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Laser etching of aluminum thin film on polyimide: Simulation and experimental studies

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ABSTRACT

Laser etching process of aluminum thin film on polyimide substrate was simulated by the finite element analysis software ANSYS to study the etching results. Theoretical etching profiles of aluminum thin film with different laser parameters were obtained from the simulation, which is in good agreement with experimental results observed by SEM, it shows that a best etching result can be obtained and it corresponded to a set of reasonable parameters. By optimizing such laser etching parameters as laser power and beam scanning velocity, etc., aluminum thin film could be etched ideally without damaging the polyimide substrate. Therefore, the simulation results can be taken as a guide for determination of practical laser etching parameters in order to obtain ideal etching patterns.

1. Introduction

With development of high capacity communication satellites, the demand for light weighted antenna is increasing [1], reflector components made of polymer coated with metal thin films (commonly patterned) were applied more widely in advanced antenna. Laser etching, based on the principle of interaction between high powered short-pulsed laser and materials, is a promising and high efficient fabrication technique for metal thin film patterns [2]. More than ten antennas were fabricated by laser etching at our group in recent years, and several of them have already passed flight test. But for the combination of polymer substrate and metal thin film, it is still a challenging technical issue to achieve high-precision laser etching result as the two materials possess quite different heat and mechanical properties [3], and space borne antennas are often single-piece products without two identical ones, etching parameters of one antenna cannot be adopted to another one directly, so understanding of interaction between laser and workpiece is essential for successful fabrication.

Interaction between laser and matter were investigated widely with different laser material processing technology using different laser sources and materials, such as laser drilling [4,5], laser ablation [6–8], laser surface modification [9,10], laser cleaning of compact disc by laser polycarbonate recovery [11,12], etc.

In this work, the emphasis is on simulation and experimental studies of laser etching of aluminum (Al) thin film on polyimide (PI) substrate by establishing a numerical model. Based on the highly nonlinear model of heat transfer and phase change within Al thin film and PI substrate after absorbing of laser energy, heat transfer equation was solved by finite element method implemented in ANSYS software. The etching profiles of Al thin film with different laser power and pulse overlap were obtained by the simulation. Investigation on laser etching of Al thin film was also carried out experimentally in order to unveil the internal relationship among materials, laser parameters and processing conditions, by comparing the theoretical and experimental results. The validity of the simulation was experimentally corroborated, and the presumed laser etching mechanism of aluminum thin film was verified.

2. Numerical simulation processes

2.1. Finite element modeling

The situation to be dealt with is that a large number of identical and overlapped laser pulse irradiating the Al thin film (2 μm in thickness), as shown in Fig. 1(a). Full modeling the process based on the given experimental conditions or practical production will make the model time so large that the simulation can hardly be accomplished by computer, so some necessary simplification should be performed. According to the trace of laser spot on the top surface of the material, as shown in Fig. 1(b), each sample was etching by one laser spot at a scanning speed of v_x (mm/s), and the interval of adjacent laser scanning lines was held constant at d. Etching process was realized by irradiate the sample with a laser beam. So, etching profiles of Al thin film by one

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laser spot can be investigated in order to unveil the internal relationship among materials, laser parameters and processing conditions. Therefore, the dimension of units can be considered to approximately one laser spot diameter (40 μm). This has led us to apply the unit with 60 μm × 60 μm × 6 μm in dimension, as outlined in Fig. 1(c), this would reduce the modeling time considerably. Before establishing the mathematical model, several assumptions were made [8,13]: (1) Thermal

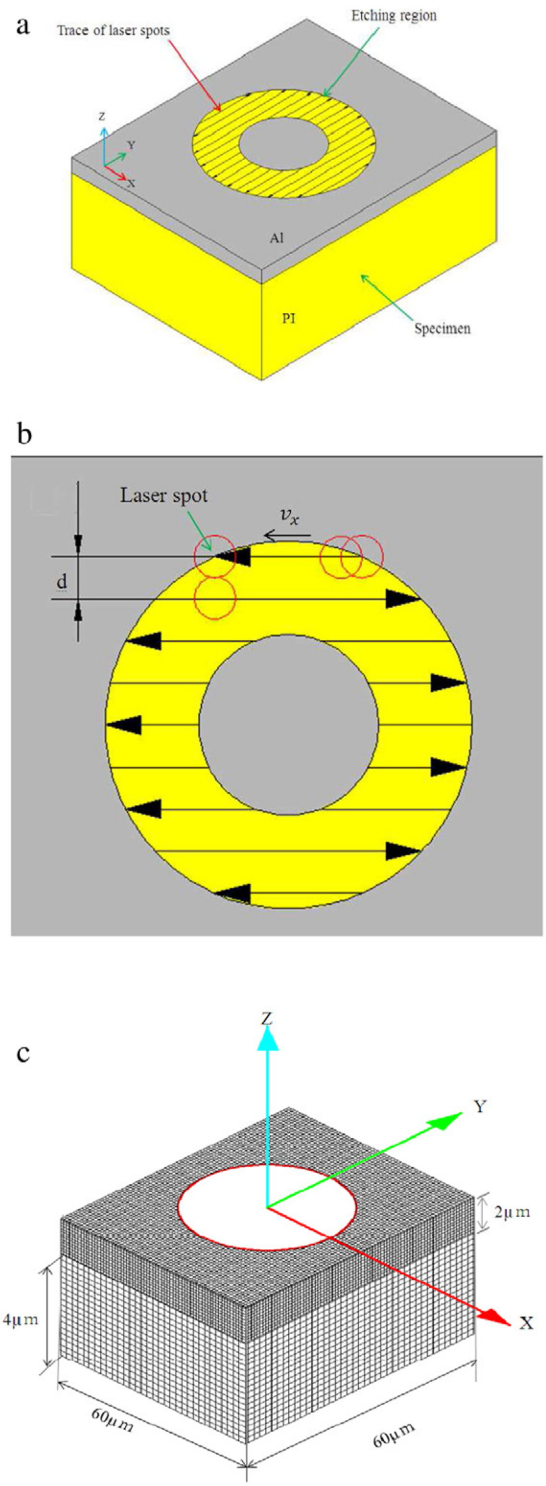

Fig. 1. 3D finite element model for the simulation, (a) schematic structure of Al/PI; (b) trace of laser spot for pattern etching; (c) modeling unit for infinite element analysis.

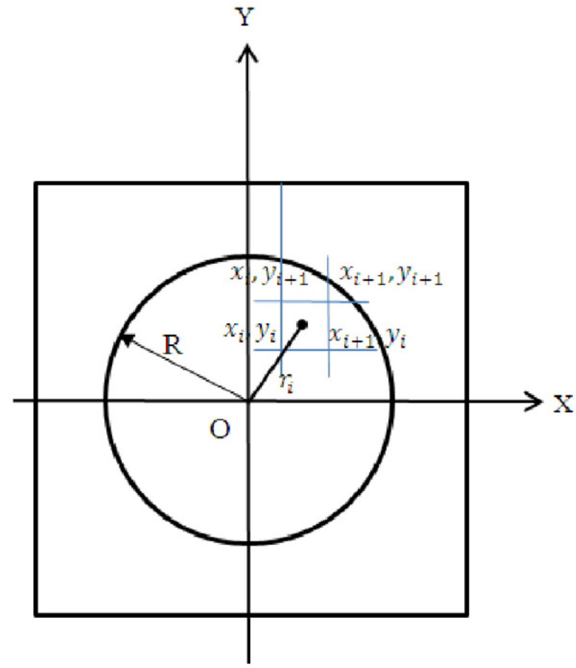

Fig. 2. Schematic radial distance of each element.

Table 1
Parameters employed in the simulation and experiment.

Laser power (W)	Pulse energy (mJ)	Pulse width (ns)	Pulse frequency (kHz)	Laser spot size (μm)	Vertical scanning distance (μm)	Scanning speed (mm/s)
3	150	100	20	40	40	500
4	200					
5	250					
6	300					
7	350					

Table 2
Properties of Al thin film adopted in the simulation.

Density (kg/m^3)		2701
Melting point (K)		933
Boiling point (K)		2740
Specific heat capacity (J/(kg·K))	Temperature (K)	Value
	200	859
	300	902
	400	949
	500	997
	600	1042
	800	1134
	1000	921
	1200	921
Thermal conductivity (W/(m·K))	Temperature (K)	Value
	373	206
	573	229
	773	268
	973	104
	1073	122

Table 3
Thermal properties of PI adopted in the simulation.

Density (kg/m^3)	Specific heat [J/(kg·K)]	Heat conductivity [W/(m·K)]	Melting point (K)
1420	2000	0.385	450