High power DUV lasers for material processing

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Abstract

A frontier in laser machining has been required by material processing in DUV region because it is hard to get high power solid-state lasers in this spectral region. DUV excimer lasers are the only solution, and now the time has come to examine the new applications of material processing with DUV excimer lasers. The excimer lasers at 193nm and 248nm have been used in the semiconductor manufacturing for long years, and have field-proven stability and reliability. The high photon energy of 6.4 eV at 193nm is expected to interact directly with the chemical bond of hard-machining materials, such as CFRP, diamond and tempered glasses. We report the latest results of material processing by 193nm high power DUV laser.

Keywords: excimer laser, 193nm, ArF laser, material processing, hard-machining material

1. INTRODUCTION

A laser under 200 nm wavelength can generate photons with high energy which exceeds that of a material's chemical bond. This fact introduces the possibility to a remarkable "1 photon energy process" which can cut the material with "a cold laser knife". Though there exist leading academic achievements, practical studies have not been enough in this field. The aim of this work is to establish the fundamentals of the cold processing with a 193nm laser.

The small heating process corresponds to the machining with high accuracy. In the usual laser machining, the laser energy is absorbed by a material, and turned to heat. In order to avoid the heating, two factors are important. One is the wavelength, and the other is the pulse duration. The short wavelength can generate high energy photons, which can cut the chemical bonding of the material directly. The short duration time is effective to avoid the excess heat generation. The laser we are going to develop is based on these two principles.

Recently, the progress of new materials is remarkable. It is often said, however, that the discrepancy between the new materials and the laser machining is found such as crack generation. Their wide band gaps require high energy photons, while the intense light source suitable for the machining didn't exist. Considering the gap energies, a 193nm laser has a good position to exceed the constraint.
As we have had much experience on ArF excimer lasers, a new challenge has now become possible to 193nm technologies. Nowadays, many attempts have been made to shorten the machining wavelengths. Using HHG, they are now as low as 266nm with the 4^{th}.harmonics of a YAG laser. But, 193nm is still far ahead.

The wavelength of 193nm of an ArF laser has two aspects at present. One is the output power. It is difficult to get high output power with solid-state lasers. The other is absolute energy. The photon energy of 193nm is bigger than the binding energy of hard-machining materials; such as SiC and diamond and tempered glass (Fig.1) [1]. The laser processing under 200nm has not been searched intensively, because we couldn't get good solid-state lasers in this wavelength region. This is the theme that we challenge this time with excimer lasers.

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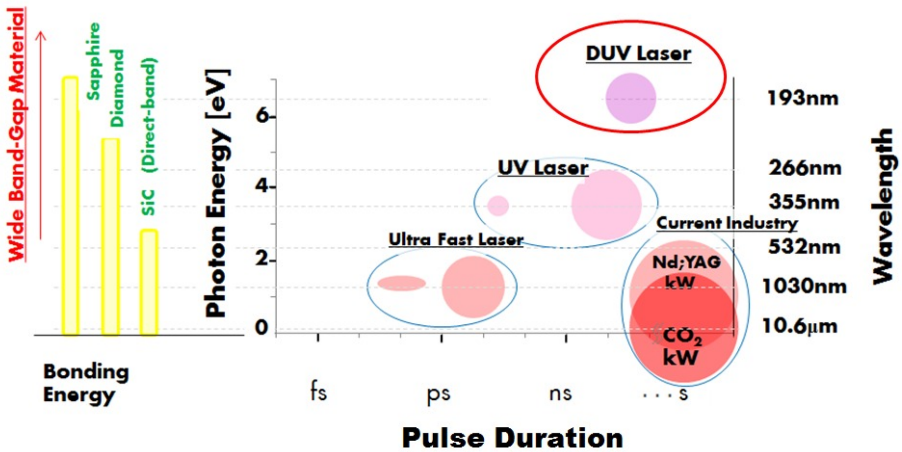


Figure 1. Laser Specifications vs. Material Bandgap

2. LASER PERFORMANCE

2.1 Experimental method and equipment

As a hard-machining material, we used tempered glass, which has large bandgap energy. In order to exclude the influence of heat, we adopted the low repetition rate of 10Hz. We used an ArF laser of 193nm as the main target, and took reference data with a KrF laser of 248nm. Both lasers have photon energies bigger than that of the bandgap, but the difference between them is worth investigating. The experiments were done in the atmospheric circumstances, considering the practicability of the processing. The evaluation criteria are the process quality and the rate dependence to the fluence.

Irradiation systems are prepared to both ArF and KrF excimer lasers. Figure 2 shows the optical layout. A slit is irradiated with an excimer laser, and is imaged on a sample. The intensity on the sample can be adjusted with a beam attenuator. It contains a CCD to monitor the operation of the system, and measurement sensors to check laser parameters.

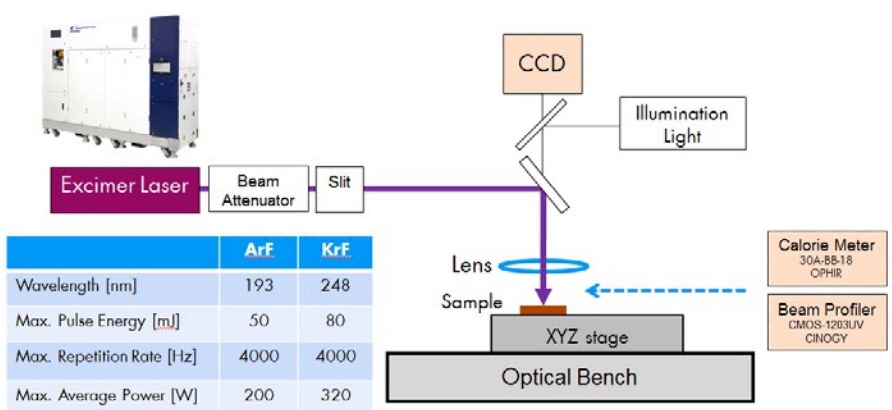


Figure 2. Laser Material Processing Equipment

Table 1 shows the experiment conditions. The aims of this presentation are to confirm the existence of short wavelength processing effects, and to find the special short wavelength effects to materials with an ArF and a KrF laser. In order to compare the results of both lasers, the experimental conditions are set similar.
We exposed samples at a low rate of 10Hz intentionally. 10Hz operation is easy to watch experiments, and can suppress thermal effects. The samples are pieces of tempered glass with thickness 300um.

Table 1. Processing Conditions

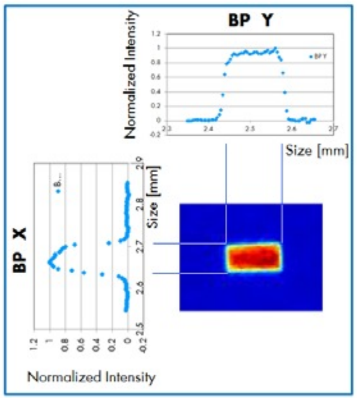
	ArF Excimer Laser	KrF Excimer Laser
Wavelength [nm]	193	248
Pulse Energy [mJ]	6~30	40~50
Repetition Rate [Hz]	10	10
Pulse Duration (FWHM) [ns]	10	20
Optics (Fixed Focal Length Lens)	f74	f78.2
Fluence [J/cm^2]	0~5	0~20
Irradiation Area [μm*μm]	140*95	160*80
Sample	Tempered Glass (Thickness: 0.3mm)	

Figure 3 shows our evaluation methods. We are observating by the laser microscope and the surface profiler.

	Material Processing Shape	
Equipment	Laser Microscope OLP4000 (OLYMPUS)	Surface Profiler Dektak 8 (Veeco)
Specification	Plane Resolution : <0.60μm	Plane Resolution : <0.51μm
	Depth Resolution : <0.05μm	Depth Resolution : <0.067μm
Photograph		

Figure 3. Evaluation methods

The intensity distribution of the irradiated area is shown in Figure 4. The irradiated area is a rectangle of about 80x150um^2, and its uniformity is around 10%.



Irradiation Area

	Wave -length [nm]	X [µm]	Y [µm]
ArF	193	95	140
KrF	248	80	160

Figure 4. Beam profile at the sample surface

2.2 Performance results

The exposed results with an ArF and a KrF excimer laser are shown in Figure 5. The advantage of the short wavelength of the ArF can be observed clearly in the photograph.

The 1st is the difference of the threshold energy density. The 2nd is the final shape of the processed pattern. In ArF, the rectangular shape on a tempered glass shows clear corners, and smooth surfaces.

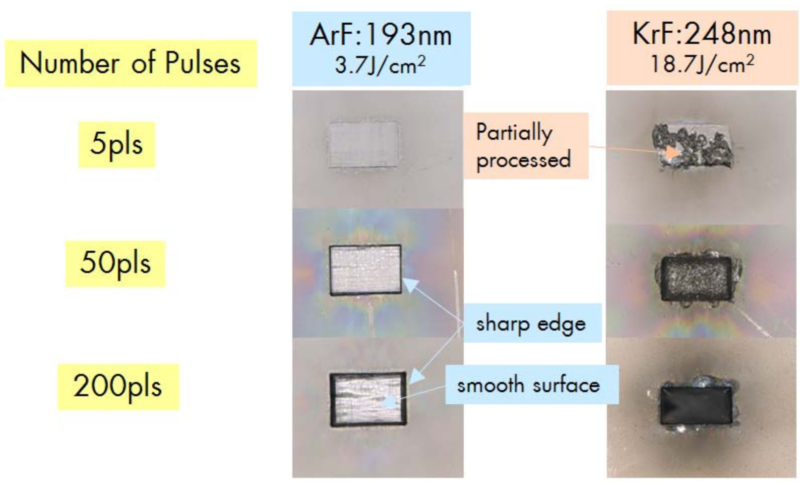


Figure 5. Surface morphology after irradiation

We measured the processed samples as shown in Figure 6. The depth of the processed sample is defined as the average. The granular surface in the KrF process gives rough edge profiles in KrF, whereas the smooth surface in the ArF creates clear edges.

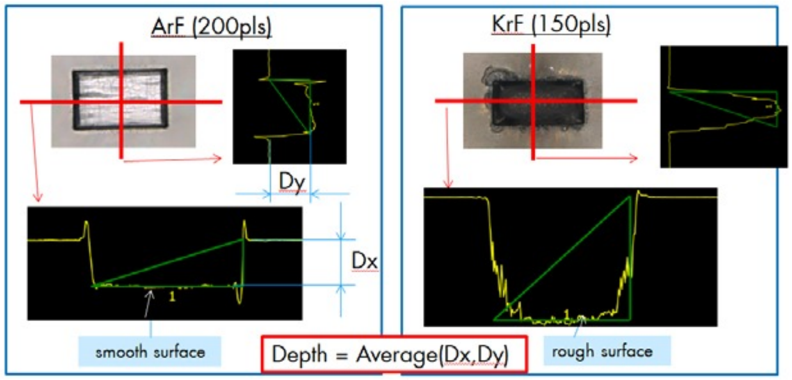


Figure 6. Depth profile of sample

We plotted the linearity of the laser processing as shown in Fig.7. The depth is proportional to the number of pulses. This demonstrates the practicability of the ArF laser processing.

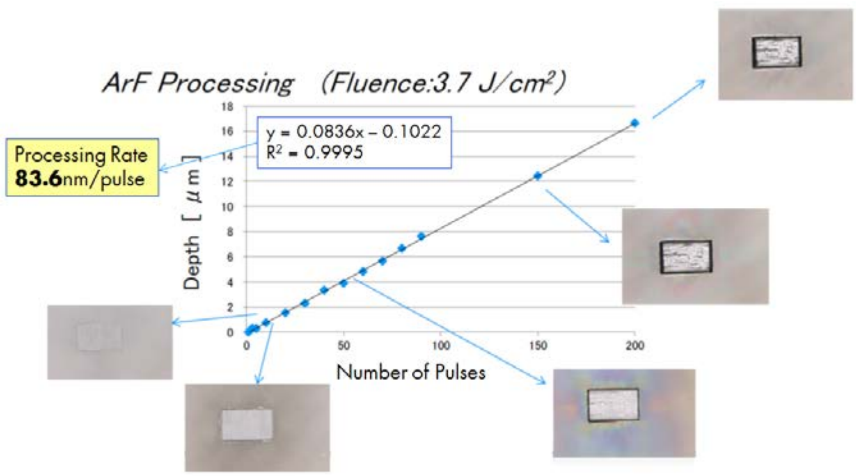


Figure 7. Processing rate measurement

The threshold energy of the process is noteworthy between the ArF and the KrF. It is 2J/cm^2 in the ArF as shown in Fig. 8, while 14J/cm^2 in the KrF. The ratio of these values exceeds that of the wavelength by far, and shows the superiority of 193nm. We are examining the cause of this difference including the internal structure of the sample material.

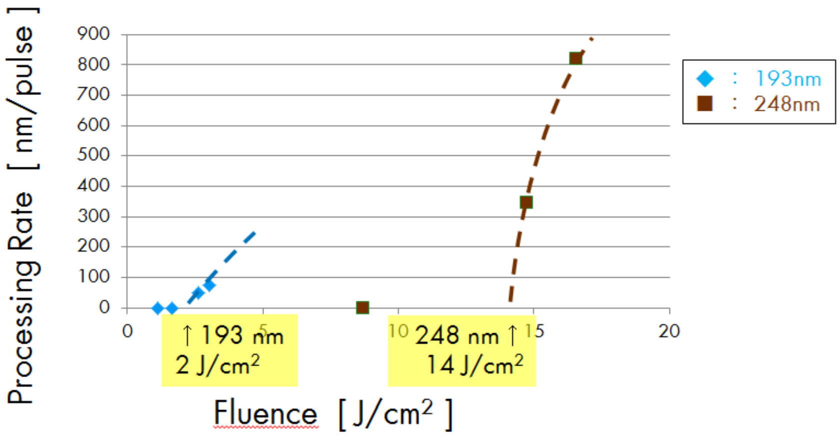


Figure 8. Processing threshold estimation

3. NEXT STEP

In the future, as the final project plan of the laser processing with ArF, we will investigate not only the application of a conventional ArF excimer laser, but also that of a new concept; a hybrid laser as shown in Figure 9 [2]. For a solid-state laser, it is difficult to make high output power in 193nm, but easy to get high coherence and short pulses. For an excimer laser, the power amplification ability is an advantage. The mixture of mutual advantages is the basic concept of the ArF hybrid laser. The solid-state laser generates a seed light, and the excimer takes charge of the power amplification. We have been developing the hybrid laser in parallel, and plan to apply it in the next stage. Our basic study of the ArF processing will be integrated with the wisdom of the hybrid.

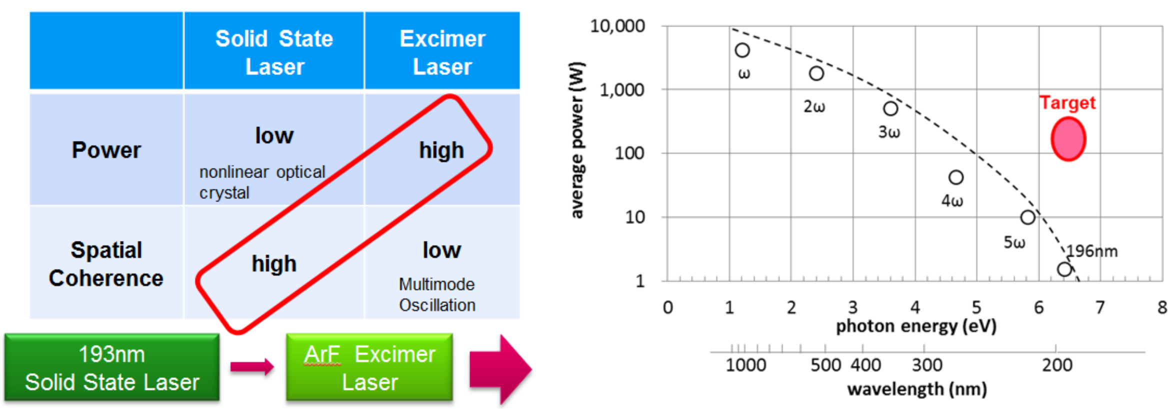


Figure 9. Concept of hybrid DUV laser in the future system

4. SUMMARY

We completed an experimental facility to search new UV light processing. The main target is to establish the ArF laser processing. We confirmed the superiority of the ArF over the KrF. The threshold energy and the surface roughness showed clear advantages with the tempered glass. For the next step, we are going to establish the practical process conditions. In the future, new possibilities with an ArF hybrid laser are to be searched with high coherence and extremely short pulse width.

5. ACKNOWLEDGEMENT

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