Femtosecond laser processing on hard-to-process materials and its application to CMP process

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論 文 名　：Femtosecond laser processing on hard-to-process materials and its application to CMP process
（フェムト秒レーザによる難加工材料加工及び CMP への応用）

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論 文 内 容 の 要 旨

This dissertation mainly presents the research of femtosecond laser processing on hard-to-process materials and its application to CMP process. SiC, Diamond, and Sapphire are regarded as the next generation power device substrate due to their outstanding properties, such as excellent thermal conductivity, high resistance to radiation, high energy-saving efficiency, high breakdown voltage of insulation destruction, and larger band gap than other semiconductor materials. These materials will have vast application prospect in solar cell, car, large-scale integrated circuit, mainboard, and smart phone, regarding applications of small-sized, high efficiency, low loss power, and low power consumption. However, owning to high Mohs hardness and high chemical stability, these materials are quite difficult to be processed.

Femtosecond laser process is considered as an invaluable machining tool for material functionalization, owing to its significant characteristics, such as extremely short pulse duration, high pulse repetition frequency and high fluence.

In this study, femtosecond laser was implemented to SiC and Diamond substrates for surface micromachining, to Sapphire for internal dicing process. Finally, CMP process was carried out to investigate the polishing properties of laser-irradiated SiC substrates.

Chapter 1 introduces the developments as well as applications of semiconductor materials and femtosecond laser. The present research status of surface machining of femtosecond laser was introduced. The present problems in CMP process and the solutions to solve the present problems as well as the research objectives were introduced.

In chapter 2, the author firstly elaborated the evolution of surface morphologies of semiconductor material SiC substrate after laser irradiation at single point, single line and plane irradiation patterns. The author further demonstrated that the ripples distribution was irrelevant to laser scanning direction and SiC crystal direction. Furthermore, the author carried out experiments at series of femtosecond laser process parameters such as different scanning pitches, different scanning velocities, different repetition rates and different fluences to investigate the surface morphology changes of SiC. The uniformity of these large-area LIPSS (Laser Induced Periodic Surface Structures) was also discussed. Uniform surface was fabricated at irradiation conditions at v=100mm/s, pitch=0.5um, and repetition rate=500 kHZ. Different overlapped areas of adjacent laser pulses resulted in different energy accumulation as well as affected the interference of incident laser beam and scattered light, which were considered the main reasons for different surface morphologies. It was found that the ripples were fabricated into new ripples after different irradiation mode.

It should be noted that laser-induced debris after transverse irradiation model process played an important role in the surface formation. Femtosecond laser irradiation at near-threshold fluence on 4H-SiC surface was also investigated. Discontinuous laser-ablated areas were observed, which was attributed to the different energy accumulation deposition caused by incubation effect.

Chapter 3 elaborated the polishing properties of laser-irradiated SiC substrate. For Si-face, it was found that the oxidized areas were easier to be polished, whereas no obvious changes were found at the non-ablated areas on Si-face. By this, the author further investigated the effect of laser irradiation for C-face at different mode. It was found that better surface and higher material removal rate (MRR) of laser-irradiated substrate than that of non-irradiated substrate were realized in the experiment. The MRR of transverse irradiation model is 27 nm/min, which is about 3 times higher than that of non-irradiated substrate. The MRR of cross-scan irradiation model is 16nm/min, smaller than that of transverse irradiation model but have much better surface roughness. Reasonable combination of femtosecond laser parameters will be clearly found for higher polishing efficiency and higher surface planarization in the future studies. X-ray diffraction (XRD) and X-ray Photoelectron Spectroscopy (XPS) was further employed for illuminating the mechanism of femtosecond laser process of SiC. The poor crystallinity and being easily oxidized in colloidal SiO2 slurry of the laser-induced ripple structures as well amorphous layer were considered to improved CMP process for SiC substrate.

In Chapter 4, single crystal diamond substrate was irradiated by femtosecond laser at different output powers. TEM observation and Raman spectral analysis indicate that laser-irradiated diamond surface was changed to be a structure mixed with amorphous and regularly-structured diamond. Quasi-radical site with a depth of about 10nm was formed in the subsurface of Diamond substrate.

Chapter 5 presented new method for dicing process for semiconductor materials due to femtosecond laser. The internal processes of femtosecond laser for semiconductor materials Si, sapphire, and SiC were introduced by investigating the defects of their cross sections. Different phenomena of internal absorption type process as well as the reasons were discussed.

In Chapter 6, the main highlights of this study was summarized, and then proposed the future works involving surface morphology formation as well as dicing process.