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Article

Laser-Induced Selective Metallization on Ceramic Substrate for Antenna Circuits

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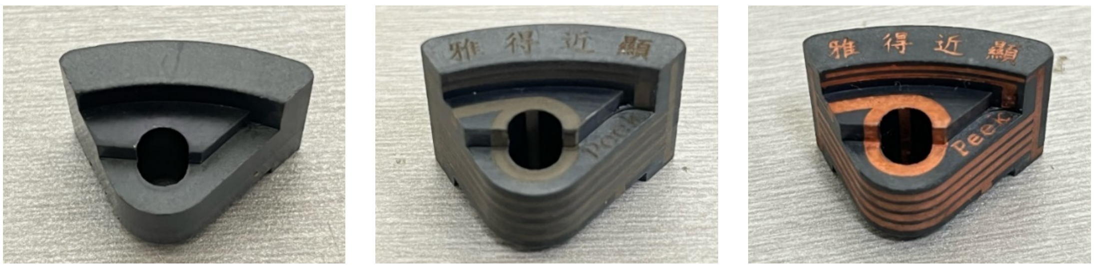
Abstract: The technology of laser-induced selective metallization, or known as laser direct structuring (LDS), on a ceramic substrate was evaluated for the fabrication of antenna circuits. A sieving pattern was scanned by the near IR laser on the ceramic substrate, and electroless copper plating was carried out. Appropriate laser activation conditions were chosen to engrave a contrast pattern on ceramic 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 80 µm. This value was used as the design limit of the antenna circuits. The designed antenna circuit patterns were fabricated on the ceramic substrate, and the simulation and direct measurement of the antenna circuit were carried out. This evaluation indicates that the application of LDS technology on the ceramic substrate for the antenna circuits would be feasible.

Keywords: Laser direct structuring, Ceramics, Laser activation, Electroless copper plating, Antenna circuits

1. Introduction

The development of laser direct structuring (LDS) technology inspired the electronic industry [1]. Various electronic products or parts with three-dimensional (3D) circuits have been claimed to be fabricated without difficulty [1–4]. Fig. 1 shows the typical process of LDS technology for plastics. First, the plastics part was made by injection molding of an LDS grade plastics containing copper dichromate as the activator. Then, the stereo circuit pattern is scanned by a pulsed near IR laser beam (1064 nm). The laser engraved area was activated for chemical plating of copper after laser scanning. Finally, the part was dipped in the chemical copper plating liquid to obtain a metalized pattern [5–7]. The key point was the optimization of laser activation and the condition of chemical plating to achieve enough contrast for practical applications. The LDS technology has been successfully applied to manufacture antenna parts for mobile apparatuses [8–10]. The antenna parts for newer generations of communication, i.e., 5G require newer directions of performance, such as finer patterns in more compact parts and a higher thermal conductivity. Since the thermal conductivity of ceramics is about an order higher than that of plastics, the use of ceramics for manufacturing antenna parts sounds reasonable to fit the future trend. The fabrication of metal patterns on the ceramic substrate by LDS technology has been claimed [11–13], In this research, LDS technology was used to fabricate a ceramic antenna part, and the simulation of the resonance band was carried out for the supporting the design of ceramic antennas.



(**a**) (**b**) (**c**)

Fig. 1. Typical process of LDS technology: (**a**) injection molded part; (**b**) laser scanned part; (**c**) chemical copper plated part (AR Display Co. Ltd, Hsinchu, Taiwan).

2. Materials and Methods

2.1. Materials

The ceramic sheets of zirconium oxide toughened alumina containing 94% Al_2O_3 with a thickness of 0.5 mm were supplied by Leatec Fine Ceramics Co. Ltd., Taoyuan, Taiwan. The electroless copper plating chemicals were obtained from Teamly Chemicals Corp., Taipei, Taiwan. The formulated electroless copper plating solution contained copper sulphate (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 alumina samples were washed with deionized water and dried. The laser activation condition can be evaluated by the standard procedure as described by LPKF [1]. A sieving pattern as shown in Fig. 2 for laser activation was used. The sheet samples was scanned by a RFL-P50Q optical fiber pulsed laser machine system (λ = 1064 nm, laser power: 0–50 W) of Raycus Fiber Laser Technologies CO., Ltd. (Wuhan, China) 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 100 min.

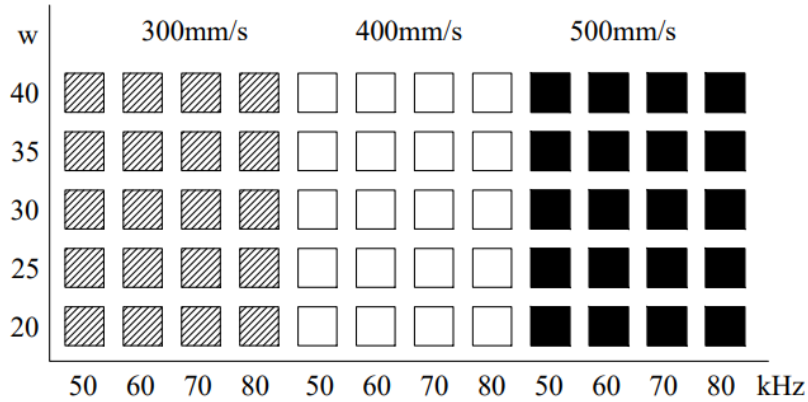


Fig. 2. Sieving pattern.

According to the sieving pattern, some conditions were chosen to analyze the suitable laser activation condition by the contrast pattern as shown in Fig. 3 and the line width pattern as shown in Fig. 4. The condition at a pulse frequency of 50 kHz, a laser scanning speed of 300 mm/s, and a laser power of 25 W showed acceptable contrast, and was used to fabricate the circuits.

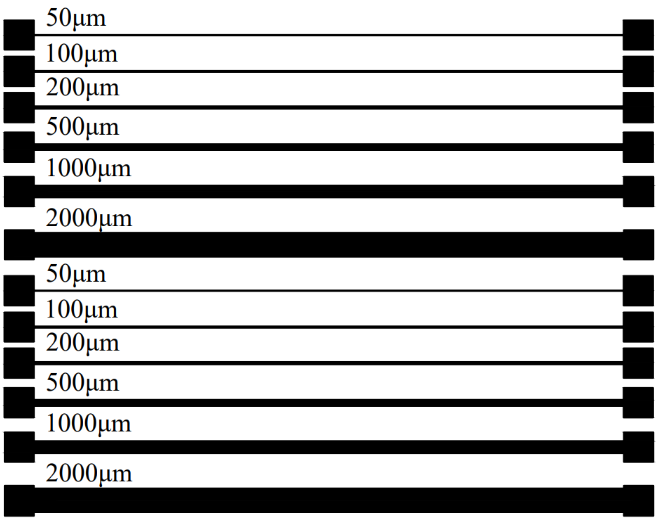


Fig. 3. Contrast pattern.

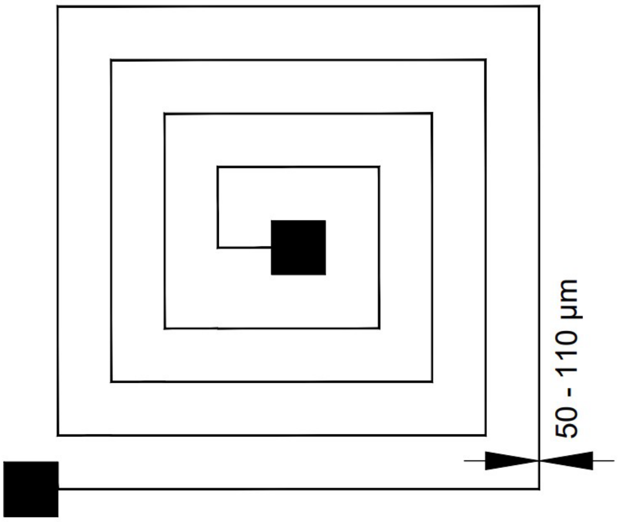


Fig. 4. Line width pattern.

2.3. Fabrication of Antenna Circuit

Fig. 5 shows a common near field communication (NFC) circuit. The antenna patterns were designed by varying the coil turns and line width. The NFC antenna patterns with square pads on the ceramic sheets were fabricated by the LDS procedure under the chosen condition.

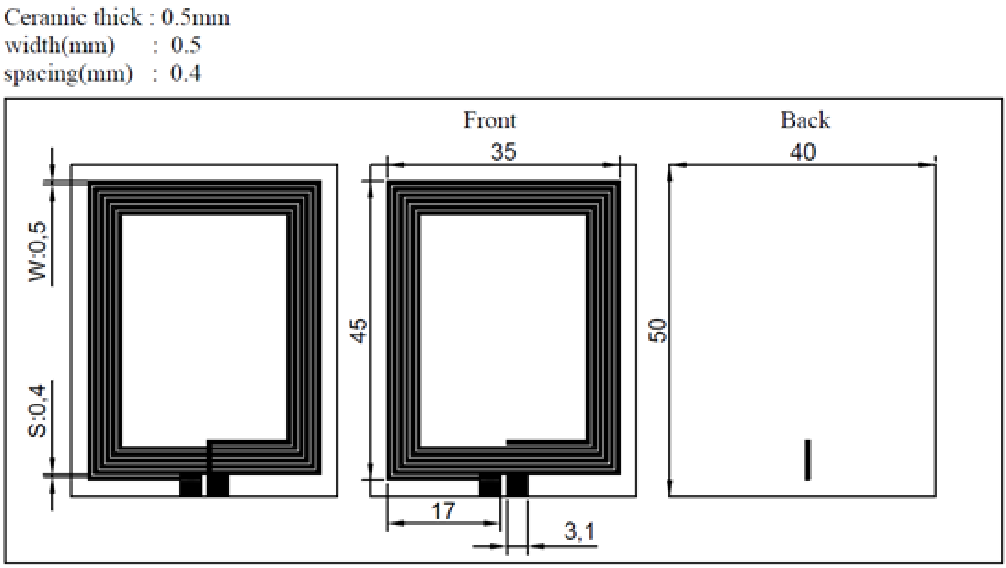


Fig. 5. NFC antenna circuit.

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., Santa Clara, United States). The resonant frequency of the NFC tag was measured using a VNA with a loop antenna. Return loss (S11) was measured from the fed port by connecting the loop antenna to the output of the VNA in reflection mode.

2.5. Simulation Tests

ANSYS Electromagnetics Suite HFSS v19.0.0 is an electromagnetic simulation (EM) simulator of ANSYS, Inc. (Canonsburg, United States). The EM simulation was performed to design the antenna by adjusting geometry sizes to fit the specification. The simulated antennas circuit at the standard frequency of 13.56 MHz is shown in Fig. 5. The electrical performance of the designed antenna was validated by the HFSS simulator. Its input impedance was also measured by a network analyzer to verify the simulation results.

3. Results and Discussion

The chemical copper plated sieving pattern after laser activation is shown in Fig. 6. Appropriate conditions were chosen to analyze the suitable laser activation condition by the contrast pattern. Fig. 7 shows the chemical copper plated contrast pattern at a pulse frequency of 50 kHz, a laser scanning speed of 300 mm/s, and a laser power of 25 W. The measured resistance of the lines with line width of 100 μm or greater was less 10 Ω, and that of the 50 μm lines was around 16 Ω. Thus, this condition showed acceptable contrast, and was used to fabricate the circuits. Of course, there can be better conditions, but the chosen activation condition showed enough quality for the present NFC applications.

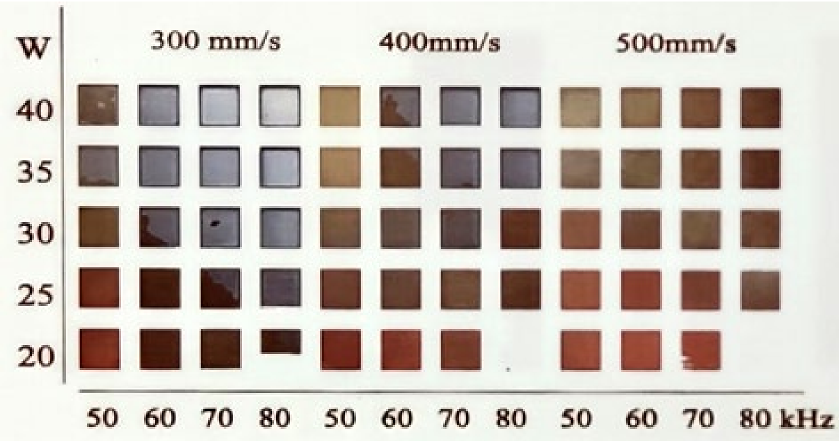


Fig. 6. Photograph of the chemical copper plated sieving pattern.

Fig. 7. Photograph of chemical copper plated contrast pattern.

Under the chosen condition, the patterns for fine line evaluation were fabricated by the LDS procedures, and Fig. 8 exhibited the results. It can be seen that a line width of 50 μm could be achieved, but the measured resistance was always greater than 100 Ω. For the case of 70 μm line width, the measured resistance was 10–20 Ω. The measured resistance values of the circuits with a line width of 90 μm or wider were less than 10 Ω. Thus, the line width of 80 μm can be used as the design limit for the antenna circuits.

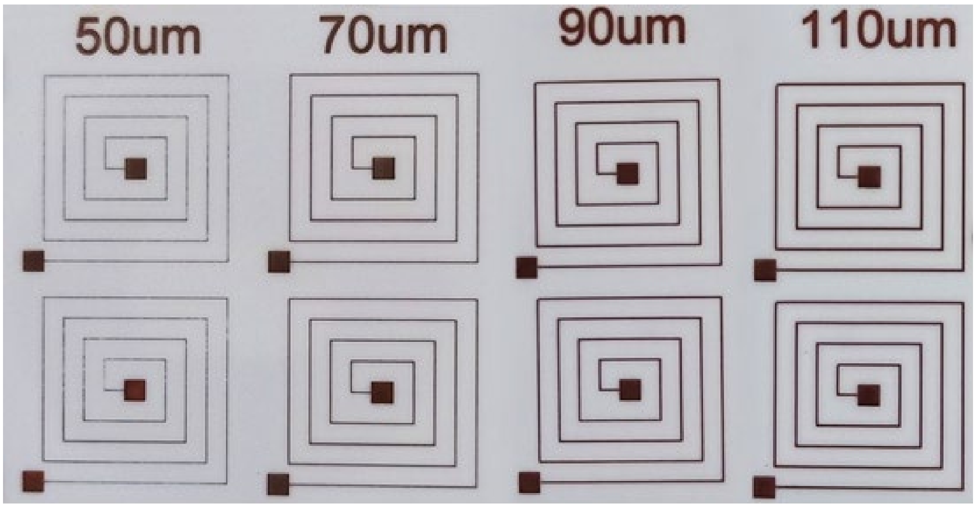
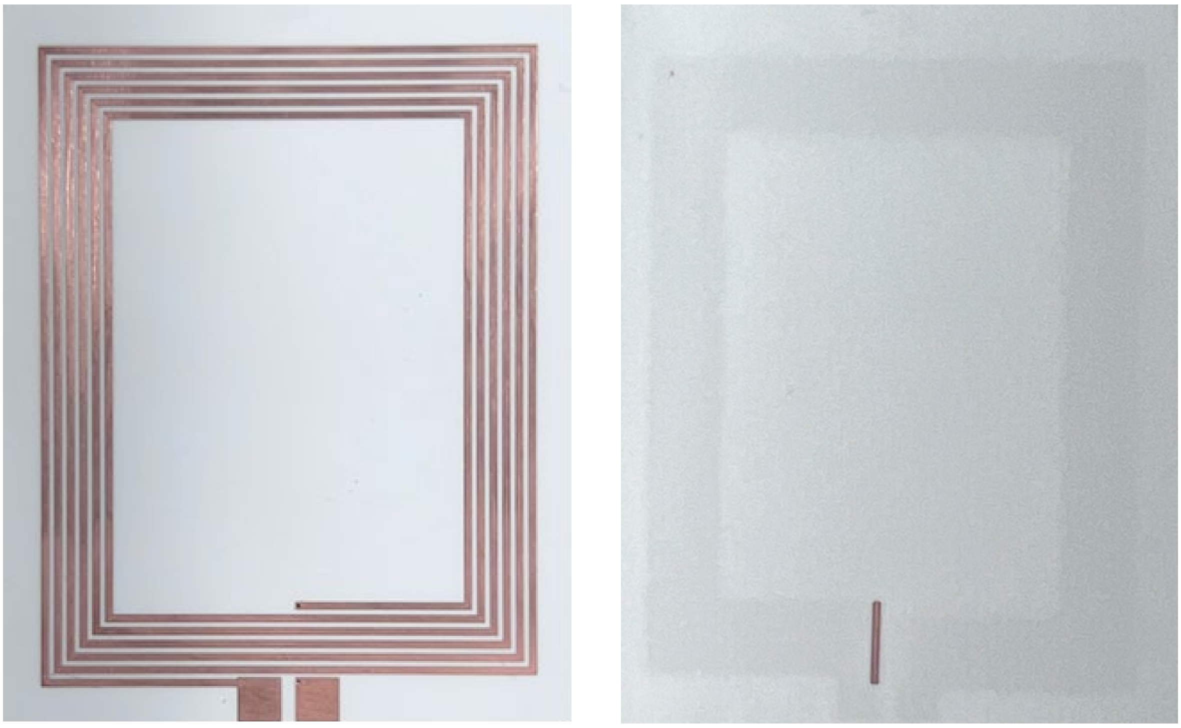


Fig. 8. Photograph of chemical copper plated fine line patterns.

The fabricated ceramic antenna circuit with line width of 500 μm is shown in Fig. 9. The right pad and inner terminal of the front side was connected to the line of the back side through the metalized wall of via holes which were formed during laser scanning. The measured resistance between the two pads was less 10 Ω indicating that the connections were achieved.



(a) **(b)**

Fig. 9. Photographs of the ceramic NFC antenna, (**a**) front side, (**b**) back side.

The two pins of the NFC chip (NTAG216F), were contacted to the pads of ceramic antenna. A Samsung S21 5G was used to access the antenna system. An APP of NFC Tag Writer of NXP was downloaded. The network address of National Ilan university was input. As the Samsung S21 5G was close to antenna system around 1 cm, the home page of National Ilan University appeared on the Samsung S21 5G screen as shown in Fig. 10. This indicated that the LDS PI antenna did work.

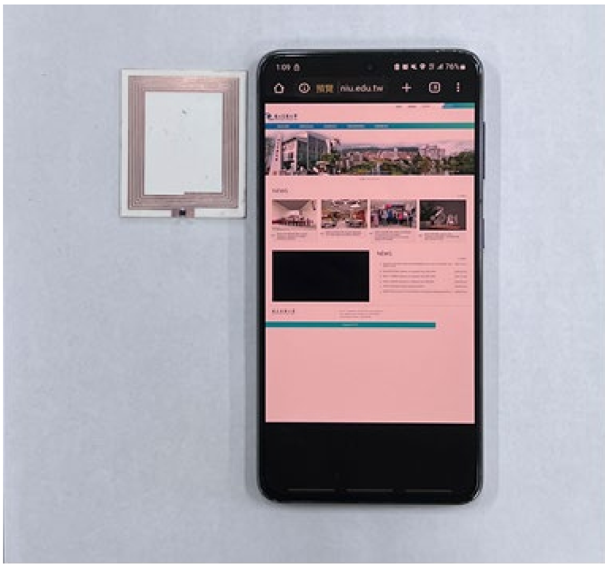


Fig. 10. The work of Samsung S21 5G as it reached the antenna system.

The simulated and measured return loss versus frequency of the NFC antenna is depicted in Fig. 11. The parameter S was defined to be related to the amplitude and phase of a signal, and the subscripts mean the ports numbers of reflected wave and incident wave, respectively. Therefore, the vertical axis S11 in Fig. 11 means the power ratio of reflected wave to incident wave in pore 1, usually termed as power ratio or return loss. The closer the measured result to the simulated result, the better the LDS PI antenna performance. It can be seen that the measured frequency response was close to that of the simulated one.

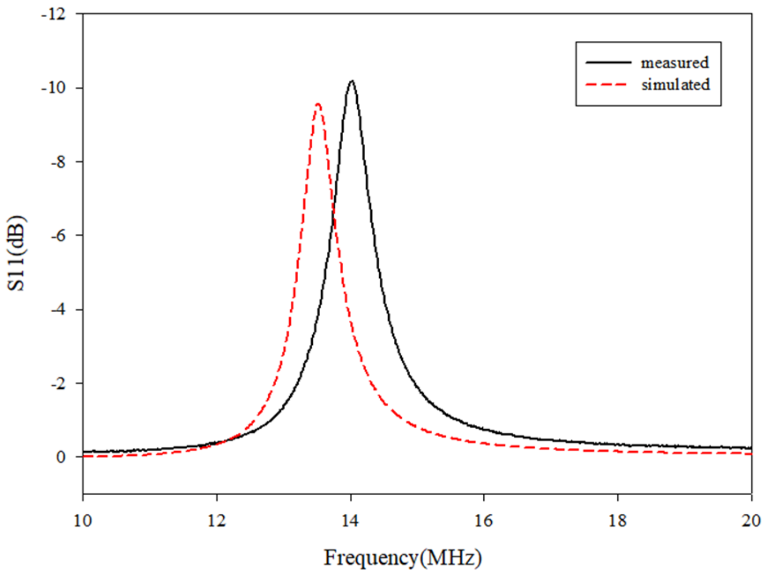


Fig. 11. Return loss versus frequency curves, --- means simulated, — means measured.

4. Conclusions

The process of laser-induced selective metallization (LDS) was evaluated for the fabrication of circuits on the ceramic substrate. The line width evaluation pattern results indicated that the feasible fine width could be as fine as 80 μm. The fabricated antenna circuit with a line width 500 μm ceramic substrate did work successfully. The peak frequencies by simulation and direct measurement of the antenna circuit were close enough in practice.

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