Laser Ablation of Thin Films for Flexible Sensor Manufacturing

Ningyue Mao[1], Pablo D. Enrique[1], Y. Norman Zhou[1], and Peng Peng[1] (✉)

[1] Centre of Advanced Materials Joining, Department of Mechanical and Mechatronics Engineering, University of Waterloo, Waterloo, ON, Canada
peng.peng@uwaterloo.ca

Abstract. This study investigates a mask-free and inkless method using nanosecond pulsed UV laser ablation for sensor manufacturing. This method greatly simplifies the patterning process into a single step and allows for a short turnaround time for custom designs. In general, the quality of the fabricated sensor depends on laser power, scanning speed, pulse frequency, and scanning strategy. In this study, the influence of these laser parameters on the ablation width and edge quality of NiCr thin films is investigated. The laser ablation process is optimized to obtain high-quality thin-film sensors that have the potential to offer custom sensor production at a low cost and with short lead times.

Keywords: Laser processing · Thin films · Flexible devices.

1 Introduction

Today, with the development of the Internet of Things (IoT), the demand for specialized sensors that can measure physical properties is greatly increased. Conventional electronics manufacturing techniques such as photolithography are typically used for large-scale production of sensors; however, this process offers little flexibility in terms of customized designs for small production volumes, due to high fixed costs and long lead times. A promising alternative manufacturing method is using laser ablation to pattern flexible thin films, which has been implemented for applications such as antenna [1], temperature [2], and pressure sensors [3].

In this work, NiCr thin films on flexible polyimide substrate were used to investigate the effect of various laser parameters including average power, repetition frequency, and scanning speed on the ablation width for flexible thin-film sensors manufacturing.

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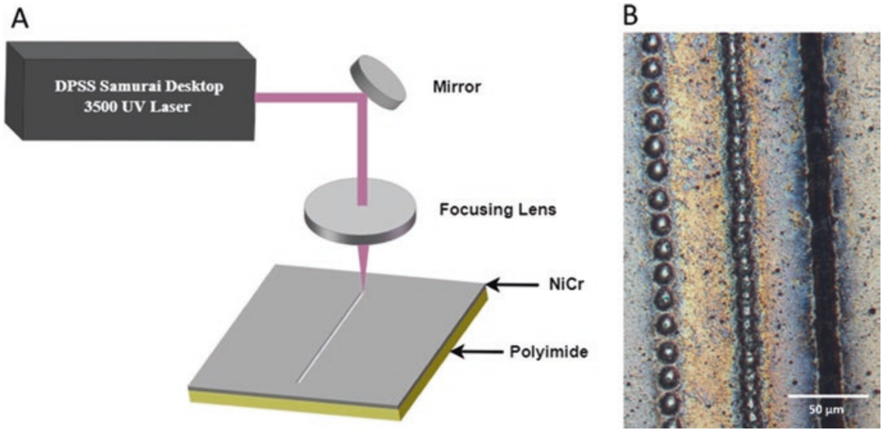

Fig. 1. (**a**) Schematic diagram of the experimental setup; (**b**) microscope image showing the ablated trace with different scanning speed.

Table 1. Summary of laser parameters used in this study.

Factors	Values
Power (W)	0.2; 0.4; 0.6; 0.7; 0.9; 1
Scanning speed (m/s)	0.1; 0.3; 0.5
Frequency (MHz)	0.03; 0.05; 0.075; 0.1

2 Materials and Methods

The samples used in this study were 5-um thick NiCr (80%Ni, 20%Cr) foils with polyimide-laminated substrates. Figure 1a illustrates the UV laser system used for thin-film patterning. A diode-pumped solid-state (DPSS) Nd: YVO4 UV pulsed laser (Samurai Desktop 3500) with a wavelength of 355 nm assembled with a 103 mm f-theta lens was used for the experiment, exhibiting a focused beam diameter of 10 µm. The maximal output power of the laser system is 1 W and the repetition frequency could range from 30 kHz to 100 kHz.

The detailed laser parameters used in this study to ablate a straight line with a length of 500 µm on NiCr film are summarized in Table 1. The surface morphology of the laser-ablated lines was evaluated using an Olympus BX51M optical microscope and the width of the lines ablated using different parameters was measured and compared. To quantify the effect of laser parameters on ablation width, a response surface methodology was implemented for this analysis using Develve software.

3 Results and Discussion

A high-accuracy model was obtained that summarized the relationship between ablation width and process parameters as shown in Eq. 1 ($R^2 = 0.937$). The actual and predicted values of the ablated width are distributed uniformly along the identity line (Fig. 2).

$$\text{Width} = 4.51 \times \text{Power} - 127.79 \times \text{Frequency} - 4.5 \times \text{Scanning Speed} + 16.96 \qquad (1)$$

Figure 3 shows the comparison of the impact of the three parameters on the ablation width. Each data point represents the average of a range of line widths created at that parameter level. The laser power and repetition frequency were major factors in determining the amount of energy passed onto the thin film, hence, they have a more significant effect on the ablation width. An increase in frequency decreases the energy per pulse, resulting in narrower ablation widths, while an increase in power increases the energy per pulse and widens the ablation width. The scanning speed has a less pronounced effect, although the slight decrease in width observed with faster scanning speeds can be attributed to less overlap between pulses and reduced heating of the foil.

The above results can be used to develop process maps that allow for the selection of parameters based on required feature sizes in thin-film sensors. A lower bound to the operating space is set by selecting parameters with sufficient overlap between adjacent pulses, while parameters that form large heat-affected zones provide an upper bound.

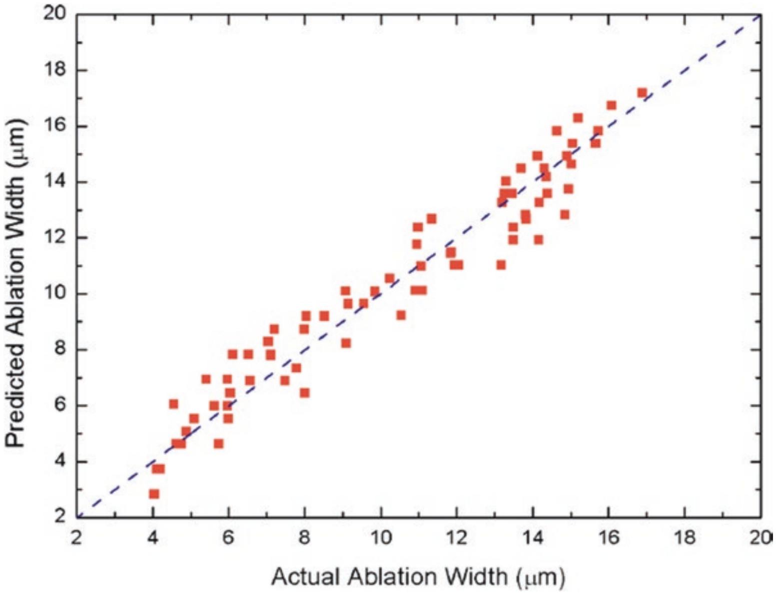

Fig. 2. A comparison of actual and predicted ablation width using the response surface model.

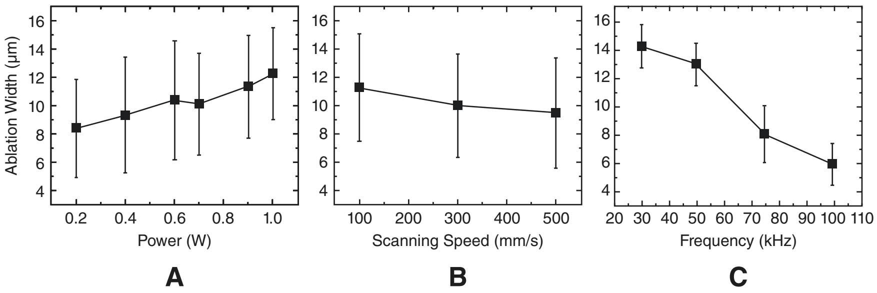

Fig. 3. The effect of (**a**) power, (**b**) scanning speed, and (**c**) frequency on ablation width with error bars representing standard deviations.

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