OBSERVATION OF HIGH HARMONIC GENERATION FROM 6H-SiC IRRADIATED BY MIR-FEL

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Abstract

SiC is attractive as a high power nonlinear optical device [1]. For verifying the possibility of a high harmonic generation from a SiC irradiated by MIR-FEL, we observed the emission from a SiC irradiated by MIR-FEL whose center wavelength was 12 μm. Two measurements observing the second harmonic generation (SHG) and high harmonic generation (HHG) were conducted. As the result, we clearly observed the SHG whose intensity was proportional to the square of MIR-FEL intensity. And emissions corresponding to the wavelength of the high harmonics (9th, 10th, and 11th) of the irradiated MIR-FEL (7.8 μm and 8.6 μm) were observed.

INTRODUCTION

Wide-gap semiconductors such as SiC, ZnO are great interest as they represent the next generation materials for power devices and photocatalyst materials. In addition, SiC and ZnO were attractive as nonlinear optical devices [2, 3]. ZnO is considered as the candidate of the thin film nonlinear optical device because ZnO has a high nonlinear optical susceptibility and an easiness of thin film fabrication [2]. Moreover, SiC has a high nonlinear optical susceptibility as well as a high resistance to the laser induced damage. Therefore, SiC is considered as a candidate of the high power nonlinear optical devices.

In 2010, the high harmonics over 20th from solid material was observed for the first time by using ZnO single crystal [3]. However, in the case of SiC, the harmonics up to only second has been observed by irradiation of Nd-YAG laser [1, 4]. For the development of the high power nonlinear optical devices, verification of the high harmonic generation from SiC is important. Our objective of this paper is to present the observation of the high harmonics from SiC.

For generating the harmonics from nonlinear optical devices, high power laser is essential. FEL is suitable as a light source because the feature of FEL is high power. However, harmonic generation from SiC by using FEL has not been reported. Therefore, at first, we verified the SHG from a SiC irradiated by MIR-FEL. As the next step, we verified the HHG from SiC.

EXPERIMENTAL SET UP

For the verification and observation of the HHG from SiC, two experiments were made; one is the measurement of SHG and the other is the measurement of HHG. The experiments were performed in the atmosphere. SiC (semi-insulator 6H-SiC: Xlamen Powerway Advanced Material Co.,LTD) was used. The size was 15 mm × 15 mm × 0.33 mm. The picture of the used SiC is shown in Fig. 1.

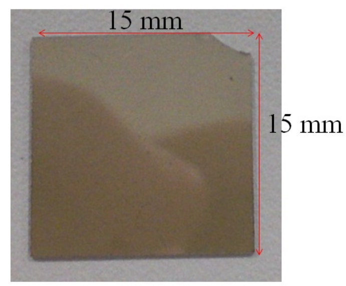

Figure 1: The picture of the used SiC.

The measurement setup for the verification of the SHG was shown in Fig.2. KU-FEL (Kyoto University Free Electron Laser) was used as the laser source. The specification of KU-FEL is reported in the reference [5]. For preventing the 2nd and 3rd harmonics inherently generated by the FEL, the long pass filter (cut-off wavelength of 9 μm, LP-9000 nm, SPECTROGON) was used. In addition, the short pass filter (cut-off wavelength of 7 μm, SP-7150 nm, SPECTROGON) was used to block the fundamental at the wavelength of 12 μm. A Mercury Cadmium Telluride (HgCdTe, MCT) detector (J15D12-M204-S01M-60, Judson Technologies) was used for the detection of the second harmonic light. Moreover, to measure the intensity of the irradiated FEL, a Mercury Cadmium Zinc Telluride (HgCdZnTe, MCZT) detector (VIGO SYSTEM R005-3) was used. Confirmation of the SHG was done by observing the reflected light from SiC. The MIR-FEL whose wavelength was 12 μm was irradiated to SiC. The repetition rate of the FEL was 1 Hz. The macro-pulse energy of FEL was around 2 mJ whose macro-pulse duration was 2 μs.

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ISBN 978-3-95450-123-6

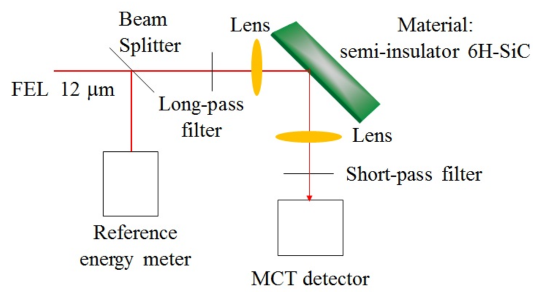

Figure 2: Measurement setup for verification of the SHG.

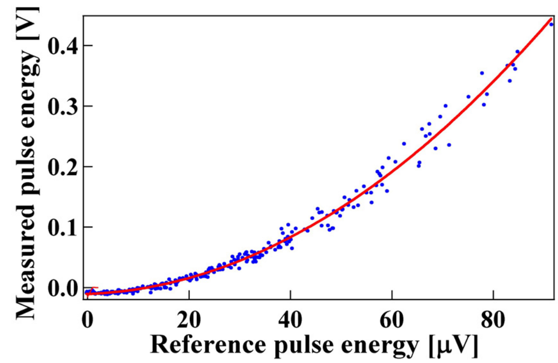

Figure 4: Intensity dependence of the observed emission.

Next, we performed the experiment for verification of the HHG. The measurement setup is shown in Fig. 3. For the observation of the HHG, a high intensity of fundamental is preferable. Therefore, the wavelength of MIR-FEL was tuned to 7.8 µm for the verification of HHG because we confirmed that the intensity of MIR-FEL of the 7.8 µm was the higher than that of the 12 µm in KU-FEL. The emission from SiC was gathered to the optical fiber by focusing mirrors. The light in the optical fiber was transported to the spectrometer (Zolix Omni-λ, 300). The grating of 300 l/mm in the spectrometer was used. The resolution of the spectrometer was 2 nm (FWHM). Finally, the light was detected by an electrically cooled CCD array (INTEVAC Mosir 350). The CCD array was triggered by the master trigger of KU-FEL for synchronizing the timing between MIR-FEL irradiation and acquisition by the CCD array. The exposure time on CCD array was 10 ms, and the observed spectrum was averaged with the spectra of 200 shots. The repetition rate of the FEL was 1 Hz. The maximum macro-pulse energy was 4 mJ whose macro-pulse duration was 2 µm.

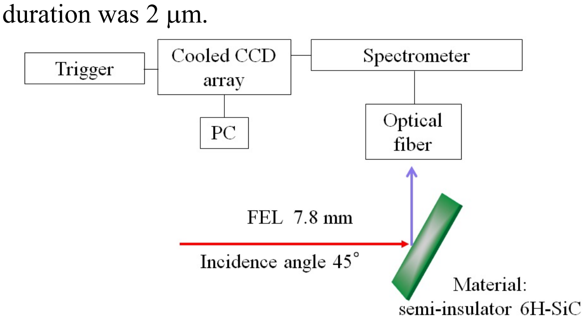

Figure 3: Measurement setup of HHG from SiC.

VERIFICATION OF SHG FROM SiC

The result of the observation of the SHG from SiC is shown in Fig. 4. It was reported the intensity of SHG from SiC was proportional to the square of the intensity of fundamental [1]. Therefore, we did the fitting with quadratic function to the observed points. The red line in Fig.4 is the fitting curve. From this result, we confirmed the SHG from SiC irradiated by MIR-FEL.

VERIFICATION OF HHG FROM SiC

Next, the result of the observation of HHG from SiC is shown in Fig. 5. In this experiment, we observed the emissions at those central energies of 1.29, 1.44 and 1.60 eV. Those energies correspond to the 9th, 10th and 11th harmonics of incident FEL (0.159 eV, 7.8 µm).

In order to investigate the emissions, following experiments were performed.

Confirmation of the Origin of the Emission

For confirming the origin of the emissions, we covered SiC with aluminium film whose thickness was 12 µm. Then, the harmonics included in the FEL it self were measured by the same spectrometer. The wavelength of irradiated MIR-FEL was 7.8 µm. The result is shown as the blue line in Fig. 5 and no peaks were observed in this experiment. From this result, we confirmed the irradiation of MIR-FEL to SiC was essential to obtain the spectrum shown as the red line in Fig. 5.

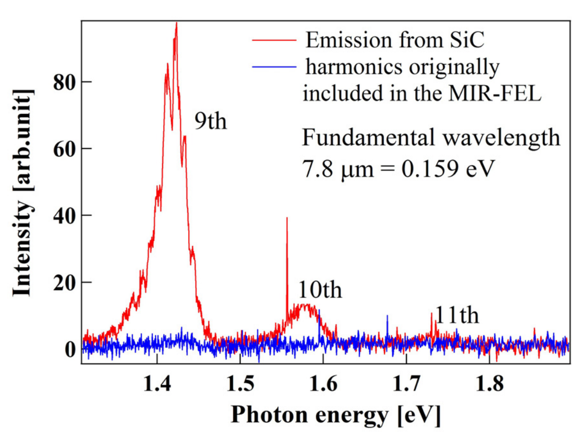

Fig 5: Emission from SiC and harmonics originally included in the MIR-FEL.

Confirmation of HHG

For confirming that the emissions observed in previous section were HHG from SiC irradiated by MIR-FEL, we performed the experiment with different wavelength of

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MIR-FEL. The wavelength of MIR-FEL was tuned to 8.6 μm for that purpose. The result is shown in Fig. 6. In this experiment, the emissions having the central energy of 1.34, 1.46, and 1.61 eV were observed. Those energies corresponded to the energies of 9th, 10th, and 11th harmonics of fundamental (0.144 eV: 8.6 μm). From these experiments, we confirmed the observed emissions in Fig. 5 and Fig. 6 from SiC irradiated by MIR-FEL were HHG (9th, 10th, and 11th).

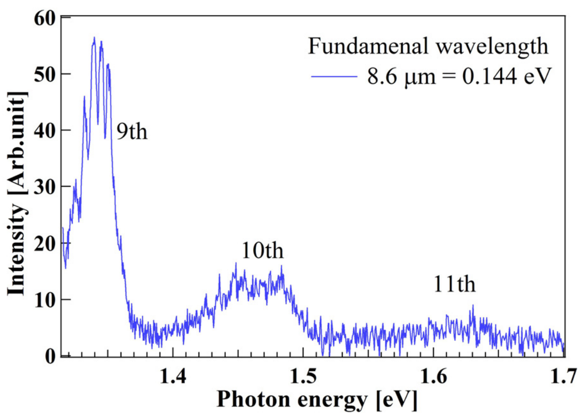

Figure 6: Spectra of the emissions from SiC irradiated by MIR-FEL whose wavelength was 8.6 μm.

CONCLUSION AND FUTURE WORK

We observed a second harmonic light from 6H-SiC irradiated by MIR-FEL. In addition, HHG up to 11th harmonics from 6H-SiC irradiated by MIR-FEL were observed.

As the next step, we will measure the intensity of the high harmonics as a function of MIR-FEL intensity for deep understanding of the mechanism of harmonic generation from SiC irradiated by MIR-FEL.

ACKNOWLEDGMENT

This work was partly supported by an "Energy Science in the Age of Global Warming" of Global Center of Excellence (G-COE) program (J-051) and by the Grant-in-Aid for Scientific Research #2165017 of the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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ISBN 978-3-95450-123-6