

Analysis of Superconducting and Optical Properties in Atomic Layer Deposition and Sputtered Thin Films for Next-Generation Single-Photon Detectors

Authors : Nidhi Choudhary, Silke A. Peeters, Ciaran T. Lennon, Dmytro Besprozvanny, Harm C. M. Knoop, Robert H. Hadfield

Abstract : Superconducting Nanowire Single Photon Detectors (SNSPDs) have become leading devices in quantum optics and photonics, known for their exceptional efficiency in detecting single photons from ultraviolet to mid-infrared wavelengths with minimal dark counts, low noise, and reduced timing jitter. Recent advancements in materials science focus attention on refractory metal thin films such as NbN and NbTiN to enhance the optical properties and superconducting performance of SNSPDs, opening the way for next-generation detectors. These films have been deposited by several different techniques, such as atomic layer deposition (ALD), plasma pro-advanced plasma processing (ASP) and magnetron sputtering. The fabrication flexibility of these films enables precise control over morphology, crystallinity, stoichiometry and optical properties, which is crucial for optimising the SNSPD performance. Hence, it is imperative to study the optical and superconducting properties of these materials across a wide range of wavelengths. This study provides a comprehensive analysis of the optical and superconducting properties of some important materials in this category (NbN, NbTiN) by different deposition methods. Using Variable angle ellipsometry spectroscopy (VASE), we measured the refractive index, extinction, and absorption coefficient across a wide wavelength range (200-1700 nm) to enhance light confinement for optical communication devices. The critical temperature and sheet resistance were measured using a four-probe method in a custom-built, cryogen-free cooling system with a Sumitomo RDK-101D cold head and CNA-11C compressor. Our results indicate that ALD-deposited NbN shows a higher refractive index and extinction coefficient in the near-infrared region (~1500 nm) than sputtered NbN of the same thickness. Further, the analysis of the optical properties of plasma pro-ASP deposited NbTiN was performed at different substrate bias voltages and different thicknesses. The analysis of substrate bias voltage indicates that the maximum value of the refractive index and extinction coefficient observed for the substrate biasing of 50-80 V across a substrate bias range of (0 V - 150 V). The optical properties of sputtered NbN films are also investigated in terms of the different substrate temperatures during deposition (100 °C-500 °C). We find the higher the substrate temperature during deposition, the higher the value of the refractive index and extinction coefficient has been observed. In all our superconducting thin films ALD-deposited NbN films possess the highest critical temperature (~12 K) compared to sputtered (~8 K) and plasma pro-ASP (~5 K).

Keywords : optical communication, thin films, superconductivity, atomic layer deposition (ALD), niobium nitride (NbN), niobium titanium nitride (NbTiN), SNSPD, superconducting detector, photon-counting.

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