§14. Temperature Dependence of Optical Constants of Silicon for 48- and 57-μm FIR Lasers

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We have developed a new two color multi channel interferometer using 48- and 57-μm FIR lasers for plasma diagnostics [1]. A choice of optical materials of a window and a beam splitter is important especially for the multi channel measurement system. A crystal quartz etalon is often used in a FIR region. However, crystal quartz has a large absorption for both wavelengths. We have already confirmed that a CVD-diamond etalon is an excellent material for the short wavelength FIR region [2]. A silicon etalon with high resistive is also a useful material in this region. In order to design the window and the beam splitter, it is necessary to know precise optical constants such as a refractive index and an absorption coefficient. Although the optical constants of silicon measured by Fourier spectroscopy have been reported [3], the reliable optical constants for short-wavelength FIR laser lines are unknown. Therefore, we have measured the optical constants (refractive index and absorption coefficient) of silicon by using 48- and 57-μm lasers. Because the optical constants of silicon depend on temperature, the optical constants at 10, 19, and 29 °C have been measured. The beam splitter at several temperatures has been designed.

The optical constants have been obtained from the transmission measurement of a rotating etalon. The temperature is measured by two thermometers. The temperature of the silicon etalon is also checked by a thermistor. In this measurement method, the accuracy of the refractive index is strongly dependent on that of the etalon's thickness and the laser wavelength. We have used three samples of different thickness (2.1704 mm, 2.1718 mm, and 1.5452 mm). The thickness has been measured by two linear gages with 0.0001 mm resolution. The uncertainty of the thickness is ±0.0003 mm. A change in the thickness of 2 mm thick by the thermal expansion (~2.6×10^{-6} /K at 293 K) for this measurement is about 0.0001 mm. The flatness is under λ/2 for visible light. The resisitivity is about ~2.8 kΩ･cm.

Table 1. Optical constants of silicon at 10, 19, and 29 °C for 48- and 57-μm laser lines.

Wavelength (μm)	Refractive index		
	29 °C	20 °C	10 °C
47.65	3.417	3.416	3.414
57.1511	3.4179	3.4164	3.4147

Wavelength (μm)	Absorption coefficient (cm^{-1})		
	29 °C	20 °C	10 °C
47.65	0.35	0.33	0.30
57.1511	0.40	0.36	0.35

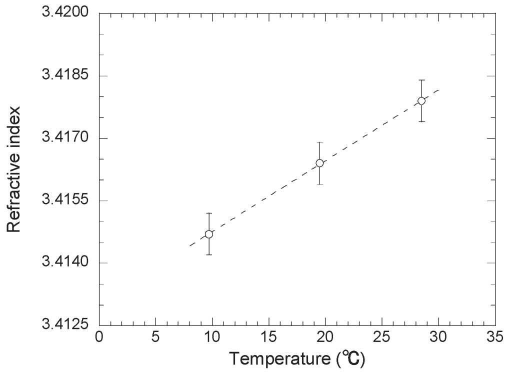

Fig. 1: Temperature dependence of the refractive index of silicon for 57-μm laser.

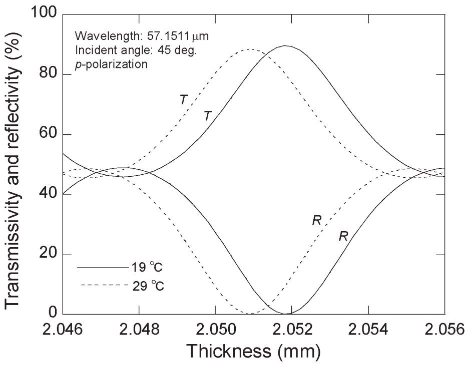

Fig. 2: Example of the design of a beam splitter.

Table 1 shows the optical constants of silicon at 10, 19, and 29 °C. The accuracy of the refractive index of 57-μm laser light is obtained at five figures. The estimated uncertainty of the refractive index is ±0.0005 on account of that of the thickness (±0.0003 mm). The uncertainty of the absorption coefficient is ±0.05 cm^{-1}. The uncertainty of the refractive index and the absorption coefficient of 48-μm laser light are ±0.001 and ±0.10 cm^{-1}, respectively, because the precise wavelength is unknown. The optimum transmissivity at 20 °C for 2.1718 mm thick is ~88 % for both lasers. Figure 1 shows the refractive index as a function of the temperature for 57-μm laser. The refractive index depends strongly on the temperature, and that is directly proportional to the temperature. The temperature dependence of the absorption coefficient is small, as shown in Table 1. Fig 2 shows an example of the design of the beam splitter at 19 and 29 °C for 57-μm laser. The beam splitter can be designed by choosing the etalon's thickness. The silicon etalon becomes a beam splitter with the different ratio of transmission and reflection by the difference between temperatures. When designing the window and the beam splitter using the silicon etalon, the temperature of an experiment environment must be considered.

Reference

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3) M. N. Afsar et al., Infrared Phys. **18** (1978) 835