, high strength and high elastic limit due to their amorphous nature. So, these materials are considered to be ideal candidates for micro electromechanical systems [13-15] and microstructures. However, till now seldom reports have been done about the microstructures in TFMGS. By this printing system, we fabricate microstructure on TFMGs with different temperature (Table 1).

| Temperature/°C | Results                                      |
|----------------|----------------------------------------------|
| <125           | No pattern or shallow pattern                |
| 125-130        | Good pattern                                 |
| 130-135        | Probabilistic good pattern or film breakup   |
| >135           | Film breakup                                 |

Firstly, some moulds were fabricated on Si surface by EBL or FIB. As shown in Fig. 5(a) and 5(c), the patterns of the moulds include grating, word, digit, and arrows. The thickness of mould is approximately 2 μm. And then TFMGs (MgZnCa) samples were fabricated with a 2μm thickness, which were placed just under the mould on the sample stage in order to be printed automatically with control parameters which were inputted in advance. The microscope pictures shown in Fig. 5(a) and 5(c) were patterns of models, and 5(b) and 5(d) were the imprinted microstructures of TFMGs with the heated temperature among 125 to 130 °C (i.e., glass transition temperature of the TFMGs),
while as the temperature out of this range, the results shown in Fig. 5(e) and Fig. 5(f) were not so good as (b) and (d).

![Mould and Imprinted Microstructures](image)

**Figure 5.** Microscope pictures of mould (a), (c) and imprinted microstructures of TFMGs (b), (d)

### 5. Conclusions

This paper presented how to develop a micro/nano thermal printing system with high precision and efficiency. Compared with traditional printing system, the system can avoid to oxidation by the gas protected circuit. Some experiments were conducted with this system. The results verified the feasibility of the system and can be used to investigate the characteristics of the TFMGs. In future, some adjustment to the system will be taken to improve the precision and stability, and more applications with this system will be explored on TFMGs.

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