A High Precision Reflectometer for the Study of Optical Properties of Materials in the Submillimeter

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ABSTRACT

A high precision reflectometer has been developed to measure the reflectivity (R) of various metals in the submillimeter frequency regime of the spectrum from 20 cm^{-1} - 85 cm^{-1}. A high-purity ($\rho \geq$ 40K Ohm-cm) single crystal silicon etalon was designed and used as the reflection standard. Optical properties of the silicon were characterized using a submillimeter ellipsometer specifically designed for materials characterization at these frequencies. This enabled the reflectivity of the silicon to be calculated to a relatively high degree and thus achieve a final measurement precision for R of ≈ 0.1%.

2. INTRODUCTION

The precise measurement of reflectivity for metals and superconductors becomes increasingly more difficult at longer wavelengths (λ > 100 µm) as the reflectivity of the specimen under study approaches unity. There are numerous quasi-optical techniques that have been developed to measure these data precisely. Methods which have been reported include; measuring the Q of a resonant cavity[1] and a Fabry-Perot interferometer designed[2] to achieve ≈ 0.1% photometric accuracy. There has even been a dual-beam interferometer designed for optical difference measurements[3] in the submillimeter with a photometric accuracy of ≥ 0.1%. This system, with its 16 mirrors and three beamsplitters demonstrates just how desirable accurate reflection data in the submillimeter spectral region is.

In approach described here, submillimeter laser radiation is specularly reflected from the metal sample and ratioed directly to the reflectivity from a silicon etalon standard. This approach hinges on the fact that the etalon's reflectivity can be calculated more accurately than it can be measured.

3. EXPERIMENTAL

The material selected for the reflection standard was a high-purity (ρ > 40K Ohm-cm) float-zone single crystal silicon wafer. The one-inch diameter wafer was optically polished on both sides to a thickness of 2809.8 µm by Kappler Crystal Optics, Holliston, MA. The thickness tolerance was kept to a minimum of ±0.25 µm. High purity silicon is an ideal far-infrared material with extremely low loss[4] and almost featureless dispersion characteristics between 10 cm^{-1} and 100 cm^{-1}.

To characterize the silicon's optical properties at these frequencies, a submillimeter ellipsometer previously developed[5] was implemented. The ellipsometer is used to measure the ellipse of polarization reflected from the test specimen. Knowing the polarization state incident on the material, one is able to back calculate, very accurately, the material's optical properties. Using this technique, the optical properties of the silicon were determined at λ = 236.60 µm to be: n = 3.4170 ±0.0001 and k ≤ 0.0001. Using this data, a second silicon etalon was polished such that it reflected the maximum amount of laser radiation (again at λ = 236.60 µm).

The precise measurement on the high-purity silicon was used to help design the standard for the submillimeter reflectometer. A schematic of the reflectometer is given in figure #1. Submillimeter radiation (λ = 236.60 µm) produced by an optically pumped molecular gas laser is focused onto various metal samples of approximately one-inch diameter. The test specimens and silicon reference were mounted on a computer-controlled wheel which alternatively stepped metal and then silicon into the focussed laser radiation. As shown in the figure the reflectometer is set-up for normal incidence measurements and the reflected radiation is collected in the signal detector. Off-axis measurements are also possible with the appropriate adjustments made to the silicon's calculated reflectivity. The reference detector is used to remove short-term laser fluctuations and thus increase the overall precision of the system.

The reflectivity measurements can be used to determine the metal's surface resistivity through the relation:

$$R_S = (Z/4)(1 - R)$$

where R is the conductor's reflectance and Z is the impedance of the dielectric medium in which the measurement is made. The submillimeter reflectivity of superconductors is also of great interest. Much remains to be learned about superconducting properties at submillimeter frequencies. Frequency scaling of the superconducting surface resistivity from submillimeter to microwave frequencies would make it possible to determine extremely low surface resistivities at these lower frequencies. The surface resistivity is expected to scale as f^2 at low power levels.[6]

4. CONCLUSION

A high precision reflectometer has been developed for the submillimeter region of the spectrum. An absolute reflection standard has been designed from a single crystalline silicon wafer. This method relies on the fact that the silicon's reflectivity can be calculated more accurately than it can be measured. Employing ellipsometric techniques, the optical properties of the silicon were determined to sufficient precision as to yield a final measurement precision of $\approx$ 0.1%. Reflectivity data for common metals will be presented using this technique at λ = 236.60 μm. Current research is being aimed at characterizing the silicon standard at other submillimeter wavelengths and thus extending the current range of the reflectometer.

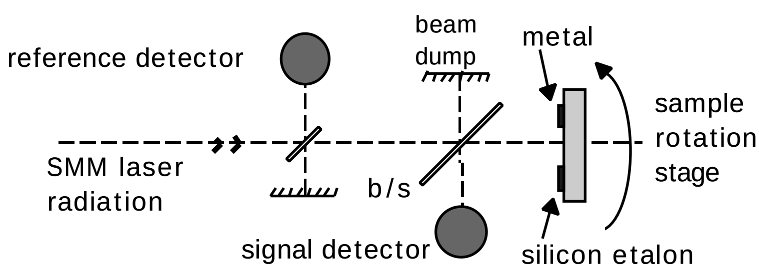

Figure 1Schematic of SMM reflectometer employing the silicon etalon standard

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