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Atomic layer deposition for hafnium oxide-based meta-optics in the ultraviolet spectral range

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Abstract. Hafnium oxide (HfO_2) is of increasing interest in both microelectronics and photonics due to its favorable optical and dielectric properties. In particular, its high refractive index, wide bandgap, and chemical stability render it attractive for optical coatings and metasurfaces down to the ultraviolet spectral range. Atomic layer deposition (ALD) has been commonly employed to produce high-quality HfO_2 films. In this contribution we are reporting on the measured refractive index from a wavelength of 120 nm to 600 nm.

1 Introduction

Hafnium oxide (HfO_2) has emerged as a material of significant interest in a wide range of optical and electronic applications due to its excellent dielectric properties, high refractive index, and wide bandgap. Its thermal stability and compatibility with silicon-based technologies have made it a key material in advanced microelectronics, particularly as a high-k dielectric in metal-oxide-semiconductor field-effect transistors (MOSFETs). Beyond microelectronics, HfO_2 also finds application in optical coatings, where its transparency from the ultraviolet (UV) to the infrared (IR) spectrum, relatively high refractive index, mechanical hardness, and resistance to radiation and chemical degradation are highly desirable[2].

2 Methodology and results

Hafnium oxide (HfO_2) thin films were deposited using plasma-enhanced atomic layer deposition (PEALD) in an OpAL tool (Oxford Instruments Plasma Technology). The metal-organic precursor tetrakis(dimethylamido)hafnium (TDMAH, $Hf[N(CH_3)_2]_4$) was employed

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as the hafnium source, while oxygen plasma served as the oxidizing reactant. The plasma conditions were set to a flow of 50 sccm with a power of 300 W. Each ALD cycle comprised the following steps: a 0.4 s precursor pulse, followed by an 8 s purge and a 2 s pump-down step to remove residual gases. Subsequently, a 3 s gas stabilization period preceded a 10 s O_2 plasma exposure (reactant pulse), followed by a final 10 s purge[4]. The total duration of a single ALD cycle was 33.4 s. The measurements were performed on a ~200 nm thick HfO_2 film, deposited on a fused silica substrate, using a combination of spectroscopic ellipsometry and spectrophotometry. A Jobin Yvon UVISEL2 VUV ellipsometer was employed to cover the spectral range from 1.5 to 8.7 eV at a fixed angle of incidence of 70°. Additional measurements in the range from 0.6 to 6.5 eV were conducted using a standard Jobin Yvon UVISEL ellipsometer, with angles of incidence varied between 55° and 75°. In the infrared range (300–6500 cm^{-1}), a Woollam IRVASE ellipsometer was used, also with variable angles of incidence from 55° to 75°. Complementary transmission and reflection data were obtained with a Perkin Elmer Lambda 1050 and a Bruker Vertex 80v Fourier-transform spectrometer. For the reflectance measurements, the sample was illuminated from both the film side and the substrate side. The experimental data were analyzed based on the universal dispersion model using newAD2 software [3,4]. The HfO_2 film was also modeled using a universal dispersion approach, with all parameters treated as free during fitting. The film thickness determined from optical characterization ranged from 217 to 221 nm, depending on the spot size and geometry of each measurement. The surface roughness of the top interface was determined to be 1.51 nm (rms height) with an autocorrelation length of 5.3 nm. The extracted optical constants of the HfO_2 layer are displayed in Fig. 1.

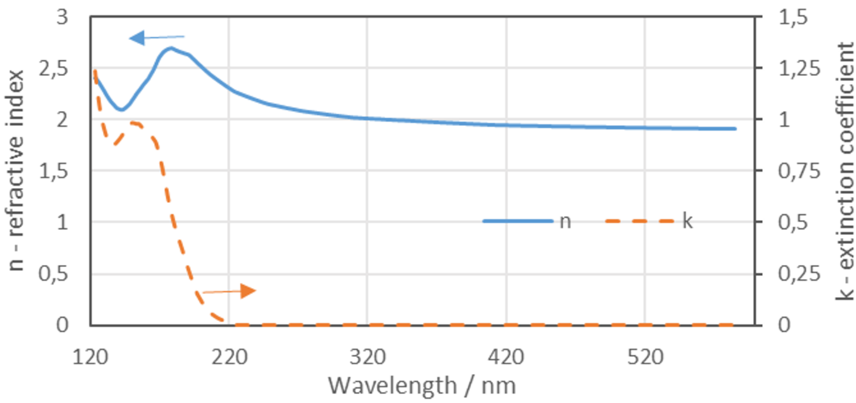

Fig. 1. Wavelength dependence of the refractive index of the fabricated hafnia

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