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Laser Etching Effects on the Electrical and Mechanical Properties of Barium Titanate Thick Films

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Summary:

The rapid spread of the Internet of Things (IoT) has increased demand for compact, high-capacity capacitors. In this study, barium titanate ($BaTiO_3$, BTO) thick films were fabricated by aerosol deposition (AD) and etched by laser. Electrical and mechanical evaluations revealed that laser etching enhanced the relative permittivity and Young's modulus of the films. These findings indicate that laser etching has strong potential as a processing technique for BTO thick films used in compact capacitors.

Keywords: barium titanate, aerosol deposition method, laser etching, dielectric properties, ceramic capacitors

Background

The Internet of Things (IoT) has rapidly spread in recent years. These IoT devices and sensor systems are all connected through the Internet, so a stable energy supply is essential. Therefore, the demand for capacitors is growing because of their ability to store and release electrical energy at high speeds. However, capacitors have limited capacity and space issues, so thick film capacitors are effective.

Barium titanate ($BaTiO_3$, BTO) is widely used as a capacitor due to its excellent relative permittivity and temperature stability. Moreover, the aerosol deposition (AD) method can improve brittleness by compositing with metal plates. The AD method is a deposition method in which raw material powders are mixed with gas and impacted onto a substrate. It can deposit dense films on any substrate at room temperature and high speed [1]. However, heat treatment is necessary to improve the low crystallinity and low relative permittivity of AD films [2]. So, in this study, we focused on laser etching as a new approach that can both process and anneal the films at the same time. Therefore, the objective is to investigate the effect on the electrical and mechanical properties of laser-etched BTO thick films.

Specimens' preparation

0.2 mm thick stainless steel and Fe-Co/Ni clad materials were used as substrates, and the AD method formed BTO thick films. The deposition was performed at room temperature using N_2 as the carrier gas at a flow rate of 15 L min^{-1}, with a nozzle measuring 0.5×30 mm^2 positioned 15 mm from the substrate and a scanning speed of 1 mm s^{-1}. The film thickness was set to 20 μm, and Au electrodes were formed on the surface using a sputtering system.

Experimental method

The fabricated specimens were etched using a laser cutting machine varying the laser power from 1 W to 10 W under fixed conditions of 1 mm s^{-1} etching speed and one processing cycle. During laser processing, the substrate temperature was recorded. Subsequently, the processing width was measured using a scanning electron microscope (SEM). Next, Young's modulus and relative permittivity were measured under various laser powers, etching cycles, and etching speeds to understand the influence of laser etching on the mechanical and electrical properties of the BTO film. The heat-affected zone (HAZ) was then estimated by evaluating the relative permittivity of samples etched with different gaps between the laser lines. Finally, X-ray diffraction (XRD) analysis was performed on both the laser-etched and as-deposited films to investigate changes in crystallinity induced by laser etching.

Results

Measurement results of substrate temperature showed a positive correlation between laser power and temperature, with the temperature rising from about 80°C at 1 W to nearly 400°C at 10 W. Similarly, the process width measurement showed a positive correlation between laser power and process width, ranging from 147 μm at 1 W to 238 μm at 10 W.

Fig. 1 gives the evaluation results of Young's modulus and relative permittivity. The numbers in the legend represent the laser power (W), etching cycles (times), and etching speed (mm s^{-1}) used in the laser etching process. Fig. 1 (a) shows that Young's modulus of the laser-etched film ranges from 120 to 140 GPa, which is higher than that of the as-deposited film, which is around 100 GPa, especially under the conditions of 7 W laser power, 2 times of etching cycle, and 4 mm s^{-1} etching speed (7-2-4). Similarly, Fig. 1 (b) shows that the relative permittivity of the laser-etched film became larger than the as-deposited film, and the 7-2-4 condition showed the highest relative permittivity, increasing from 75 to about 180. Frequency sweep measurement of the relative permittivity showed that relative permittivity decreased as the frequency increased, and this is typical ferroelectric behavior. It is evident that laser etching increases both Young's modulus and the relative permittivity of the AD-fabricated BTO thick films, and the laser etching parameters influence these enhancements.

Therefore, the condition labeled 7-2-4 was selected to etch the BTO thick film with varying gapping distances ranging from 0.5 mm to 2.0 mm in 0.25 mm intervals. The relative permittivity in each etched area was then measured to understand the HAZ of the laser etching better. As a result, the relative permittivity of the film reaches its highest value when the gap between the laser etching lines is 1.0 mm. It is assumed that a too-small gap causes the HAZs to overlap, leading to damage in the film and a decrease in relative permittivity. In contrast, a too-large gap results in some areas of the film not being affected by the laser, leading to a lower relative permittivity. Therefore, the width of the HAZ under the laser etching condition labeled 7-2-4 is estimated to be approximately 1.0 mm.

The XRD patterns of the as-deposited and laser-etched BTO films are presented in Fig. 2. The results show that laser etching enhanced the intensity and sharpness of the diffraction peaks, accompanied by a shift toward higher angles. These changes indicate improved crystallinity, which suggests that laser etching may have helped relieve residual compressive stress. These structural modifications may explain the film's relative permittivity and Young's modulus enhancement.

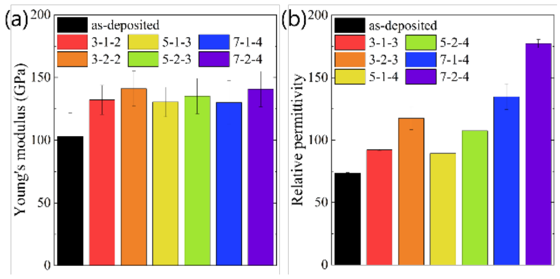

Fig. 1. (a)Young's modulus and (b)relative permittivity measurement at 1 kHz. Legend: laser power (W) – etching cycles (times) – etching speed (mm s^{-1})

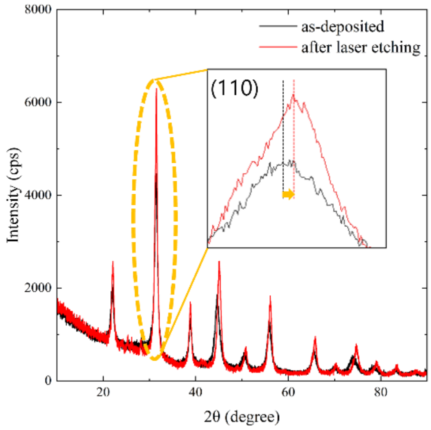

Fig. 2. XRD patterns for as-deposited and after laser etching film.

Conclusion

In this study, BTO thick films fabricated by the AD method were successfully etched by laser processing, and this laser etching improved Young's modulus and relative permittivity of the BTO thick films. It was also found that the increased crystallinity of the BTO thick film due to laser etching was one of the factors that improved Young's modulus and relative permittivity. These results demonstrate the potential of laser etching for processing in thick-film capacitors.

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