Scribing and cutting a sapphire wafer by laser-induced plasma-assisted ablation

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Transparent and hard materials such as sapphire are used for many industrial applications as optical windows, hard materials on mechanical contact against abrasion, and substrate materials for opto-electronic semiconductor devices such as blue LED and blue LD etc. The materials should be cut along the proper shapes possible to be used for each application. In case of blue LED, the blue LED wafer should be cut to thousands of blue LED pieces at the final stage of the manufacturing process. The process of cutting the wafer is usually divided into two steps. The wafer is scribed along the proper shapes in the first step. It is inserted between transparent flexible sheets for easy handling. And then, it is broken and split in the next step. Harder materials such as diamonds are usually used to scribe the wafer, while it has a problem of low depth of scribing and abrasion of the harder material itself. The low depth of scribing can induce failure in breaking the wafer along the scribed line. It was also known that the expensive diamond tip should be replaced frequently for the abrasion.

Many kinds of lasers which are absorbed well in materials are directly used in micro machining of the materials with the merits of fine accuracy and easy control of shape to cut. It may be possible to use a CO_2 laser in machining of sapphire material for some applications since it is absorbed well in sapphire, too. But it is hard to use a CO_2 laser in scribing blue LED wafer since CO_2 laser machining accompanies a lot of heat by the absorption of laser beam in the material. The device can be easily damaged by the heat while scribed and it's very hard to be scribed so accurately and finely with CO_2 laser as with Nd:YAG laser because of the long wavelength of CO_2 laser. Most of the dielectric materials are known to be ablated with ultra-short pulse laser regardless of the wavelength of it. But ultra-fast high power laser has many difficulties for practical use such as high photon cost, large size and short of reliability until now. So, it is still hard to apply ultra-short pulse laser to the scribing of blue LED wafer in the manufacturing process.

In this way, there's difficulty in using laser directly for the scribing of blue LED wafer in the manufacturing process. Another way of using laser in material processing is to use not only the laser but also the other assistant way together. An example is the laser-induced plasma-assisted ablation(LIPAA) method. The method is an efficient way in machining of transparent hard materials. It can be applied to the machining of transparent material since the material is machined by plasma induced by laser not by the laser itself. LIPAA was applied for the fabrication of microgratings and hole drilling in fused quartz using KrF excimer laser, second harmonic Nd:YAG laser and fourth harmonic Nd:YAG laser while the target is located in a vacuum chamber.

Here, we demonstrated that sapphire wafer can be scribed and cut freely using the method, LIPAA, with a q-switched fundamental Nd:YAG laser. The wafer is scribed by plasma generated from metal surface, on which a q-switched Nd:YAG laser beam is focused through the wafer. It was experimented at atmospheric environment without a vacuum chamber while the previous experiments were done in a vacuum chamber. LIPAA is successfully applied to the manufacturing process of commercial blue LED by splitting each device from a blue LED wafer, including about ten thousand blue LED devices. It is the first application of LIPAA, in my knowledge, to the manufacturing process of commercial opto-electronic device.

A diode-pumped solid-state Nd:YAG laser(Model DPY-S20IR), made by ourselves(LGIS), is used for the experiment. The wavelength of laser is 1.064 m and it is q-switched with an acousto-optic q-switch within the oscillator. The maximum output power of the laser is 20 W at cw operation. We used beam scanning method in scribing by composing an optical scanning system. It is composed with a f-theta lens and two sets of a mirror mounted on a galvanometer. The shape of scribing is controlled by adjusting the incident angle of the laser beam using the optical scanner.