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Article

Formation of Fine Line Circuits on Ferrite Substrate by Laser Direct Structuring Technology

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Abstract: The technology of laser direct structuring (LDS) on ferrite substrates was evaluated for the fabrication of fine-line circuits. The LDS technology involves laser activation followed by electroless copper plating. A sieving pattern was scanned by the near IR laser on the ferrite substrates, and electroless copper plating was carried out. The results showed that the LDS technology applied to Ni-Zn-Cu-ferrite films. Appropriate laser activation conditions were chosen to engrave a contrast pattern on ferrite sheet samples. A chosen condition was used to fabricate a line width evaluation pattern, and the results indicated that the feasible fine width could be as fine as 50 μm.

Keywords: Laser direct structuring, Ferrites, Laser activation, Electroless copper plating

1. Introduction

Ferrites are magnetic ceramic compounds based on iron oxides [1–4]. The soft ferrites are not permanent magnets and are commonly used in transformers or electromagnetic cores. Soft ferrites may contain manganese (Mn), Zinc (Zn), and/or Nickel (Ni). Ferrites are insulators, if conductive patterns, or circuits, can be made on the ferrite substrate, wider applications may be developed. For example, some researchers have used printing technology to fabricate circuits on the ferrite substrate [5,6]. A more convenient method is laser-induced selective metallization, known as laser direct structuring (LDS) technology [7–10]. Typical LDS process involves shaping, laser scanning of circuit pattern by pulsed near IR laser beam to activate the engraved area, and chemical plating to obtain a metalized pattern [7–10]. However, the fabrication of circuits on the common ferrite substrates such as Zn-ferrites or Mn-Zn-ferrite by the LDS process seemed to fail in the experiments in our laboratory. We found that the LDS process successfully fabricated circuits on the Ni-Zn-Cu-ferrite substrate. This article describes the preliminary results of this topic.

2. Materials and Methods

2.1. Materials

The Ni-Zn-Cu ferrite films with a thickness of 0.3 mm were supplied by Toda Kogyo Corp., Hiroshima, Japan. The determined contents of Ni, Zn, and Cu were 5.2, 15.9, and 4.4%, respectively. The Mn-Zn ferrite sheets with a thickness of 20 mm were compared to Ni-Zn-Cu ferrite films and were obtained from Wireless Power Co., Shenzhen, China. The determined contents of Cu, Mn, and Zn were 0.01%, 11.9% and 4.9%, respectively. The standard chemical plating solutions, ECM-60, were supplied by Teamly Chemicals Corp., Taipei, Taiwan. The formulated electroless copper plating solution contained copper sulfate (8.8 g/L), sodium hydroxide (6 g/L), EDTA (42 g/L), formaldehyde (5 g/L), and 2,2'-bipyridine as the stabilizer (4 mg/L).

2.2. Laser Activation

The ferrite samples were washed with deionized water and dried. The laser activation condition was evaluated by a sieving pattern as shown in Fig. 1. The ferrite samples were scanned by a BRIMO 20W R2+ laser machine of Brimo Technology CO., Ltd., Taiwan, under various parameters. The laser-scanned samples were washed with distilled water and dried and then dipped in the chemical copper plating liquid at 55 °C for 15 min.

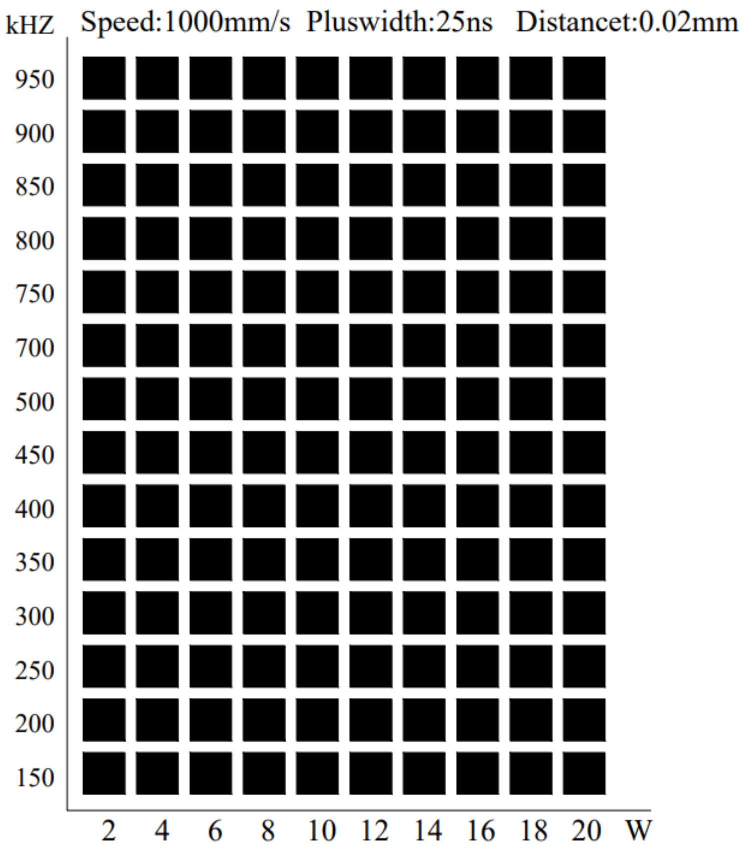


Fig. 1. Sieving pattern.

According to the results of the sieving pattern, appropriate conditions were chosen to analyze the suitable laser activation condition by the contrast pattern as shown in Fig. 2 and the line width pattern as shown in Fig. 3. With a laser scanning speed of 1000 ms^{-1}, a pulse frequency of 450 kHz, and a laser power of 5 W, acceptable contrast was shown to fabricate the circuits.

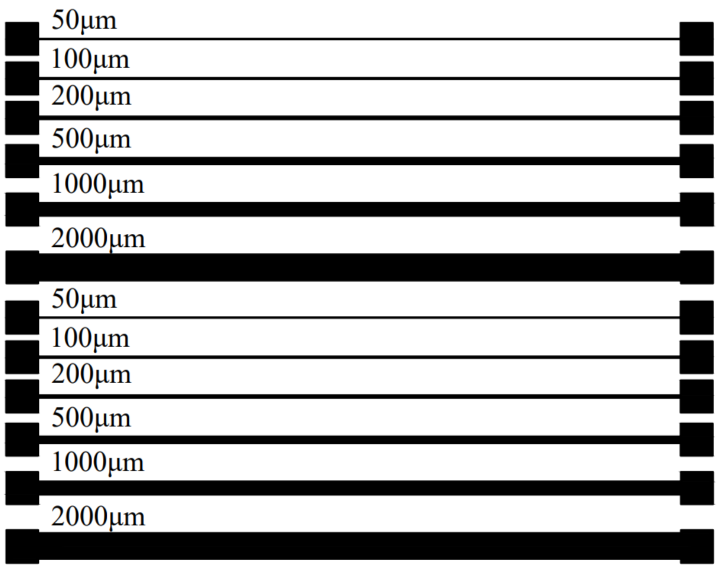


Fig. 2. Contrast pattern.

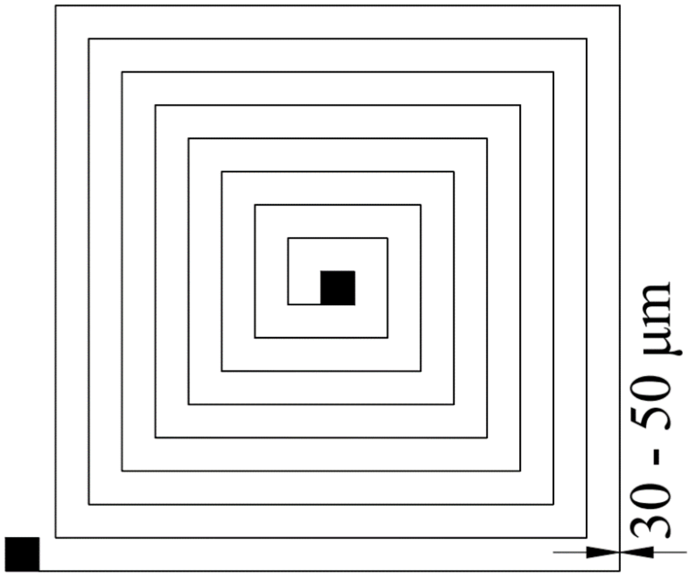


Fig. 3. Line width pattern.

2.3. Fabrication of Antenna Circuit

Fig. 4 shows a common near-field communication (NFC) circuit. The antenna patterns with square pads on the ferrite films were fabricated by the LDS procedure under the chosen condition.

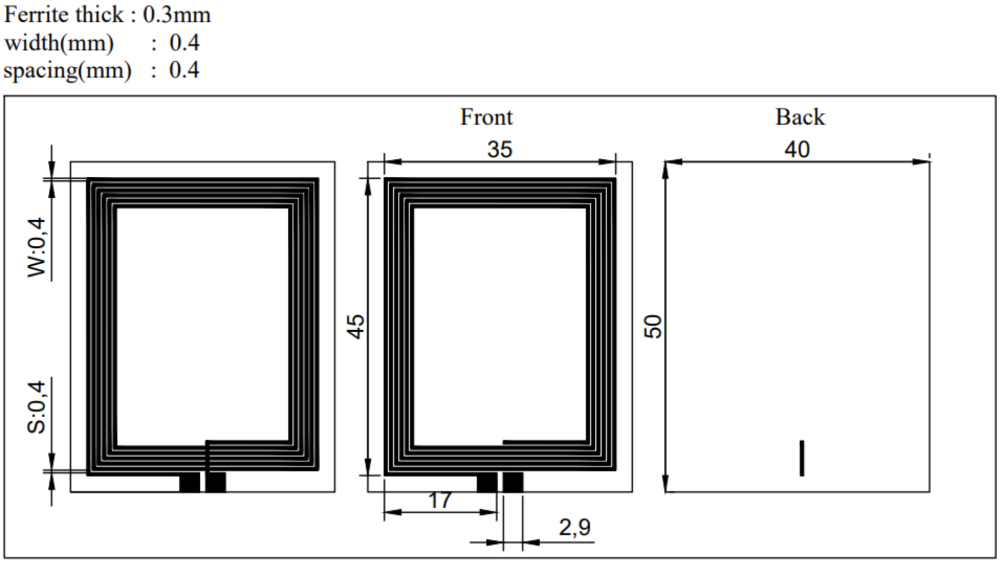


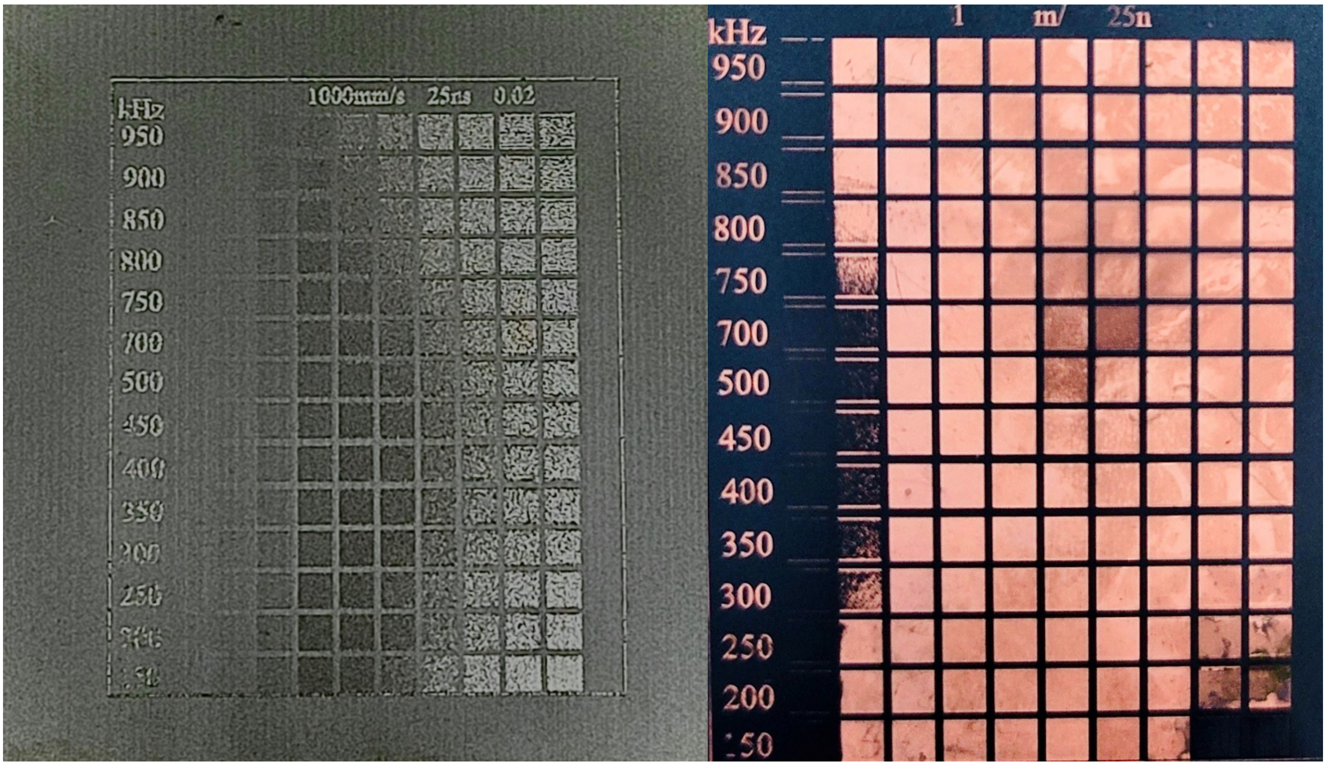
Fig. 4. NFC antenna circuit.

2.4. Measurements

The complex input impedance of the NFC antennas was measured by Agilent E5071B ENA RF Network Analyzer, 300 kHz to 8.5 GHz (Agilent Technologies, Inc.). The resonant frequency of the NFC tag was measured using a VNA with a loop antenna. S11 was measured from the fed port by connecting the loop antenna to the output of the VNA in reflection mode.

3. Results and Discussion

The photographs of the sieving patterns on ferrites after laser scanning followed by chemical copper plating are shown in Fig. 5(a). No significant copper deposition on the laser-scanned area on MnZn ferrite was observed. Thus, the LDS process failed in the fabrication of circuits on Mn-Zn ferrites. On the contrary, there were many scanned squares on the Ni-Zn-Cu ferrite film exhibiting full copper deposition as shown in Fig. 5(b). The results indicated that the presence of copper elements played an important role in the LDS process for ferrites. Since there are few commercial ferrites containing enough copper, the researchers may feel that LDS does not apply to ferrites.



(a) **(b)**

Fig. 5. Photographs of the chemical copper-plated sieving patterns: (**a**) MnZn ferrite, (**b**) Ni-Zn-Cu ferrite.

From the sieving pattern, some conditions were chosen to analyze the suitable laser activation condition by the contrast pattern. Fig. 6 shows the chemical copper-plated sieving pattern at a laser scanning speed of 1000 ms^{-1}, a pulse frequency of 450 kHz, and a laser power of 5 W. The measured resistance of all lines was less than 10 Ω. Thus, this condition showed acceptable contrast and was used to fabricate the circuits. Fig. 7 shows the chemical copper-plated fine line patterns under the chosen condition. The lines with a line width of 30 μm were achieved, but the measured resistance was always greater than 100 Ω. For 40 μm line width, the measured resistance was about 50 Ω. The measured resistance values of the circuits with a line width of 50 μm were less than 10 Ω. Thus, the line width of 50 μm can be used as the design limit for the circuits on Ni-Zn-Cu ferrites. The fabricated antenna circuit with a line width of 400 μm is shown in Fig. 8. The right pad and inner terminal of the front side have been connected to the line of the back side through the metalized wall via holes formed during laser scanning. The measured resistance between the two pads was less than 10 Ω indicating that the connections were achieved.

Fig. 6. Photograph of chemical copper plated contrast pattern of Ni-Zn-Cu ferrite.

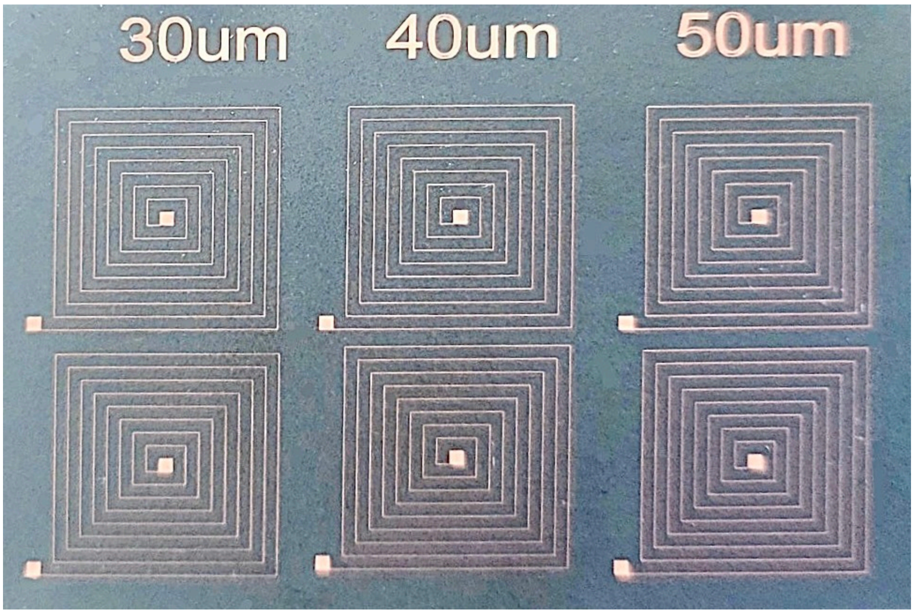
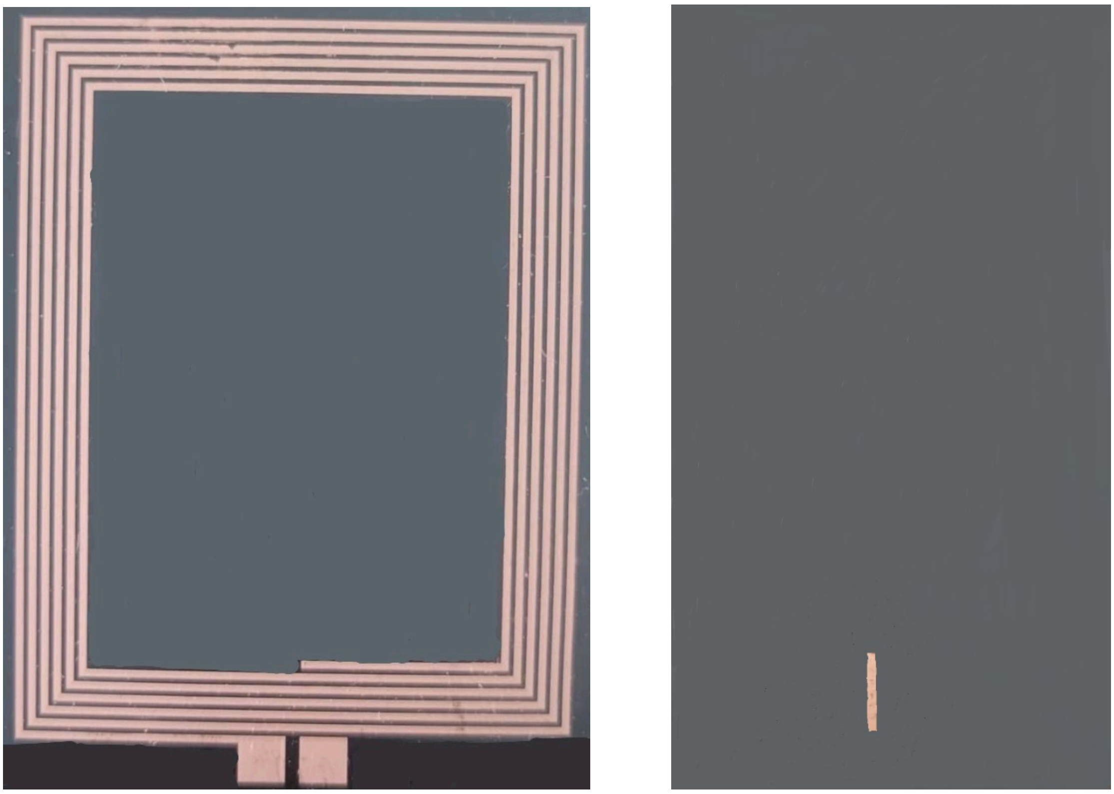


Fig. 7. Photograph of chemical copper-plated fine line patterns.



(a) (b)

Fig. 8. Photographs of the NFC antenna with a line width of 400 μm, **(a)** front side, **(b)** backside.

The measured return loss versus frequency of the ferrite antenna is shown in Fig. 9(a). Similar to descriptions in our previous study [11], the parameter S was defined to be related to the amplitude and phase of a signal, and the subscripts mean the port numbers of the reflected wave and incident wave, respectively. Therefore, the vertical axis S11 in Fig. 9 was usually termed as power ratio or return loss. As a comparison, the same antenna circuit was fabricated on a ceramic substrate by the LDS process as described previously [11]. The measured peak frequency of the ceramic antenna was 13.7 MHz, which is very close to the NFC specification frequency (13.56 MHz). However, the measured peak frequency of the ferrite antenna was 9.9 MHz, indicating that its resonance frequency would be affected by the intrinsic magnetic property of the ferrite greatly.

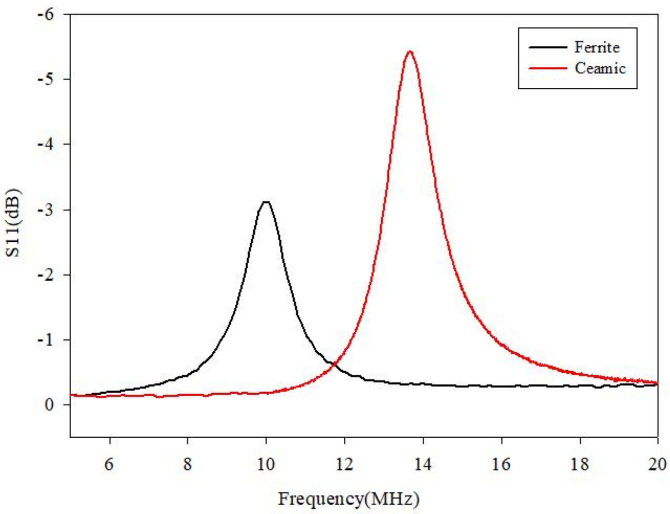


Fig. 9. Return loss versus frequency of the antenna with a line width of 400 μm on the Ni-Zn-Cu ferrite film (black curve) and a ceramic substrate (red curve).

4. Conclusions

The LDS technology was applied to Ni-Zn-Cu-ferrite films, but not to common ferrites without enough copper. The line width evaluation pattern results indicated that the feasible fine width could be as fine as 50 µm. The fabricated NFC antenna circuit with a line width of 400 µm exhibited a resonance of 9.9 MHz, which deviated largely from the NFC specification frequency (13.56 MHz). This indicated that the resonance frequency would be affected by the intrinsic magnetic property of the ferrite greatly.

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Conflicts of Interest: The authors declare no conflict of interest.

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