OPEN ACCESS Freely available online

ISSN 2737-5323
Volume 4, Issue 1
https://www.iikii.com.sg/journal/AFM
Applied Functional Materials

Article

Laser-Induced Selective Metallization on Aluminum Nitride for Fine Line Circuits

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Received: Jan 1, 2024; **Revised:** Feb 1, 2024; **Accepted:** Feb 15, 2024; **Published:** Mar 30, 2024

Abstract: The technology of laser direct selective metallization on aluminum nitride substrate was investigated for manufacturing fine line circuits. In laser direct structuring, laser activation and electroless copper plating were used. The feasibility was evaluated by analyzing the sieving, contrast, and fine linewidth patterns, and the results showed that the width of the feasible fine reached 100 µm. A near-field communication (NFC) antenna circuit of the width of 400 µm was fabricated on the aluminum nitride substrate. The measured resonance frequency was close to the NFC specification frequency.

Keywords: Laser direct structuring, Aluminum nitride, Laser activation, Electroless copper plating, Antenna circuit

1. Introduction

Overheating has been encountered in electronic products for a long time [1]. The application of ceramic circuits may be an intrinsic solution for overheating. The range of the thermal conductivity of ceramic materials is wide, i.e., about 1−200 $Wm^{-1}K^{-1}$ [2]. Aluminum nitride seems to be an excellent insulator among them. The thermal conductivity of aluminum nitride is around 170 $Wm^{-1}K^{-1}$, which is close to that of aluminum metal (around 250 $Wm^{-1}K^{-1}$). Thus, ceramic circuits based on aluminum nitride are expected to be widely applied. Various technologies have been applied to fabricate the ceramic circuits [3]. Laser-induced selective metallization is a more convenient method, laser direct structuring (LDS) technology [4−7]. This method can be used to fabricate circuits on common ceramic substrates [8−11] and aluminum nitride [12]. In this research, we chose aluminum nitride as an insulator for the fabrication of fine-line ceramic circuits and their evaluation.

2. The Materials and Methods

2.1. Materials

The aluminum nitride sheets with a thickness of 0.38 mm were supplied by Tokuyama-Dowa Power Materials Co. Ltd, Yamaguchi, Japan. The electroless copper plating chemicals (ECM-60) for manufacturing fine line circuits were purchased from Teamly Chemicals Corp., Taipei, Taiwan. The chemicals including 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) were used to formulate an electroless copper plating solution.

2.2 Laser Activation and Chemical Plating

As pretreatment, aluminum nitride samples were washed with deionized water 3 times and dried in an oven at 60 °C for 6 h. The operating condition for laser activation was examined by the standard procedure mentioned in our previous studies [11]. Figure 1 shows a sieving pattern of multiple squares adopted for laser activation. Each square represented a laser activation condition at a given laser scanning speed, laser pulse frequency, and laser power. sheet samples were scanned by the laser machine (BRIMO 20W R2+ laser machine of Brimo Technology CO., Ltd., Taiwan) in a controlled condition. The laser scanning speed set was from 500 to 1500 m/ms, the laser pulse frequency used was from 20 to 80 KHz, and the laser power was from 4 to 10 W. After scanning with the laser, the samples were washed three times with distilled water and dried in an oven at 60 °C for 6 h again. Finally, the samples were dipped in ECM-60 solution at 55°C for 30 min to perform the copper plating.

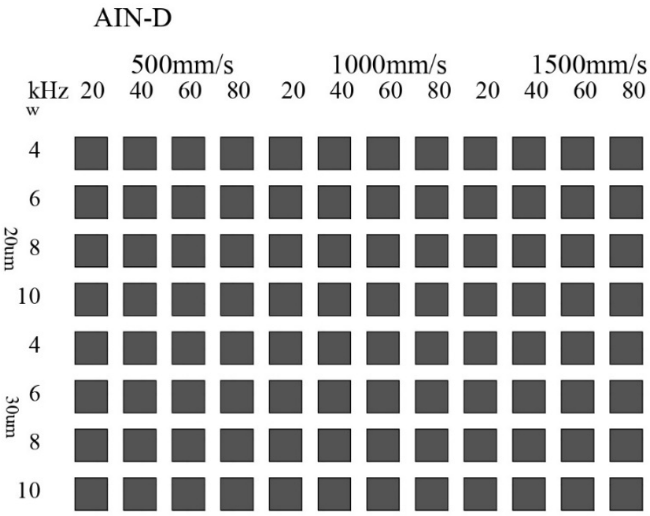


Fig. 1. Sieving pattern.

The contrast pattern of the sieving pattern was analyzed to determine the operating conditions for the suitable laser activation condition as shown in Fig. 2. Since the contrast conditions at a laser scanning speed of 500 m/ms and a laser power of 10 W were acceptable, the conditions were adopted to fabricate the circuits.

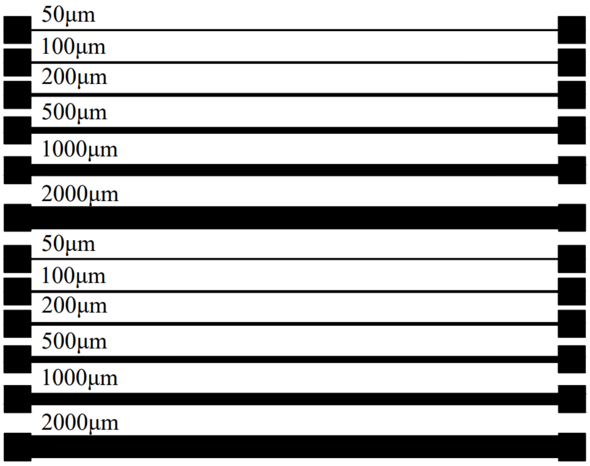


Fig. 2. Contrast pattern.

The fine line evaluation pattern (Fig. 3) was then scanned by the laser machine under the chosen condition on the aluminum nitride samples, and then electroless copper plating was performed for 30 min. The design limit of line width for the circuits on aluminum nitride by LDS technology was estimated.

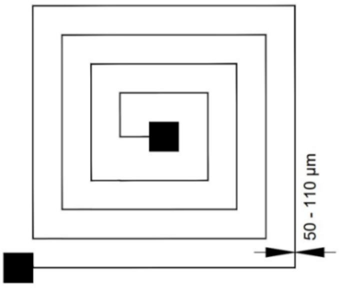


Fig. 3. Fine line pattern.

2.3 Fabrication of Circuit

A common NFC circuit is shown in Fig. 4. In the determined conditions, the square pads on the aluminum nitride were designed to fabricate the antenna patterns by the LDS procedure.

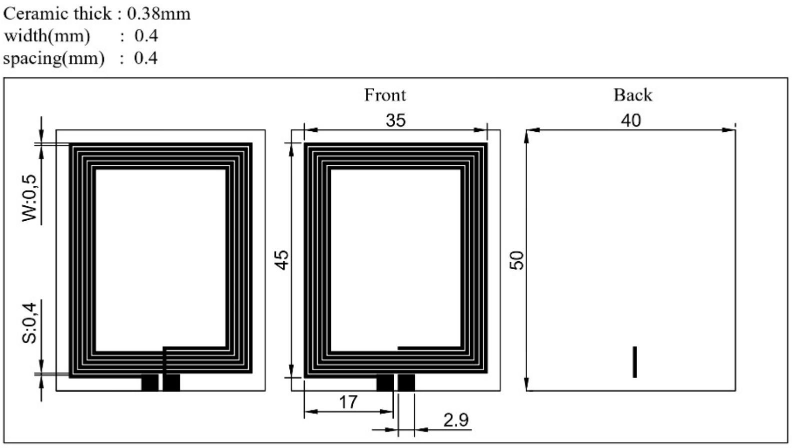


Fig. 4. NFC antenna circuit.

2.4 Measurements

An Agilent E5071B ENA RF Network Analyzer of Agilent Technologies Inc. was used to detect the complex input impedance of the NFC antennas and the frequencies were controlled from 300 KHz to 8.5 GHz. A vector network analyzer (VNA) with a loop antenna was used to detect the resonant frequency of the NFC tag. In addition, the fed port through a connection of the loop antenna to the VNA output in reflection mode was used to determine the return loss (S11).

3. Results and Discussion

Figure 5 shows the sieving pattern for laser activation at various conditions and chemical copper plating in which the laser power played an important role. The laser power had to be at least 8 W to maintain satisfactory quality in the LDS process for aluminum nitride. Appropriate conditions were selected to compare the sieving pattern with other patterns. Figure 6 and Table 1 demonstrate that the activation condition was acceptable at a laser scanning speed of 500 m/ms and a laser power of 10 W. The resistance measured for the 50 µm line was about 15 Ω, indicating that this condition was acceptable.

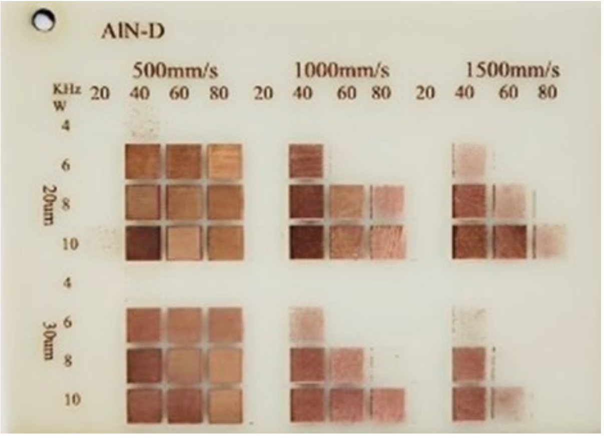


Fig. 5. Photograph of sieving pattern after laser activation at various conditions and chemical copper plating.

Fig. 6. Contrasted images of chemical copper plated.

Table 1. Measured resistance of the lines of the contrast pattern.

Line width (μm)	Measured resistance (Ω)
50	15 ± 3
100	11 ± 2
200	7.0 ± 0.5
500	4 ± 0.3
1000	2.4 ± 0.2
2000	1.5 ± 0.1

Laser direct structuring was adopted to fabricate the fine line patterns in the selected condition, and the fabricated patterns are shown in Fig. 7. The measured resistance values are listed in Table 2. A resistance of less than 10 Ω was acceptable for the LDS circuits on ceramic circuits. Tables 1 and 2 indicate that the feasible fine width was about 100 μm for the aluminum nitride circuits.

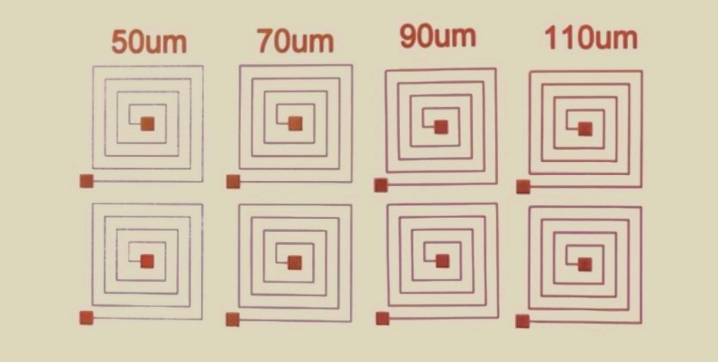
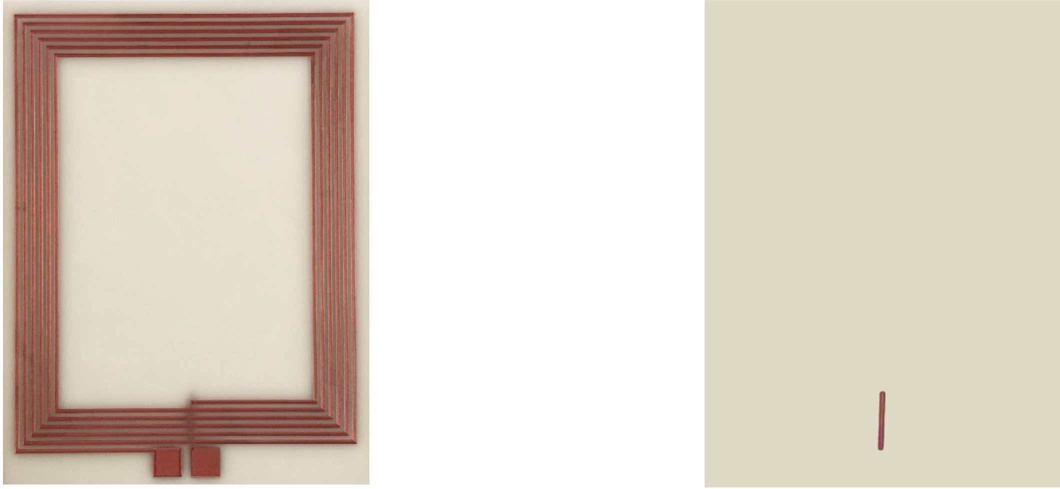


Fig. 7. Images of electroless copper plated thin wire pattern.

Table 2. Measured resistance of the lines of the fine line patterns.

Line width (μm)	Measured Resistance (Ω)
50	43 ± 7
70	31 ± 5
90	21 ± 5
110	8 ± 1

As shown in Fig. 8, the design of the NFC antenna circuit included 6 turns and a line width of 400 μm. Two via holes were formed by the laser before laser scanning of the circuits. The right pad and inner terminal of the front side were connected to the line fabricated from the back side, and the line was also connected to the metalized wall via holes. The obtained resistance between the two pads was less than 10 Ω, thus the result showed successful connections.



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

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

HP 5071 B vector network analyzer was used to determine the complex input impedance of the NFC antennas. Figure 9 shows the relationship between the obtained S11 return loss and frequency of the aluminum nitride antenna of 6 coil turns with a line width of 400 µm. The same antenna circuit on an aluminum oxide ceramic substrate was manufactured by a similar process, referred to [11] for comparison. The maximum S11 return loss was found at 13.43 MHz for aluminum nitride and 13.7 MHz for aluminum oxide. The peak frequencies were close enough and approached the NFC specification frequency (13.56 MHz). This implied that the design of common ceramic antenna circuits is appropriate for aluminum nitride substrate by the LDS process.

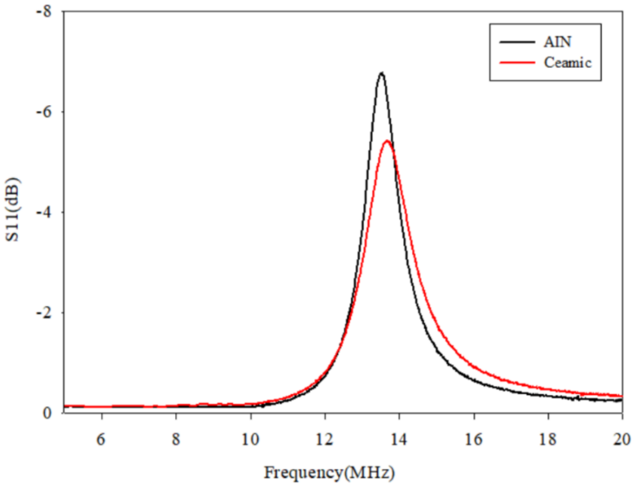


Fig. 9. Relationship between the obtained S11 return loss and frequency on the AlN (black curve) sheet and a ceramic (Al_2O_3) substrate(red curve).

4. Conclusions

The LDS technology was applied successfully to the aluminum nitride substrate. The evaluation results showed that the feasible fine width was around 100 µm. The measured resonance frequency for the manufactured NFC antenna circuit with a line width of 400 µm was similar to the NFC specification frequency.

Author Contributions: conceptualization, H.-B. Tsai; methodology, H.-B. Tsai; validation, H.-B. Tsai and S.-Y. Lai; formal analysis, S.-Y. Lai; investigation, Q.-T. Pham and H.-T. Wu; resources, H.-B. Tsai; data curation, S.-Y. Lai; writing—original draft preparation, H.-B. Tsai; writing—review and editing, Q.-T. Pham and H.-T. Wu; visualization, H.-T. Wu; supervision, H.-B. Tsai.

Funding: This research did not receive external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thank AR Display Co. Ltd., Taiwan for the financial and technical support of this work.

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

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