

Abstract

As nanofabrication and characterization efforts expand across institutions with diverse infrastructure capabilities, there is a growing need for scanning and patterning tools that deliver high precision while remaining accessible, robust, and scalable. Scanning probe-based metrology and lithography offer nanometer-level resolution with comparatively modest laboratory and cost requirements; however, conventional silicon tips are limited by unfavorable slope profiles, scanning artifacts, and mechanical fragility. To address these challenges, we are developing gallium nitride (GaN) nanowire (NW) tips integrated into a single-probe system onto Si(111) in-house fabricated cantilevers for multimodal scanning probe applications, including atomic force microscopy (AFM), scanning tunneling microscopy (STM), nanolithography, and near-field scanning optical microscopy (NSOM).

GaN nanowires provide several intrinsic advantages over silicon probes, including high aspect ratios that minimize slope-induced artifacts, exceptional mechanical robustness for extended operational lifetimes, wide bandgaps enabling ultraviolet (UV) optical emission, and tunable electrical conductivity through controlled doping. In this work, we present recent progress toward a high-volume, wafer-scale fabrication process for GaN NW AFM probes on silicon cantilevers. The probe design incorporates a GaN nanowire with a diameter below 300 nm and a length of approximately 2 μm , terminating in an apex of ~ 2 nm for high-resolution imaging of high-aspect-ratio features. The silicon cantilevers are engineered for a resonant frequency of ~ 75 kHz and a force constant of 5.8 N/m.

These GaN cantilevers have demonstrated superior durability across multiple AFM and STM platforms and have already proven to be comparable to conventional W tips in STM operation, while exhibiting superior performance in AFM measurements of lateral sidewall resolution, deep-trench imaging, and patterning-based probe lithography (SPL). We discuss key fabrication challenges, including deep etching of (111) silicon cantilevers and dry etching of GaN as a unique way to form the 2 nm apex, while preserving nanowire integrity, and evaluate probe performance. Finally, we outline ongoing design efforts toward optically pumped GaN nanowire probes capable of UV emission for integrated NSOM, enabling multifunctional nanoscale imaging, metrology, and lithography within a single platform.

