

# Instrument Development for Spectroscopic Ellipsometry and Diffractometry in the EUV

S. L. Moffitt<sup>1</sup>, B. M. Barnes<sup>1</sup>, T. A. Germer<sup>1</sup>, S. Grantham<sup>1</sup>, E. L. Shirley<sup>1</sup>, M. Y. Sohn<sup>1</sup>, D. F. Sunday<sup>2</sup>, and C. Tarrío<sup>1</sup>

1. *Physical Measurement Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 20899, USA*  
2. *Material Measurement Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 20899, USA*

## INTRODUCTION

Semiconductor devices are noted for ever-decreasing dimensions, and for becoming more and more complex. While scanning probe microscopy can still resolve the smallest features, it does not have the throughput for high-volume characterization of full wafers. Instead, optical scatterometry, operating at wavelengths in the visible and deep ultraviolet (DUV), has the throughput needed for process control. State-of-the-art visible and ultraviolet scatterometry should be acceptable through at least 2026, but five years from now, no known optical solutions exist for metrology<sup>1</sup>.

We are currently developing a new scatterometry tool that will utilize the extreme ultraviolet (EUV). Shorter wavelength, higher energy photons will enable both the improved spatial resolution and elemental sensitivity needed to extend optics-based high-volume characterization of patterned wafers for the foreseeable future. The instrument will include two different types of measurements, spectroscopic ellipsometry and diffractometry. The first measurement will require the development of all-reflective optics to enable ellipsometry in the 50 nm to 150 nm wavelength range. All materials are strongly absorbing in this wavelength range, meaning that the technique will be surface sensitive, measuring only the top few nm of samples. The second measurement will concentrate on the 10 nm to 50 nm wavelength range. These shorter wavelengths will allow deeper penetration into samples as well as measurements above and below atomic absorption edges. The latter will enhance our ability to determine the dimensions of a specific material within multi-material samples, which reduces ambiguities in feature dimensions.

Initial development will be done at the Synchrotron Ultraviolet Radiation Facility (SURF III), an electron storage ring on the campus of the National Institute of Standards and Technology (NIST). The tool will then be attached to a laser-based high-harmonic-generation (HHG) source that is compact enough to be installed in a NIST laboratory and potentially within a fab facility.

## INSTRUMENT DESIGN CONSIDERATIONS

### Spectroscopic Ellipsometry

A conventional ellipsometer consists of a light source, polarization-state generator (PSG), sample stage, polarization-state analyzer (PSA), and detector. Both the PSG and PSA consist of a polarizer and wave plate, which are enabled through transmissive optics. Absorption at EUV wavelengths prevents the use of transmissive optics, a significant roadblock in the development of EUV ellipsometry. Recently, T. A. Germer has determined that reflective optics can be designed to enable effective PSG and PSAs in the 50 nm to 150 nm wavelength range<sup>2</sup>. Using multiple grazing-incidence mirrors (Fig. 1) it is possible to introduce both polarization and phase shifts to an incident beam.

A four-mirror system can be rotated about the optical axis to introduce a variable phase shift without deviating the beam.

Fig. 1D shows the results of rigorous coupled wave analysis simulations<sup>3</sup> for a binary silicon grating consisting of 10 nm wide, 100 nm tall lines with a 50 nm pitch on a silicon substrate (see illustration in Fig. 1C). The incident angle for the simulations was 65°, with the grating vector in the plane of incidence. The optical constants,  $n$  and  $k$ , for silicon were taken from Palik<sup>4</sup>. The results shown are the normalized Mueller matrix elements  $m_{01} = -\cos 2\Psi$ ,  $m_{22} = \sin 2\Psi \cos \Delta$ , and  $m_{23} = \sin 2\Psi \sin \Delta$ , where  $\Psi$  and  $\Delta$  are the ellipsometric amplitude and phase parameters, respectively. While most traditional ellipsometry measurements are limited to approximately 5 eV in photon energy (250 nm wavelength), Fig. 1D shows significant structure out to almost 30 eV (40 nm). It is anticipated that extending ellipsometry to these much shorter wavelengths will enhance the ability for scatterometry to better measure details of the structure shape.

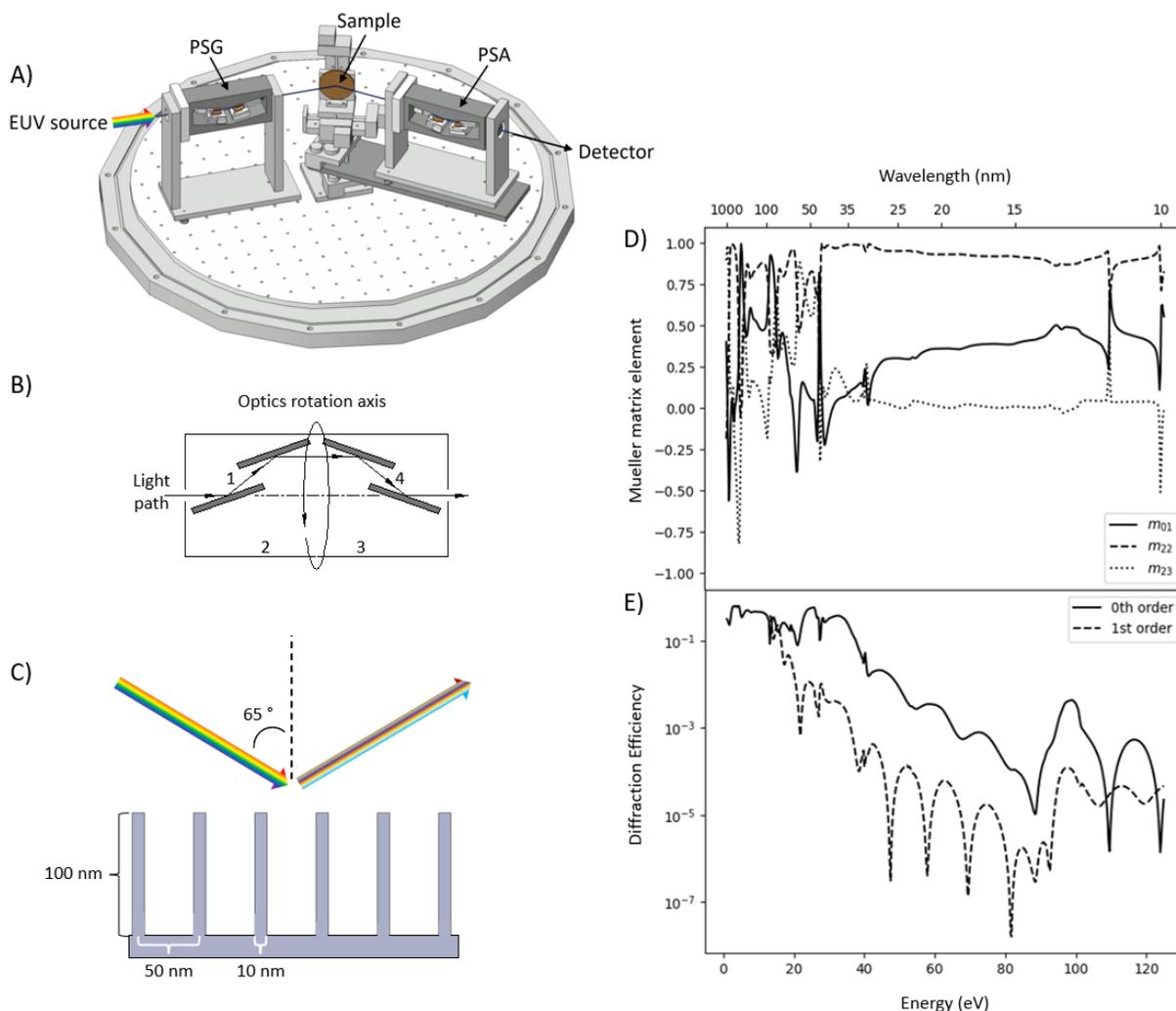


Fig. 1 A) Instrument design for spectroscopic ellipsometer. B) Schematic of the four-bounce reflective optics system which enables PSG and PSA for EUV wavelengths. C) 100 nm high, 50 nm pitch, 10 nm wide silicon lines with 90° side-wall angle, evaluated at 65° angle of incidence in a normal mounting configuration (grating vector in plan of reflection). D) Three curves corresponding to 3 unique ellipsometric parameters,  $m_{01}$ ,  $m_{22}$ , and  $m_{23}$ , which are simulated by assuming the model shown in C. E) Diffraction efficiency simulated assuming the structure shown in C.