Laser induced fractal structure on magnetic dielectric thin film

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The Richardson plots method is employed to measure the fractal dimensions D of the surface of magnetic dielectric film fractured by excimer laser irradiation near the ablation threshold. It is shown that the fractured surfaces are fractal character. The value of D decreases while the laser pulse number increases. This relation may reflect how the fractured surface changes from irregular structure to regular structure with laser pulse number.

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Matter irradiated by laser has been extensively studied because of its many useful applications. To reduce stiction during start up of a disk drive, laser zone texturing has recently been implemented in the start/stop zone of magnetic dielectric thin film disks. The sombrero, volcano, W-type, waning moon and mech tex structures have been observed on thin film disks after YAP laser irradiation by IBM's storage division[1]. In this paper we studied the modification surface of thin film disks by XeCl excimer laser. The surface is fractured near the ablation threshold and changes from "coastline" shape to a roll-like shape when the laser pulse number increases.

Fractals are the concern of a new geometry, whose primary object is to describe the great variety of natural structures that are irregular[2−4], rough or fragmented, having irregularities of various sizes that bear a special "scaling" relationship to one another. In very loose terms, they seem to fall into a regular hierarchy in which each level is an up-sized version of the levels below or above it. Fractal geometry characterizes the scaling structure of a surface by a number D, called the fractal dimension, that can range from 1, when the line is smooth, up to 2. In general, there are many measurement procedures that are used to determine the fractal dimension of a profile[5,6], such as Richardson (Hausdorf), Minkowski, or Kolmogorov techniques. One of the earliest methods was carried out by Richardson, when he observed the fractal behavior of boundary line in 1961.

Coastlines, metal fracture surfaces[7] and fractal surfaces of adsorbents[8] have been well studied by fractal theory. In recent years, quantitative analysis of fractured surfaces has become an important feature in the process of obtaining a better knowledge of the microstructural processes involved during the deformation and rupture of material. The dimension of the fractured surface is related to metal characteristics, and widely used to analyze the elements of the metal. The magnetic dielectric film is fractured by laser irradiation, and the fractured surface can be studied by fractal theory.

After the laser interacts with solid matter, some regular structure can be drawn on the surface of the solid matter, such as ripple structure on semiconductor Ge[9] and microcolumns on semiconductor Si (100)[10]. This coastline like structure is investigated for the first time.

An XeCl excimer laser generated 30 ns pulses at 308 nm. A rectangle homogenizer is used to generate a homogeneous laser beam, with the thin film disk glued to a metal holder and vertically placed in an X-Y station. Spots with a dimension of about 3×4 mm^2 are obtained. Laser fluences in the range 20 mJ/cm^2−2 J/cm^2 are used in this study. The repetition rate is 5 Hz and the number of shots is changed between 1 and 3000. The energy was measured with thermoelectric energy meter, and the surface morphology was measured by a scanning electron microscopy (SEM).

The ablation threshold is 220 mJ/cm^2 and the ablation behavior is like other matter such as Si[11]. The ablation rate related to laser energy fluence is shown in Fig. 1. The ablation rate per pulse has been calculated for punch through the thin film completed by laser pulses. Near the threshold, the ablation rate is not measurable, after the threshold, it formed a linear zone, but after 500 mJ/cm^2, it formed a nonlinear zone, which is similar to the ablation of silicon.

The surface ablated near the threshold energy fluence was studied. It is fractured by the laser shock and it is coastline like, but when the laser pulse number increases, the coastline structure becomes a roll-like structure as shown in Fig. 2.

When the magnetic dielectric film is irradiated by 5 laser pulses near the ablation threshold, the fractal structure on the film surface occurs, which is shown in Fig. 2(a). The fractured surface is like islands in the ocean, and the edge of the island is coastline-like. When the

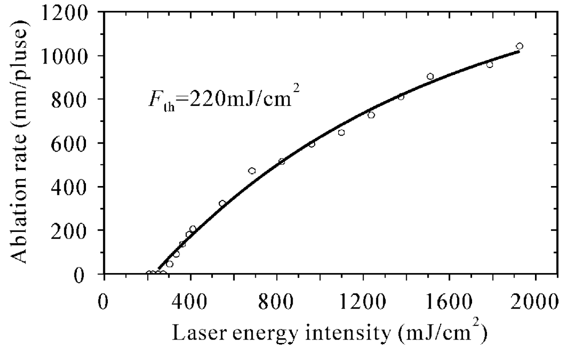

Fig. 1. Ablation depth per pulse dependence on the laser fluence, the laser ablation threshold $F_{th} = 220$ mJ/cm^2.

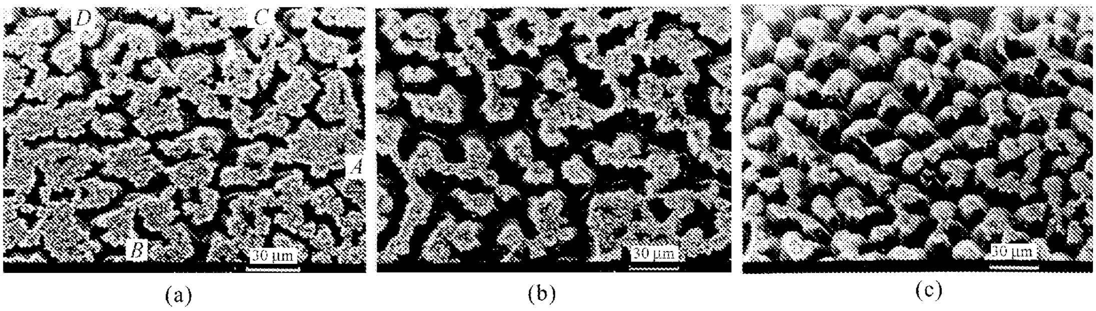

Fig. 2. SEM image of fractal structure formed after laser irradiation and roll-like structure by the cumulation of laser pulses. (a) Laser fluence is 230 mJ/cm^2, pulse number is 5. (b) Laser fluence is 230 mJ/cm^2, pulse number is 10. (c) Laser fluence is 230 mJ/cm^2, pulse number is 40.

laser pulse number increases, the distance between the islands increases as shown in Fig. 2(b). When the number of the laser pulse increased to 40, the fractal structure vanished, and the roll-like structure appeared as shown in Fig. 2(c).

The fractured surface can be studied by fractal theory, and the dimension of the fractal can be measured by the Richardson plot method. An irregular outline is converted to poly-folded line approximation using different step length. The product of the total number of step $N(\eta)$ and the step length η gives an estimate of the total length. The procedure can be executed by "walking" along the boundary with a pair of dividers set to a fixed stride length. The minimum step is η_0, suppose $\delta = \eta/\eta_0$, if the total number of step $N(\delta)$ is related to δ as shown in the relationship

$$N(\delta) \propto \delta^{-D}$$

or

$$\ln N(\delta) = A + D \ln (1/\delta),$$

in which, A is a constant, D is the dimension of the irregular coast-like line. The dimension D was calculated by Richardson plot method. At the beginning of the line, plot a circle with radius η, and at the cross point between the circle and the line, plot the second circle with radius η, and so on until the line is completely covered by the circles. Change the radius η, then plot the curve $\ln N(\delta)$ against $\ln(1/\delta)$, if the curve is a beeline, then the slope of the line is dimension D.

In Fig. 2(a), we measured line AB by using the Richardson plot method, the minimal ruler is 1 mm; the $\ln N(\delta)$ vs $\ln(1/\delta)$ line is shown in Fig. 3. It describes the fractal formed after 5 laser pulses irradiation shown in Fig. 2(a). Making a linear fit to the measured data, the values of A and D are shown in Table 1. From the table, the line is perfectly fit to the measured data and the dimension of the fractal is 1.077355.

When the pulse number increased, the dimension of the fractured surface decreased, until it reached to 1 after 50 laser pulses irradiation. At the same time the coastline became smooth and the fractal structure turned into a roll-like structure. It is interesting to note that an irregular structure becomes a regular structure with the increase of the number of the laser pulses. The change of dimension of the fractured surface is shown in Fig. 4.

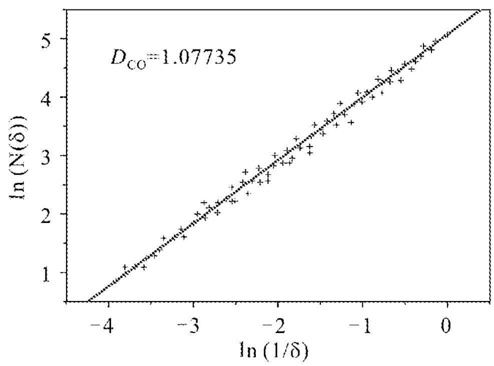

Fig. 3. Relationship between the number of the circles and the δ of line $A \to B$, $\eta_0 = 1$ mm, $\ln (N(\delta)) = A + \ln (1/\delta)$.

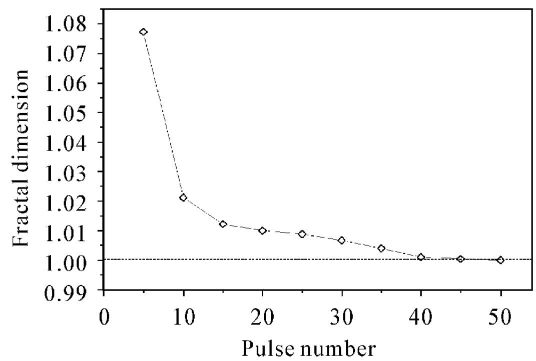

Fig. 4. Fractal dimension versus pulse number.

Table 1. Linear Fit to the Measured Data

Line	A^*	Error of A	D	Error of D
$A \to B$	5.06918	0.0125	1.07733	0.00426
$C \to D$	3.51638	0.0131	1.07741	0.00415

$^*\ln (N(\delta)) = A + D \ln (1/\delta)$

In summary, a laser induced fractal structure on magnetic dielectric film has been found. The most interesting thing is that the fractal dimension decreases while the laser pulse number increases. When the pulse number reaches 50, the dimension of the fractal becomes 1 and the fractal structure becomes a roll-like structure.

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