193 NM HIGH-POWER LASERS FOR DRILLING WITH HIGH ASPECT RATIO INTO WIDE BANDGAP MATERIALS

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Abstract

Laser machining is required for material processing in deep ultra violet region where the wavelength is less than 300 nm. However it is hard to get high power solid-state lasers in this spectral region. In this study, we investigated process capabilities with ArF and KrF excimer lasers to explore its possibilities for micromachining on wide bandgap materials. These results were observed with three types of microscopies. We have successfully drilled 100 micron meter holes with aspect ratio of 5 into a typical tempered glass sheet without any significant defects. As the ablation rate was quite affordable, excimer lasers are expected to be put into practical use for mass production.

Introduction

Laser machining is required for material processing in deep ultra violet (DUV) region where the wavelength is less than 300 nm. However it is hard to get high average power solid-state lasers in this spectral region, as shown in Figure 1 [1-4]. DUV excimer lasers are the only solution for high power and expected to be examined for new applications in material processing. In the DUV region, energy from a single photon can match the bond energy levels of various carbon compounds and band gaps of solid materials, enabling these compounds and solids to be processed directly by one or two photons as shown in Table 2. DUV light also has an advantage when it is used for making small patterns or holes on a material because it has a relatively smaller diffraction limit. Recently, drilling with a high aspect ratio into wide bandgap materials is required, such as a glass interposer. Considering the absorption spectrum of oxygen, ArF excimer laser has the shortest wavelength of 193 nm suitable for laser processing in air.

We have developed two types of 193 nm lasers. The first is an injection-locked ArF excimer laser of 120 W with an ultra-narrow spectrum below 0.3 pm [5]. The ArF excimer lasers at 193 nm as well as KrF excimer lasers at 248 nm have been used in semiconductor manufacturing for many years, and have field-proven stability and reliability. The second is an 193 nm "hybrid" laser, which is the combination of a solid-state laser oscillator and an excimer laser amplifier. High light-harvesting efficiency and high coherence of the hybrid laser has been achieved, which has M^2 value of 1.6, and an average power of 110 W with three-pass amplifications [6]. We have established an experimental facility to investigate material processing by high-power DUV lasers and started to evaluate ArF and KrF excimer lasers capabilities for glass materials.

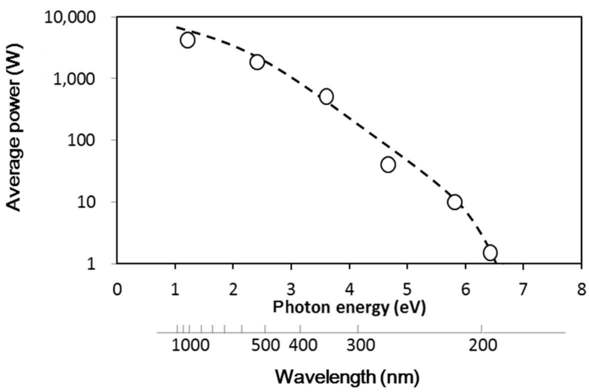

Figure 1 Average power of highly coherent high power lasers as a function of photon energy and wavelength.

Table 1 Photon number for wide bandgap materials

Material		Band Gap (eV)	193 nm 6.4 eV	266 nm 4.7 eV	1030 nm 1.2 eV
	SiC	3.24	1	1	3
	GaN	3.4	1	1	3
CFRP	C=C(π)	5.5	1	2	5
	Ga_2O_3	4.9-5.3	1	2	5
Diamond	Diamond	5.5	1	2	5
	SiO_2	5.8	1	2	5
	cBN	6.2	1	2	6
	AlN	6.0-6.3	1	2	6
Glass	Al_2O_3/SiO_2	5.8-8.4	1-2	2	8
	Sapphire	7.0-8.4	2	2	8

Experimental Setup

Figure 2 shows our test stand to measure the ablation rate and drill a through via hole. We used Gigaphoton's excimer lasers, both KrF and ArF. The major laser specifications are in Table 2. In order to remove thermal effects, we mainly adopted a low repetition rate of 100 Hz for the ablation rate measurement. The experiments were done in atmosphere, under the same conditions as in practical use. We have evaluated it based on balances between its processing quality and irradiated fluence. The irradiated fluence was adjusted by an internal laser pulse energy control system and an external optical attenuator. The beam shape was formed by a mask and a reduction ratio which was adjusted by lens. We used a CCD camera to monitor system operations, and a calorie meter and a beam profiler to check laser parameters. Figure 3 shows methods to measure via hole size and depth profile by three types of microscope which are an optical type (BX35: OLYMPUS), a laser type (OLP4000: OLYMPUS) and a scanning electron type (SEM, SU3500: HITACHI, JCM-6000: JEOL).

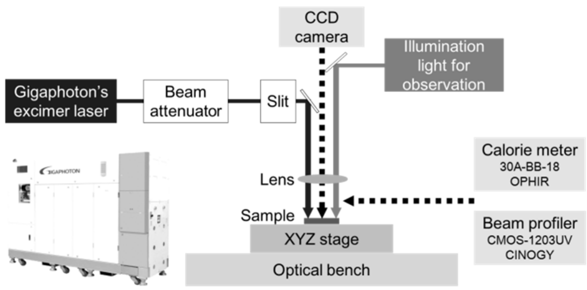

Figure 2 Laser material processing test stand

	ArF Excimer Laser	KrF Excimer Laser
Wavelength (nm)	193	248
Pulse Energy (mJ)	6 – 30	40 – 50
Repetition Rate (Hz)	10 – 4000	10 – 4000
Pulse Duration (FWHM) (ns)	10	20

Table 2 Specifications of ArF and KrF excimer lasers

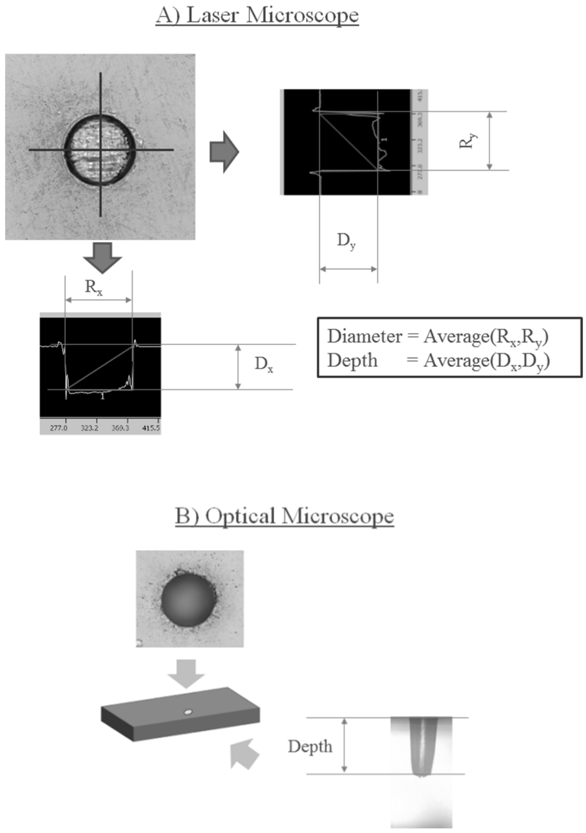

Figure 3 Via hole size and depth measurement

Experimental Result

We have chosen the tempered glass, Eagle Slim XG: Coring which is a popular interposer material. Laser beam profiles that are used in the experiment are shown in Figure 4. The beam spot size is about 100 µm, which is the target via hole size for the glass interposer.

Ablation rate and Appearance

We measured the relationship between laser fluence and ablation rate. The test was carried out in laser fluence from 1 to 10 J/cm^2 on ArF and from 9 to 24 J/cm^2 on KrF. The threshold energy of the process is noteworthy between the ArF and the KrF. It is 2 J/cm^2 on ArF as shown in Figure 5, while 14 J/cm^2 on KrF. The ratio of these values exceeds that of the wavelength by far, and shows the superiority of 193 nm [7]. The ablation rate was measured by dividing hole depth by number of irradiated laser pulses. The hole depth was measured by laser microscope. As a result, we obtained a rate of 130 nm/pls on ArF and 1150 nm/pls on KrF as maximum rate in this experiment, as shown in Figure 5. Two types of optical reduction rates were carried out but the results obtained were almost the same. Appearance of processed results by an ArF and a KrF excimer lasers are shown in Figure 6. It was measured by SEM and showed results from 5 pulses to about 60 μm depth. The laser fluence was 7.0 J/cm^2 on ArF and 19.4 J/cm^2 on KrF. There is a clear difference between both results; it is smooth on ArF, while it is rough on KrF.

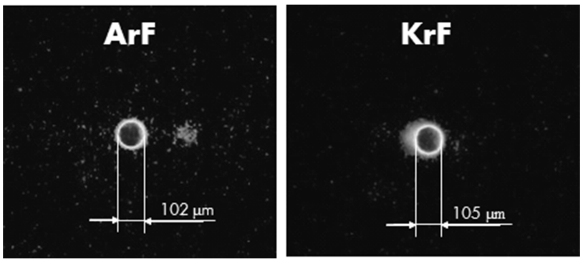

Figure 4. Laser beam prifile for glass processing

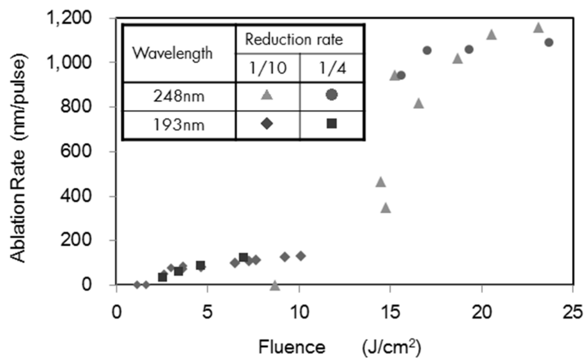

Figure 5 Ablation rate measurement on ArF and KrF excimer lasers

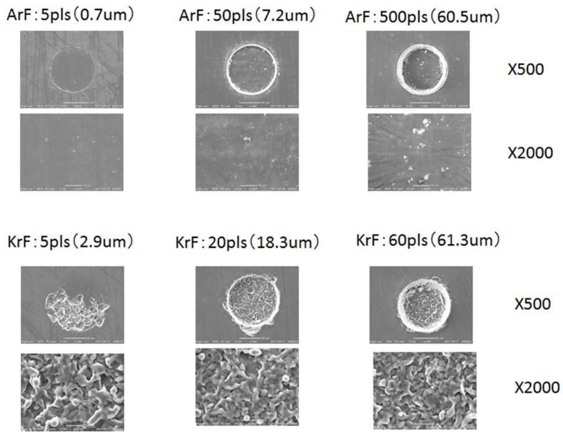

Figure 6 Appearance of processed results on ArF and KrF excimer lasers

Drilling with High aspect ratio into Tempered glass

For the glass interposer, a high aspect ratio hole is required. We tried to drill a through via hole into the tempered glass which is 500 μm thick. We used the following setup. Laser: ArF and KrF excimer lasers, Repetition rate: 100 Hz, Pulse duration: 20 ns, Fluence: 5.5 J/cm^2 on ArF, 13 J/cm^2 on KrF. We observed the ablation process pulse by pulse until via holes appeared through the glass sheet. Side view of via holes was measured by optical microscope, as shown in Figure 7 by ArF excimer laser and Figure 8 by KrF excimer laser respectively. It was found that we made holes of 100 μm in diameter and aspect ratio of 5 without any significant cracks

Next, taper angle rate of via holes was calculated by dividing bottom diameter by upper diameter. As a result, we obtained a rate of 55% at 4500 pulses on ArF excimer laser and 48% at 2000 pulses on KrF excimer laser in this experiment. Then we measured via hole depth from Figure7 and Figure 8. The via hole depth versus laser pulses were shown in Figure 9 by ArF and Figure 10 by KrF excimer lasers respectively. The ablation rate of ArF and KrF lasers are 120 nm/pulse at fluence 5.5 J/cm^2 and 300 nm/pulse at fluence 13.0 J/cm^2 respectively.

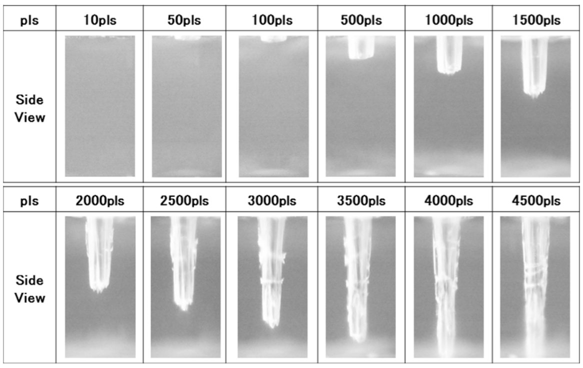

Figure 7 Side view of via holes into tempered glass by ArF excimer laser (Corning Eagle Slim XG, 500 μm thick)

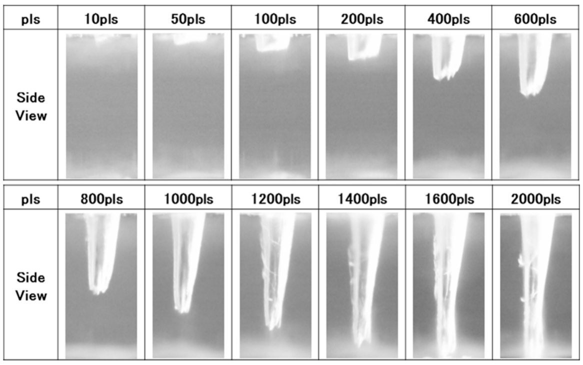

Figure 8 Side view of via holes into tempered glass by KrF excimer laser (Corning Eagle Slim XG, 500 μm thick)

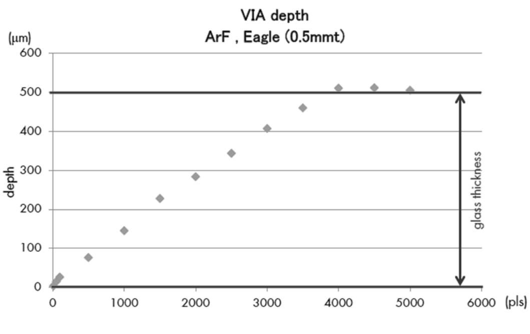

Figure 9 Ablation rate of glass on ArF excimer laser, repetition rate: 100 Hz, Fluence: 5.5 J/cm^2

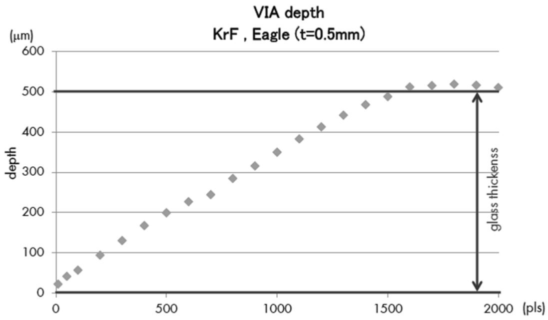

Figure 10 Ablation rate of glass by KrF laser, repetition rate: 100 Hz, Fluence: 13.0 J/cm^2

Summary

We have made holes of 100 μm in diameter and aspect ratio of 5 without any significant cracks into the tempered glass. It shows ArF and KrF excimer lasers are applicable for glass interposer processing. This result shows DUV excimer laser has great potential to be a useful tool for the glass interposer application in future generations. Because DUV excimer lasers are able to also easily deliver higher power even greater than an average power of 100 W.

Next Steps

The 193 nm “hybrid” laser is the combination of a solid-state laser oscillator and an excimer laser amplifier. It is able to realize a high fluence and small diameter beam. Therefore we will drill higher aspect ratio holes, for example more than 10, into various wide band gap materials.

Acknowledgement

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References

[1] V. Kuhn, T. Gottwald, C. Stolzenburg, S. Schad, A. Killi & T. Ryba (2015) Latest advances in high brightness disk lasers, Proc. SPIE 9342, 93420Y.

[2] M. Nishioka, S. Fukumoto, F. Kawamura, M. Yoshimura, Y. Mori & T. Sasaki (2003) Improvement of laser-induced damage tolerance in $CsLiB_6O_{10}$ for high-power UV laser source, Tech. Dig. CLEO CTuF2.

[3] T. Katsura, T. Kojima, M. Kurosawa, J. Nishimae, M. Sekiguchi, K. Yasui, M. Yoshimura, T. Eiro & T. Sasaki (2007) High-power, high-repetition UV beam generation with an all-solid-state laser, Tech. Dig. CLEO/Europe CA5.3

[4] J. Sakuma, K. Deki, A. Finch, Y. Ohsako & T. Yokota (2000) All-solid-state, high-power, deep-UV laser system based on cascaded sum-frequency mixing in $CsLiB_6O_{10}$ crystals, Appl. Opt. 39, 5505.

[5] K. Ishida, T. Ohta, H. Miyamoto, T.Kumazaki, H. Tsushima, A. Kurosu, T. Matsunaga & H. Mizoguchi (2016) The ArF laser for the next generation multiple-patterning immersion lithography supporting green operations, Proc. SPIE 9780, 9780-10.

[6] S. Tanaka, M. Arakawa, A. Fuchimukai, Y. Sasaki, T. Onose, Y. Kamba, H. Igarashi, C. Qu, M. Tamiya, H. Oizumi, S. Ito, K. Kakizaki, H. Xuan, Z. Zhao, Y. Kobayashi & H. Mizoguchi (2016) Development of high coherence high power 193 nm laser, Proc. SPIE 9726, 66.

[7] J. Ihlemann & B. Wolff-Rottke (1996) Excimer laser micro machining of inorganic dielectrics, Applied Surface Science 106**,** 282.

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