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E-2-5

Accurate Measurement of Nonlinear Optical Coeffcients of 6H Silicon Carbide by Rotational Maker-Fringe Technique

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1. Introduction

Silicon carbide (SiC) is a widegap semiconductor transparent from ultraviolet to infrared wavelength regions. High thermal conductivity and wide transparency range of SiC will allow us to utilize SiC as a material of high-power and highly effcient wavelength conversion devices. Although some experimental data on the magnitude of quadratic nonlinear optical coeffcients of SiC have been reported [1, 2, 3], their accuracies seem to be quite low mainly because of low crystal qualities of samples used in the measurements. In this decade, however, crystalline qualities of bulk SiC crystals have been significantly improved, and high quality large size wafers are now commercially available. In this paper, we report Maker-fringe measurements on high-quality plane-parallel plates of 6H-SiC and accurate determination of nonlinear optical coeffcients taking account of multiple reflection effects.

2. Experiment

We have performed rotational Maker-fringe experiments on 6H-SiC plates in order to deternine the nonlinear optical coefficients of 6H-SiC. We used two plane-parallel plates of high-purity semi-insulating 6H-SiC. One sample was a $(000\bar{1})$ plate with a thickness of $L = 380\ \mu$m and another was a $(11\bar{2}0)$ plate with a thickness of $L = 307\ \mu$m. Both samples were manufactured by SiXON Ltd., Japan. Experimental setup schematically shown in Fig. 1 is a standard one similar to that described in Ref. [4]. In order to assure high accuracy in our measurements, we used a cw-pumped Q-switched Nd:YAG laser oscillating at 1.064 μm (Spectron, SL902) as a fundamental light source, much improved power stability of which makes it possible to perform highly accurate Maker-fringe measurements. The pulse width was 100 ns, the peak power was 5 kW, and the repetition rate was 5 kHz. The output second-harmonic intensities were averaged over 1000 pulses. In addition, to compensate for the residual fluctuations of the laser pulse power, the measured second-harmonic power from the sample was normalized by the second-harmonic signal generated by a nonlinear optical organic powder placed on a separated fundamental beam line. The fundamental beam passed through a half-wave plate, a polarizer, and a couple of lenses, becoming a linearly polarized collimated beam with a radius of $a = 412\ \mu$m incident upon the sample. The second-harmonic output beam passed through an analyzer, long-wavelength cut and band-pass filters, and then was detected with a photomultiplier tube.

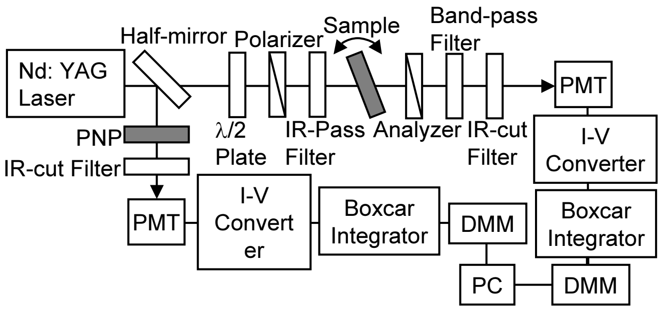

Figure 1: A schematic showing the experimental setup for rotational Maker-fringe measurement.

Maker fringes of (0001) SiC obtained with an s-polarized fundamental input and a p-polarized second-harmonic output (s-p configuration) and Maker fringes of $(11\bar{2}0)$ SiC obtained with a p-polarized fundamental input and an s-polarized second-harmonic output (p-s configuration) are shown in Figs. 2 and 3, respectively. Experimental data depicted by open circles are plotted only in the positive angle regions in separated three parts on expanded horizontal scales in order to make the oscillatory structures clearer. The second-harmonic powers are normalized with respect to the envelope of the Maker fringes obtained from a standard sample (an anti-reflection coated *b*-cut quartz plate). As is evident in the data shown in the figures, the Maker fringes are modulated with large amplitude double-period oscillations which is caused by the multiple reflections and interferences of the fundamental and second-harmonic waves. Clear Fabry-Perot patterns and a high symmetry of the obtained Maker-fringe data indicates an extremely high optical quality of the sample and high accuracies of the experiment.

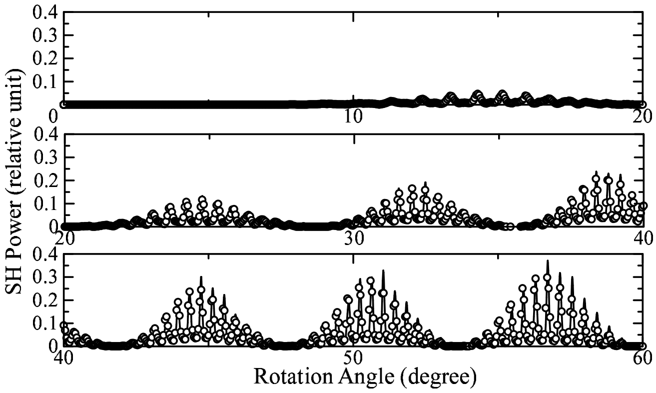

Figure 2: Maker fringes of a (0001) 6H-SiC plate obtained in the s-p configuration. The open circles are experimental data, and the solid curves show the theoretical fitting, which are plotted only in the positive angle regions in separated three parts on expanded horizontal scales.

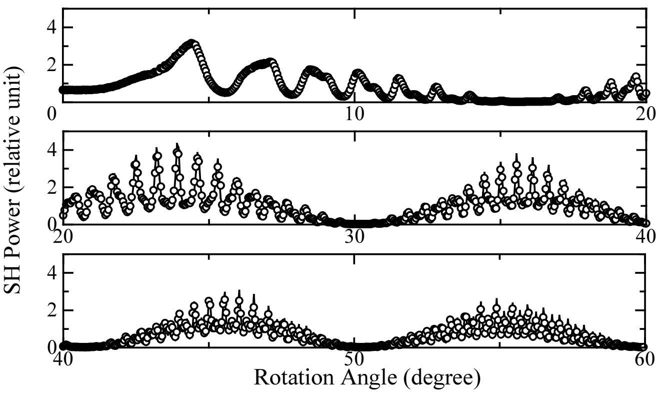

Figure 3: Maker fringes of a (11$\bar{2}$0) 6H-SiC plate obtained in the p-s configuration. The open circles are experimental data, and the solid curves show the theoretical fitting, which are plotted only in the positive angle regions in separated three parts on expanded horizontal scales.

We fitted the experimental data with the theoretical calculations taking account of the multiple-reflection effects and parttial beam overlap of fundamental waves and second-harmonic waves [5] using a standard least-squares fitting routine. Based on the fitting combined with relative measurements using quartz as a reference material, we determined the magnitudes of the nonlinear optical coefficients of 6H-SiC. Including the estimated experimental errors, the results are summarized in Table I. We used the absolute magnitude of the reference nonlinear optical coefficient d_{11}(quartz) = 0.30 pm/V [6, 7]. Relatively large error of d_{33} coefficient obtaind with the (0001) SiC sample is due to the relatively small contribution of this coefficient expressed approximately with a projection factor of $\sin^3\theta'$ where θ', the internal refraction angle, is relatively small owing to high refractive indices. Two sets of determined values obtained from (0001) and (11$\bar{2}$0) samples agreed well with each other within the experimental accuracies. The obtained value of d_{31} is smaller than the value reported by Singh *et al.* [1] and larger than those reported by Lundquist *et al.* [2] and Niedermeier *et al.* [3], whereas present data of d_{33} is much smaller than those reported by them.

3. Conclusion

We have performed rotational Maker-fringe measurements on a high quality plane-parallel (0001) and (11$\bar{2}$0) plates of 6H-SiC which exhibited significant multiple-reflection effects owing to large refractive indices. We have obtained almost ideal Maker-fringe data with prominent multiple-reflection effects, qualities of which are much higher than data reported to date, to the best of our knowledge. From the fitting of the numerical simulations to the experimental data, we have determined the magnitudes of the quadratic nonlinear optical coefficients of 6H-SiC. Since the obtained magnitudes of the nonlinear optical coefficients are quite large, 6H-SiC is expected to be used in practical wavelength conversion devices.

Table I: Nonlinear optical coeffcients of 6H-SiC determined in this study.

Sample	d_{31} (pm/V)	d_{15} (pm/V)	d_{33} (pm/V)
(0001)	6.7 ± 0.8	6.4 ± 1.1	−9.7 ± 8.0
(11$\bar{2}$0)	6.9 ± 0.8	7.5 ± 0.9	−12.8 ± 1.5

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