저융점 금속 인쇄롤 직접식 패터닝 기술

Direct laser patterning of a printing roll plated with a low melting-point metal

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1. Introduction

In printed electronics, electronic ink is transferred onto a flexible substrate using printing rolls to print various electronic devices. In order to fabricate a printing roll, the laser lithography has generally been employed in which laser beam is irradiated onto a photo-resist (PR) layer, pre-coated on a copper-plated roll. The laser-cured layer acts as an etch barrier for patterning the copper layer [1,2]. After the chemical wet-etch process, the patterned copper layer is electroplated with chromium. Although well-established, the laser lithography is a multi-step process and is followed by the etch process which is environmentally unfriendly. Thus, many efforts have been devoted to developing direct patterning methods [3,4].

In this work, we have directly patterned a printing roll electroplated with zinc using a fiber laser. We also fabricated a prototype equipment for the direct laser patterning. Using the equipment, we conducted experiments to investigate the effects of the process parameters: laser power and revolution speed.

2. Experimental setup

As shown in Fig. 1, the experimental setup consists of a fiber laser (a 12W pulse-modulated fiber laser), a precision rotation motor for rotating a printing roll and a precision one-axis linear stage for transferring, and an objective lens for focusing laser beam onto the rotating roll.

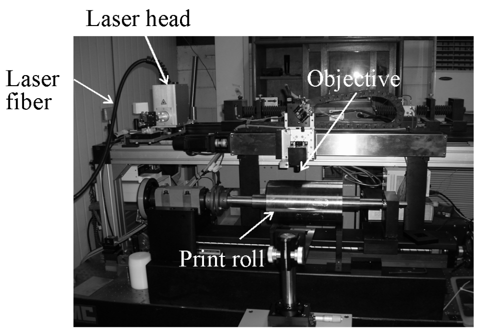


Fig. 1 Experimental setup

The specifications for the fiber laser are summarized in Table 1. Laser beam from the laser head is delivered using bending mirrors and focused on the roll by an objective lens.

Table 1 Specifications for the fiber laser

Wavelength (nm)	Average power (W)	Pulse duration (ns)	Repetition rate (kHz)
1070	12	34	20-80

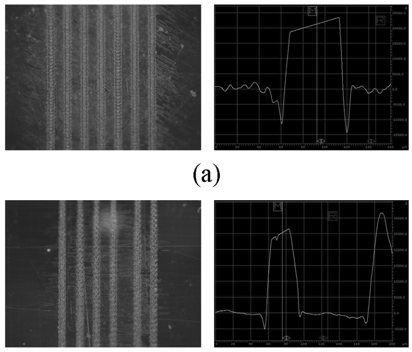
One end of a printing roll is fixed using a dead center and a flange similarly in case of a lathe. The flange is indirectly connected to the rotation motor using a timing belt in order to decouple the vibration from the motor as much as possible. The other end of the roll is fixed using a steel ball to minimize the deviation of the roll from the rotation center. To control the rotation of the roll, a rotational encoder with 131,072 counts per revolution is attached to the flange.

3. Results and discussion

To prepare a printing roll for the direct laser patterning, first a hollow steel roll is machined and polished. It is then electroplated with copper and polished again. Finally, a 20-30 μm thick zinc layer is electroplated. The diameter of the roll was 125 mm. Since copper has the higher evaporation energy and thermal conductivity than zinc, the copper layer acts as an ablation barrier while the zinc layer is being ablated. In other words, the difference in evaporation energy between copper and zinc confines the patterning within the zinc layer [5].

In experiments, the laser power and the revolution speed were the process parameters. The fiber laser used in experiments irradiates succeeding pulses each of which has the same amount of heat energy. The amount of energy of each pulse [J] is calculated by dividing laser power [J/s] by repetition rate [1/s]. Thus, the energy density of laser beam transferred to a rotating roll is determined by the combination of repetition rate and revolution speed. In experiments, the laser power ranges from 1.2-12W and the revolution speed from 100-150 rpm, while the repetition rate was set at 20 kHz.

Figure 2 shows that as the revolution speed increases, the cross-sections of the engraved patterns become narrower. This is because the energy density on the printing roll becomes smaller at a higher revolution speed. And fig. 3 shows that as the laser power increases, the cross-sections of the engraved patterns become wider. This is because the energy density becomes larger at a higher laser power. The minimum width of the patterns is about 27 μm and the maximum width 40 μm. After being cleaned and polished, the patterned roll is electroplated with chromium as thick as approximately 5 μm. Thus, the final widths of the chromium plated patterns range from 17-30 μm.



(a)

(b)

Fig. 2 Patterns on a roll at a laser power of 6 W and a revolution speed of: (a) 100 rpm, (b) 150 rpm.

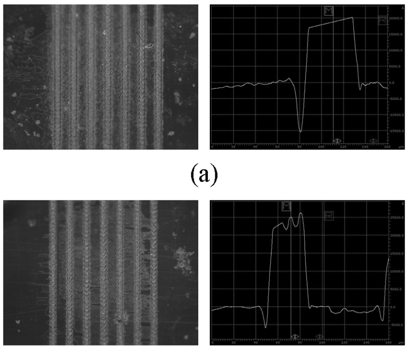


Fig. 3 Patterns on a roll at a revolution speed of 130 rpm and a laser power of: (a) 12 W, (b) 6 W.

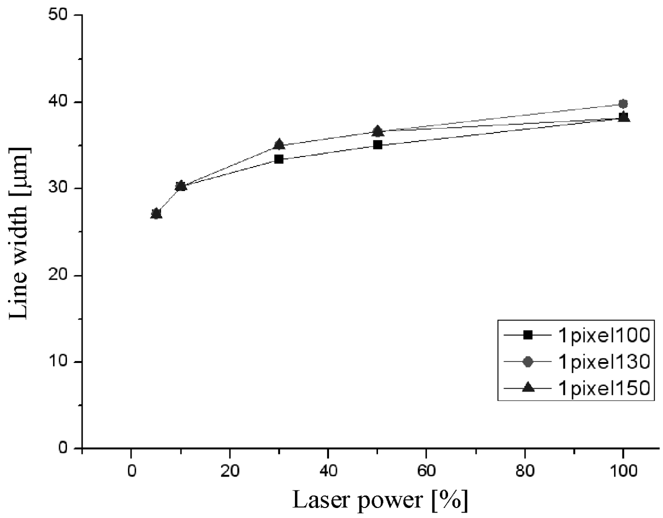


Fig. 4 Relationship between laser power and pattern width (When laser power is set at 100%, it actually is 12W).

Based on experimental results (Fig. 4), we directly patterned a printing roll electroplated with zinc. The actual size of the whole patterns should be adjusted by mapping the input file onto the surface of a printing roll. The surface can conceptually be divided into a large number of pixels (Fig. 5). The minimum pixel size along the x axis Δx depends on the resolution of the one-axis linear stage transferring an objective lens, i.e., Δx equals to 1 μm. And the minimum pixel size along the y axis Δy depends both on the resolution of the rotational encoder and the printing roll diameter. Since the rotational encoder is with 131,072 counts per revolution and the printing roll has a diameter of 125 mm, Δy equals to 2.99 μm (Fig. 6).

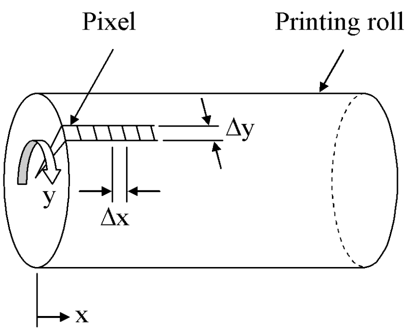


Fig. 5 Input file mapping onto a printing roll.

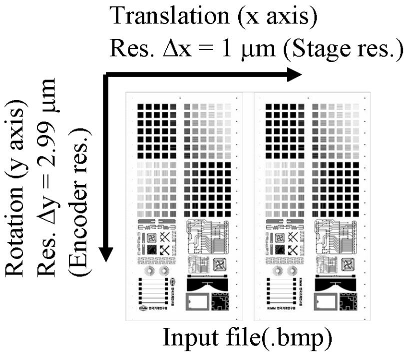


Fig. 6 Input file and the resolutions of the encoders.

To map the input file to have a designed size on the printing roll surface, Δx and Δy should be calculated based on the ablated pit size on the printing roll surface at a certain combination of laser power and revolution speed. The overall size of the input file was 142 mm × 122 mm and the pixel size (Δx and Δy) was set accordingly. Figure 7 shows the patterns engraved directly into the surface of a zinc-plated printing roll.

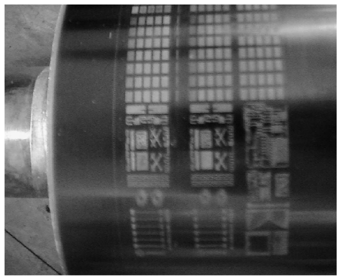


Fig. 7 Directly patterned printing roll.

4. Conclusion

To address some challenges of laser lithography, micro-scale patterns have been directly engraved into a zinc-plated printing roll using a fiber laser. According to the combinations of the process parameters (laser power and revolution speed), the widths of the patterned patterns range from 27-40 μm. Based on the experiment results, we have engraved various patterns on a zinc-plated printing roll with a diameter of 125 mm.

References

1. B.Y. Ahn: *Printing Engineering* (Sejinsa, Korea 1997).
2. H.H. Xiao: Proc. SPIE Vol. 2118 (1994), p. 209-212Font: Times New Roman 9pt.
3. www.daetwyler.com
4. www.think-lab.com
5. C. Jagadish: *Zinc oxide bulk, thin films and nanostructures: processing, properties, and applications* (Elsevier Science Ltd, 2006)