Design of a Submillimeter Ellipsometer for the Measurement of Complex Indices of Refraction of Materials

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Abstract

The principle objective of the research is the design and fabrication of an automated submillimeter ellipsometer. The ellipsometer has been designed to measure the amplitude and phase of submillimeter radiation reflected from or transmitted through materials. The key component of the ellipsometer is a birefringent quartz plate which has an adjustable incidence angle. Control of this angle, as predicted by multiple reflection theory for birefringent dielectric plates[1], allows the retarder to be precisely oriented to produce a quarter wave retardation without the use of AR coatings. The radiation source is provided by CW optically pumped submillimeter laser lines, and a liquid He-cooled bolometer is utilized as the detector. Results of dielectric constant data measured with the ellipsometer will be reported.

Introduction

Ellipsometry is the preferred technique for measurement of the refractive index, $n + ik$, at visible and near IR wavelengths. Optical configurations of ellipsometers require a combination of retardation plates and linear polarizers. These optical devices are used to determine reflection properties of polarized radiation which can be correlated to the refractive index.

The quarter wave plate condition, $2\pi(n_e-n_o)t/\lambda=(2m+1)\pi/2$, typically used in the design of a retardation plate requires that there be no reflections from the plate's surfaces. This condition is easily satisfied in the visible or near IR region through the use of anti-reflective (AR) coatings. However the technology of applying AR coatings suitable for use in the submillimeter region is not well developed.

An alternative method for designing a quarter wave plate, the ellipsometer's key optical component, was designed and demonstrated in this research. Approximately 20 years ago, D.A. Holmes calculated the reflection and transmission properties of reflecting birefringent etalons at arbitrary incident angles[1]. Using this multiple reflection theory and the refractive index data for quartz provided by E.E. Russell[2] and Afsar[3], the thickness for the quarter wave plate can be determined. Then, as suggested by Oldham[4], an exact $\pi/2$ phase shift can be obtained by adjusting the angle of incidence.

Design and Implementation

A prototype FIR ellipsometer, including mechanical, optical and electrical components has been specifically designed and fabricated to measure the amplitude and phase of the reflected radiation from materials (see Figure 1). This ellipsometer consists of two major components. The first component is a quarter wave plate rotated by a stepping motor in a manner as to precess the plate about the incident direction of the radiation beam. The second component is a linear polarizer driven by a DC motor and rotated at speeds up to 3000 rpm. An optical sensor attached to the linear polarizer mount generates a square wave reference signal used to determine the orientation of the polarizer.

Ellipsometric Measurement System

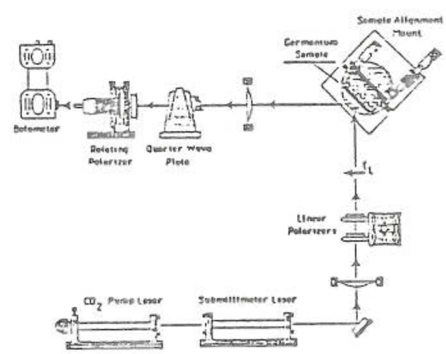

Figure 1

The radiation source, operating at a wavelength of 236.6 μm, is a CW optically pumped submillimeter laser. Wire grid polarizers consisting of 10 μm wires with a 25 μm spacing are used to create linearly polarized radiation at the laser output. A liquid He-cooled bolometer is utilized as a detector for the ellipsometer.

Software created for use on the MINC-23 allows users to control the prototype submillimeter ellipsometer system. Incorporated into this system is a two phase lock-in amplifier which utilizes two signals: the reference from the rotating linear polarizer mount and the modulated intensity signal from the bolometer. The outputs of the two phase analyzer are the filtered in-phase and quadrature demodulated signals. The software has been designed to receive and store this output through the computer's A/D converter.

The data, a function of the quartz plate azimuth, is shown graphically in Figure 2. In this case vertically polarized radiation was incident on the ellipsometer and each of the demodulated intensity peaks represent polarized radiation being transmitted along the plate's axes. The peak-to-peak ratio represents the transmissivity ratio of the quartz plate. If the linearly polarized radiation had an azimuth of 45 degrees the intensity peaks would shift to the right by 45 degrees. If the radiation were elliptically polarized then the peak-to-peak ratio would approach unity and finally equal unity for circularly polarized radiation. Software has been designed to perform a least squares fit of each peak. This fit determines the orientation of the quartz plate and allows for the analysis of the polarization state of the incident radiation.

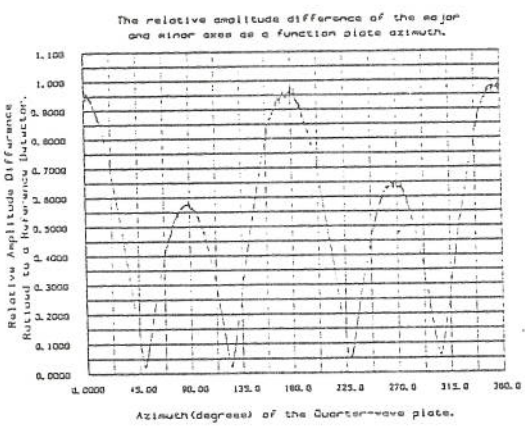

Figure 2

The optical constants of germanium were determined utilizing standard ellipsometric techniques[5] at angles of incidence ranging from 60 to 72 degrees. Results of the data measured with the ellipsometer will be reported.

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References

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