Development of Methods and Instruments for Optical Ellipsometry at the Institute of Semiconductor Physics of the Siberian Branch of the Russian Academy of Sciences

E. V. Spesivtsev, S. V. Rykhlitskii, and V. A. Shvets

Abstract—The current status of ellipsometric methods and hardware tools developed at the Rzhanov Institute of Semiconductor Physics of the Siberian Branch of the Russian Academy of Sciences is considered. A unique static scheme for ellipsometric measurements is presented, which is used as a basis for instruments designed for various purposes: spectral and laser ellipsometers and also ellipsometers for local measurements. The capabilities of ellipsometric instruments are illustrated by results of studying various objects and fast processes. It is demonstrated that complete experiments can be performed with the use of static-type ellipsometers with determination of all parameters of partly depolarized light.

Keywords: ellipsometric instruments, spectroscopic ellipsometry, thin films, fast processes.

DOI: 10.3103/S8756699011050219

INTRODUCTION

Achievements of modern science and the latest technologies are directly connected with the development of analytical methods of research and high-accuracy diagnostic equipment. Ellipsometry occupies a special place in this row. At the very beginning of its vigorous development, which coincided with the great progress in microelectronics, it became clear that the high sensitivity of the method and the absence of perturbations of the examined object can become governing criteria in choosing diagnostic tools. As the methodical procedures were improved and ellipsometric equipment was developed, the possibility of using ellipsometry in new fields became obvious: solid-state physics, crystallophysics, optical technologies, chemistry, biology, and medicine. Applications required new aspects of instrument development. That was how spectroscopic ellipsometry and ellipsometry with high resolution in space and time appeared.

A number of ellipsometer models were developed at the Institute of Semiconductor Physics of the Siberian Branch of the Russian Academy of Sciences (ISP SB RAS) in the 1970s–1980s [1, 2]. These ellipsometers were replicated and successfully used in various academic institutions and in industry. A real breakthrough, however, was observed when a unique static scheme [3] was developed and patented. This scheme was based on the entire accumulated experience and new ideas of the ISP SB RAS team. A specific feature of this scheme is the absence of moving elements and signal modulation, which was used to develop and fabricate ellipsometric instruments for various functional purposes.

The goal of this paper is to analyze the current status of ellipsometry at ISP SB RAS and present a review of the most recent developments.
The ellipsometric instruments developed and fabricated at ISP SB RAS are based on a unique static scheme of measurements, which is shown in Fig. 1. The beam from the light source $L$ is polarized by a linear polarizer $P$ and is reflected from the examined surface $S$ and divided by an aperture $D$ into two optically independent channels. In the first (amplitude) channel, light is spatially split by a polarized Wollaston prism $W_1$ (analyzer) into two beams with mutually orthogonal components and intensities $I_1$ and $I_2$ recorded by a two-element photodetector $PD_1$. The second (phase) channel differs from the amplitude channel only by the presence of a phase-retarding element in the optical path, which is an achromatic Fresnel rhomb $F$. The intensities $I_3$, $I_4$ for the phase channel calculated by using the Jones matrix formalism are

$$I_3 = \left| (\rho \cos P \cdot \cos C + \sin P \cdot \sin C) \cos(A_2 - C)\rho_c - (\rho \cos P \cdot \sin C - \sin P \cdot \cos C) \sin(A_2 - C) \right|^2 I_0,$$  

$$I_4 = \left| (\rho \cos P \cdot \cos C + \sin P \cdot \sin C) \sin(A_2 - C)\rho_c + (\rho \cos P \cdot \sin C - \sin P \cdot \cos C) \cos(A_2 - C) \right|^2 I_0,$$  

where $P$, $C$, and $A_2$ are the azimuthal positions of the polarizer, compensator, and analyzer axes in the phase channel, which are determined with respect to the incidence plane, $I_0$ is the source intensity, $\rho_c = e^{i\delta_c}$ is a complex parameter of the compensator characterizing the relative phase shift $\delta_c$, and $\rho = \tan \Psi \cdot e^{i\Delta}$ is a complex ellipsometric parameter to be measured. Similar expressions for the amplitude channel are obtained by setting $\rho_c = 1$ in Eqs. (1) and (2), which corresponds to removal of the compensator from the optical scheme.

In contrast to the classical photometry, the static scheme is insensitive to light source intensity fluctuations. Indeed, the ratio of Eqs. (1) and (2) allows us to eliminate $I_0$ and, therefore, the corresponding noise. The scheme discussed here was analyzed in detail in [4]. It was demonstrated that determination of the ellipsometric parameters $\Psi$ and $\Delta$ requires only the light intensities in both channels to be measured at certain fixed positions of optical elements (configurations), i.e., such a scheme does not require rotation of optical elements and signal modulation. It is due to this specific feature that the response of the measurement system and the signal-to-noise ratio can be significantly improved. The best response reached with high differential sensitivity is several tens of microseconds. Moreover, the scheme allows working with a low intensity of the probing beam. Specific features of this scheme offer wide possibilities of its application in instruments designed for various purposes.

### ELLIPSOMETRIC EQUIPMENT AND METHODS OF ANALYSIS

#### Time-Resolved Laser Ellipsometry

The laser ellipsometer is a device with the simplest functional capabilities. The light source in the laser ellipsometer is a stabilized He–Ne laser, which provides high-power narrowband monochromatic radiation.