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ELECTRONICS AND RADIO ENGINEERING

A Terahertz Ellipsometer

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Abstract—A terahertz ellipsometer, based on the Novosibirsk free electron laser (FEL), is described. The device operates using the dynamic photometric "polarizer–sample–analyzer" scheme with a rotating analyzer. Sources of systematic errors, attributed to imperfections of optical elements, the accuracy of their alignment, and the influence of random errors, which are caused by measuring-section noises, were analyzed. The whole device and its separate units were tested. From results of measurements on tested samples, the operation accuracy of the ellipsometer was determined: $\delta\Psi \leqslant 0.3°$ and $\delta(\cos\Delta) \leqslant 0.01$. The measurement data obtained at a wavelength of 147 μm on the thickness and reflective index of blood films, which were deposited on a silicon substrate, are presented. In this case, the measurement accuracy of the reflective index is ±0.05 and thickness is 0.2 μm.

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1. INTRODUCTION

At present, optical ellipsometry is the commonly accepted analytical method for studying surfaces and layered structures. The method is characterized by a high sensitivity to optical properties and layer thicknesses of the studied objects. For a long ellipsometry development period, researchers gained a rich arsenal of methodological approaches, which allow one to successfully solve problems from different areas of knowledge.

In this connection, it seems interesting and promising to use principles of optical ellipsometry in the terahertz frequency range. Quite different mechanisms of interaction of light with substances are involved in producing reflection responses at these frequencies. Thus, for semiconductor micro- and nanoelectronics, the medium and far infrared (IR) ranges are the area of lattice absorption, photon–phonon interaction, and absorption by free charge carriers. Therefore, the optical measurements in the spectral range of 10–100 μm prove to be informative in investigations of structural and electrophysical properties of semiconductors [1–4].

The transition to the submillimeter wavelength region is intended to eliminate one of the fundamental physical limitations of optical ellipsometry, related to the light scattering during reflection from heterogeneous media with micron inclusions and rough surfaces, when the sizes of heterogeneities are comparable to the wavelength or larger. For the long-wavelength terahertz radiation with a wavelength of about 100 μm, this material seems optically uniform and interfaces become optically smooth.

Thus, the transition to new wavelength scales of the probing radiation opens new prospects for applying already developed ellipsometric methods in industrial technologies, namely, during creation of hardening coatings, for testing destruction and formation processes of near-surface fractured layers, and for the process inspection of lacquer and oil coatings [5, 6], including the motor-car industry. The terahertz ellipsometry can be especially interesting for biomedicine technologies and in the development of new diagnostics methods.

Lately, the time-domain spectroscopy has gained wide application [3, 7–9] or the IR Fourier spectrometry methods have been used [2, 10] to measure amplitude–phase responses of materials in the terahertz band. In this work, the ellipsometer, based on the classical scheme with a rotating analyzer [11], is described and the Novosibirsk free electron laser (FEL) is used as a terahertz radiation source [12].