Some Experiments on Optical Processing of Metals with Ruby Laser

Some Experiments on Optical Processing of Metals with Ruby Laser*

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The present paper describes some experimental results of the optical processing of thin films of metal with the ruby laser excited by a straight Xe flashlamp whose maximum input energy is 400 joule.

The experiments were performed by changing values of the parameters, such as the distance between specimen and focussing lens, the thickness of thin films of metal and the input energy of Xe flashlamp.

Discussion is made on some fundamental problems concerning the optical processing with the ruby laser based on the results of the experiment.

1. Introduction

Since T. H. Maiman[1] suceeded in operating the pulsed ruby laser, many investigations as to the characteristics and applications of it have vigorously been performed. The laser techniques also have greatly improved. The laser provides quite a new experimental tool for the study of scientific researches[2] and engineering applications,[3)~8)] for the laser beam is not only intense and coherent, it may be further concentrated by means of lenses and mirrors.

It has been demonstrated in the laboratory that a laser beam, when focused on various materials can give local vaporization or burn small holes through them.

The present paper describes the result of the optical processing of thin films of Al, Cu, Ge and Ni with the ruby laser excited by a straight Xe flashlamp.

2. Apparatus

The schematic diagram of the ruby laser is shown in Fig. 1, and the photograph of the laser head in Photo. 1. The laser head is composed of a reflecting elliptical cylinder including a cylinder of pink ruby at one of the focal lines and an exciting flashlamp at the other. The Xe flashlamp is a straight tube (E G & G FX-38A) whose efficiency is known to be better than a helical one.

The cylinder of pink ruby used contains 0.05 percent chromium ion and is 5 mm in diameter and 50 mm long, the one of the end faces is coated with completely reflecting multilayer dielectric films, the other is partially reflecting (98%). The cylinder axis coincides with the optic axis of ruby (c-axis). The power supply of the laser is equipped with a 200μF oil condenser whose breakdown voltage is about 2000 volt. The electric input

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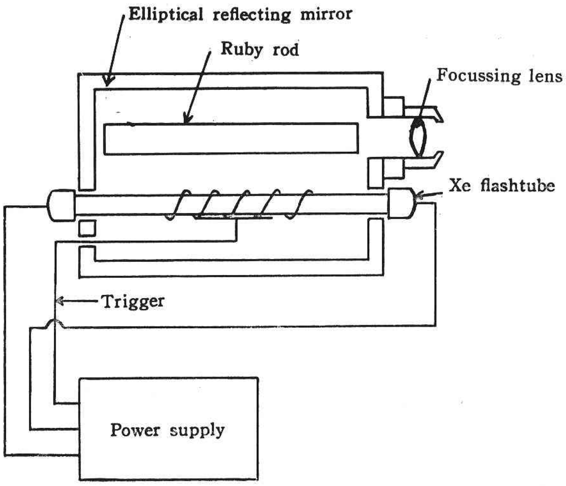


Fig. 1. Schematic diagram of ruby laser.

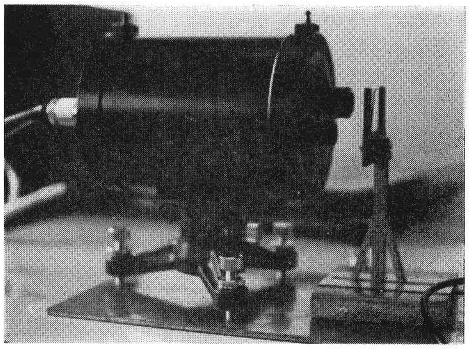


Photo. 1. Laser head.

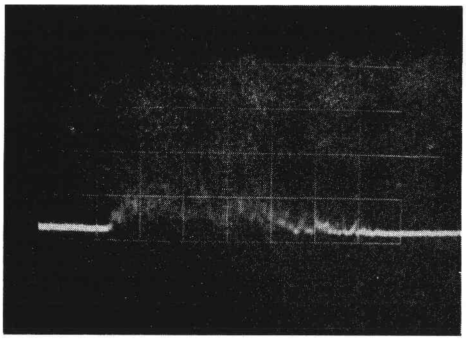


Photo. 2. Intensity of radiation from ruby versus time. 100μ sec/div. 200μ sec delay.

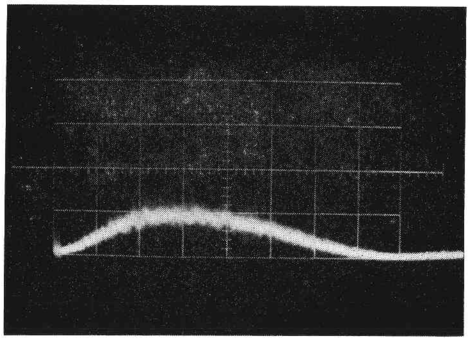


Photo. 3. Intensity of radiation from Xe flashlamp versus time. 200μ sec/div.

energy of flashlamp can be changed by changing the voltages applied to the condenser. The threshold energy of the laser used is about 170 joule. Photos. 2 and 3 show the traces of laser output and exciting radiation from the Xe tube respectively, which are measured by a photomultiplier (Toshiba 7305) and a synchroscope. As it is difficult to measure the accurate output energy of the laser, the detailed description of power measurement can not be included in this paper. The authors measured the output energy with a calorimeter* based on an electrical principle.

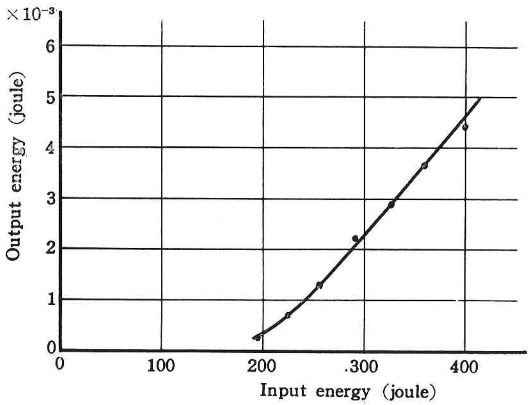


Fig. 2. Optical output versus electric input.

* To be published by the authors.

The result is shown in Fig. 2. It appears that the optical output of the laser increases linearly with the electrical input of the flash-lamp except the vicinity of the threshold.

3. Experimental results

When a material was irradiated with the beam of ruby laser, a part of radiation will be absorbed by the material, and converted into the thermal energy. Therefore, this energy can be used for processing of the material. While, the processing is influenced by the parameters, such as the total energy and energy density of laser output, the reflection coefficient, absorption coefficient, melting point and thermal conductivity of the material.

In the present experiment, an attempt was made to practise the processing of the films of various thickness of Al, Cu, Ge and Ni using the ruby laser mentioned above. All the specimens were prepared by vacuum evaporation on the slide glasses used for a microscope. Then, the thickness of each film was measured by an interference microscope (measuring range: 0.03—20μ). Every processing was carried out in air-atomosphere at room temperature.

(a) Effects of the distance between specimen and focussing lens:

In order to determine the position of focus, Ge film was irradiated with laser beam at various distances between the film and the focussing lens. The input energy of Xe flash-lamp is 400 joule in each case. These results are shown in Photo. 4. The values in this figure are the distances between the film and the front surface of the lens. It is found that the focal point is 25 mm apart from the front surface of the lens.

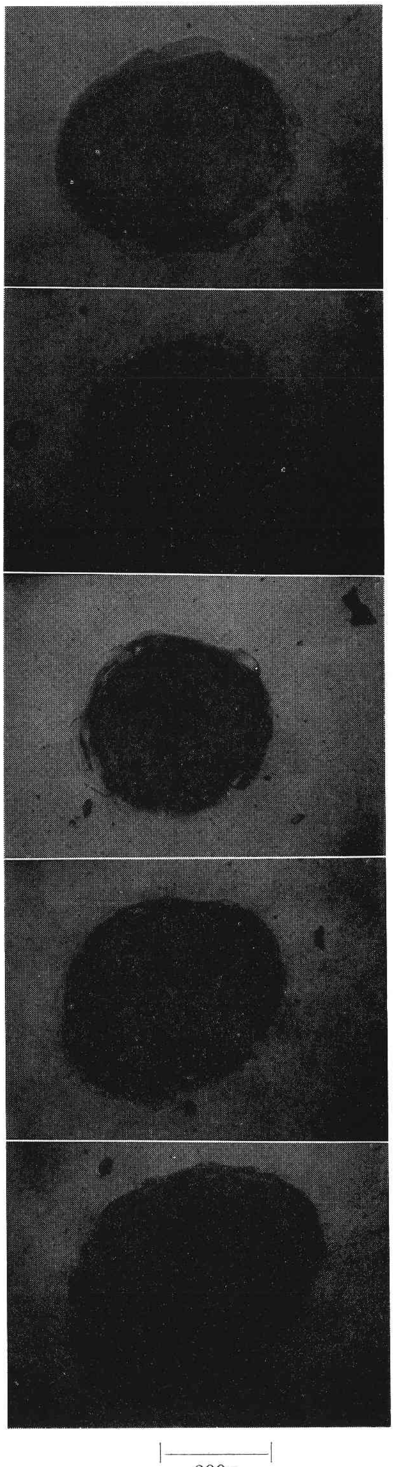
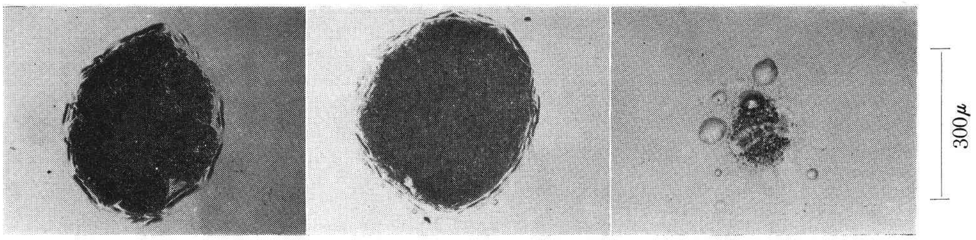


Photo. 4. Holes burned through Ge film in and out of focus.

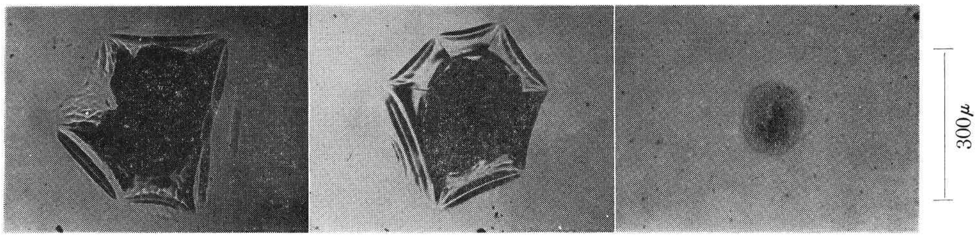
(b) Processing of the films of various thickness;

Photos. 5, 6, 7 and 8 show the photographs of Al, Cu, Ge and Ni films of various thickness respectively. It is observed that for Al and Cu films thicker than 0.5 and 0.7μ respectively, some traces of irradiation of the beam can be found, but no hole is observed. In the present case, the input energy of Xe flashlamp is 400 joule, and the distance between the specimen and the lens is 25 mm.



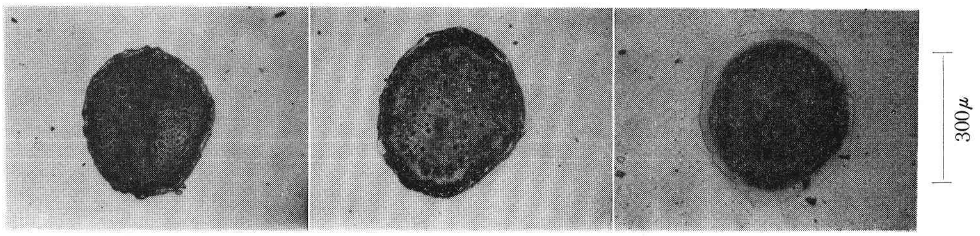
0.13μ 0.2μ 0.5μ

Photo. 5. Holes burned through Al films of various thickness.



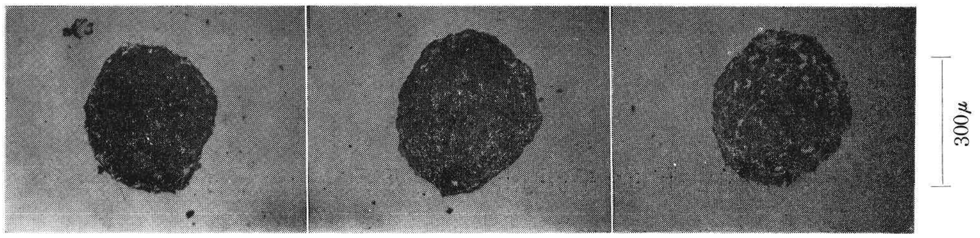
0.07μ 0.1μ 0.7μ

Photo. 6. Holes burned through Cu films of various thickness.



0.33μ 0.7μ 1.7μ

Photo. 7. Holes burned through Ge films of various thickness.



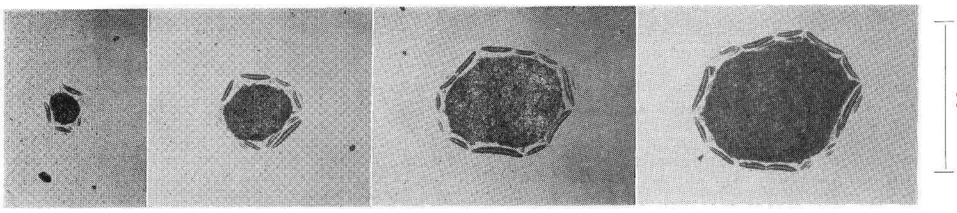
0.07μ 0.33μ 0.6μ

Photo. 8. Holes burned through Ni films of various thickness.

(c) Processing of the films at various input energy of Xe flashlamp:

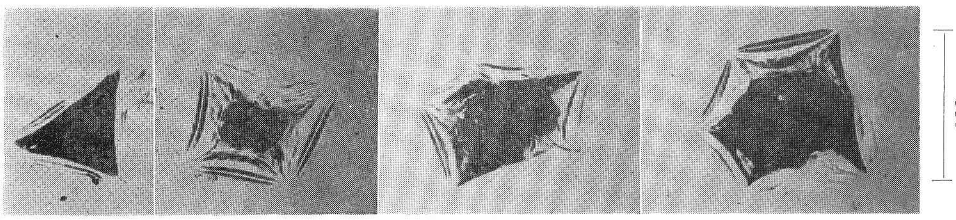
In Photos. 9, 10, 11 and 12, the photographs of the films processed at various input energy of Xe flashlamp are shown. The thickness of the films is equal for every specimen of the same element, and all the specimens were placed at the focal point in the experiments.

As the threshold energy of the laser used is found to be 170 joule. However, in the



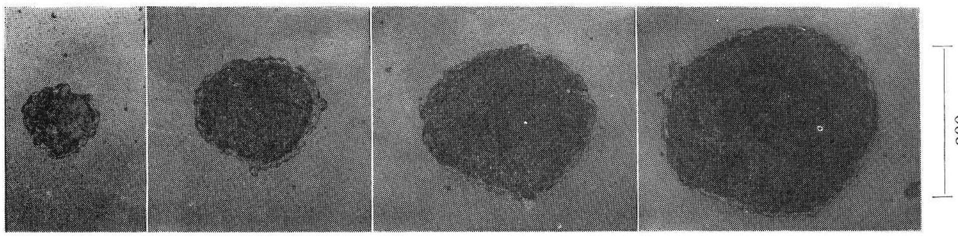
225 joule 270 joule 325 joule 400 joule

Photo. 9. Holes burned through Al films at various input energy.



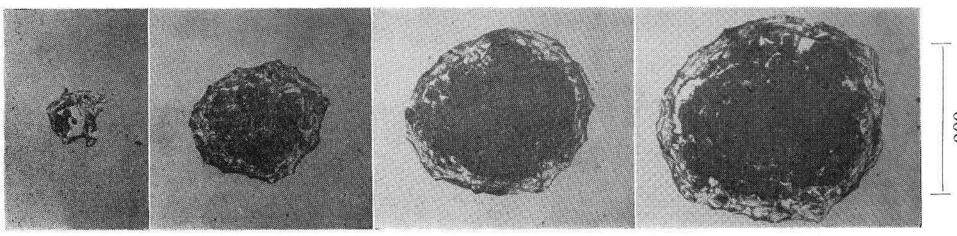
290 joule 325 joule 360 joule 400 joule

Photo 10. Holes burned through Cu films at various input energy.



170 joule 225 joule 290 joule 400 joule

Photo. 11. Holes burned through Ge films at various input energy.



170 joule 225 joule 290 joule 400 joule

Photo. 12. Holes burned through Ni films at various input energy.

cases of Al and Cu films, no hole was observed unless the input energy of Xe flashlamp is more than 225 and 290 joule respectively.

4. Discussions

Assuming that the ruby laser beam is perfectly parallel and the focussing lens whose focal distance is 30 mm has no spherical aberration, the diameter of the spot becomes 10μ owing to theoretical calculation. However, as shown in Photo. 4, the diameters of holes bored through the thin films are about 400μ in all cases. This fact shows that the rays of beam emitted from the ruby rod are not parallel but scatter pretty wide. Consequently, there is no remedy for the case but to use a focussing lens of short focal distance in order to achieve fine processing. According to Photos. 5, 6, 7 and 8, it is found that Ni and Ge are easy to process in comparison with Al and Cu. On the other hand, Ag film shows no marks indicating damages by irradiation of the beam. From these results, it is remarkable that the processing of metals with laser beam is more affected by reflection coefficient than melting point of material. Further, in such metals as Al and Cu which have high thermal conductivity the circumference of the hole becomes jagged by irradiation. This fault can be avoided, to a certain extent, by using the so-called giant pulse.[9)10)]

Table 1 shows the melting points, the reflection coefficients at the wavelengh of 0.7μ and the thermal conductivites of Al, Cu, Ge, Ni and Ag. The values of reflection coefficients shown in Table 1 are those of the metal films prepared on slide glasses and these values are, as is known, larger than those of the polished surface of the same metals. The smaller the input excitation energy becomes, the smaller the diameter of hole becomes. Up to this time, the effective method to control directly the output energy of laser beam has not yet been established. At present, a simple method to control the laser output is to change the input energy of Xe flashlamp.

Table. 1. Melting points, heat conductivities and reflection coefficients of metals used.

	Melting point (°C)	Heat conductivity (cal/cm sec deg)	Reflecting coefficient (%)
Al	659.8	0.545 (at 400°C)	89.9
Cu	1,084	0.844 (at 600°C)	97.5
Ge	973	0.150 (at 25°C)	—
Ni	1,455	0.146 (at 800°C)	68.8
Ag	960.5	0.867 (at 500°C)	98.5

From above experiments, it is found that the processing with ruby laser has various merits and faults. First, the merits are as follows: (1) The processing with ruby laser beam is very simple as compared with electron beam processing, because the vacuum apparatus is unnecessary for the former. (2) The materials in a transparent vessel can be worked through it. (3) Various insulators are easily worked by heat of the beam. Second, the faults are the followings: (1) When a focussing lens of short focal distance is used in order to minimize the damaged spot diameter, the depth of a focus of the lens becomes short. Consequently, it becomes difficult to adjust the position of samples in experiments. (2) When the beam is concentrated by focussing lens, the smallest diameter of the spot will be unable to decrease less than 100μ at the present situation, because it is determined by the focal distance of lens and the degree of coherency of laser beam. (3) The processing of materials with high reflection coefficient is hard. (4) At present, it is difficult to get high and continuous output energy. Although there are some faults described above as to the processing with ruby laser, it will afford promise of a wide application in future.

5. Conclusions

As mentioned above, the authors carried out some experiments on optical processing of metal with ruby laser. At present, it is technically very difficult to get the ruby laser which has large energy and narrow beam fit for practical purposes. The reasons for this seems due to the following facts. The efficiency of energy conversion between flashlamp and ruby is not so good and samples of good quality are not easy to get. Further, the rays of beam are rigidly not parallel each other, but spread pretty wide contrary to our expectation. The cause of this seems to depend on the internal crystal homogeneity of ruby and the existence of various modes of oscillations. Therefore, the investigations of the method of excitation, the development of new active materials, the control of various oscillation modes, the production of intense continuous waves and the like seem to be very important hereafter.

Acknowledgement

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