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Hybrid metal-insulator-metal structures on Si nanowires array for surface enhanced Raman scattering

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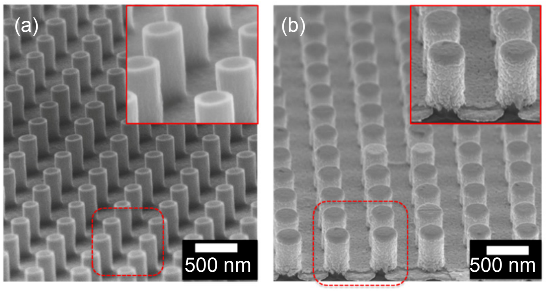

(a) Surface morphology of SiNWs array and (b) metal-insulator-metal layers.

Abstract: Surface enhanced Raman spectroscopy (SERS) has attracted a great amount of research interests in the past decades due to its fascinating use for finger-print molecules' detection. Two main mechanisms, chemical and electromagnetic enhancement, are used to explain the SERS phenomenon. In particular, the latter mechanism is widely accepted as the dominated effect. In recent years, a new kind of intriguing platform built from "elevated" cavity or bowtie arrays has been developed for reliable SERS detection. Known as the lightning-rod effect, bowtie nanoantenna arrays are able to confine the optical radiation into nanoscale volumes, performing excellent field concentration, which can exhibit distinct SERS effect due to strong LSP resonance in the vicinity of sharp nanotips of nanoparticles and small gaps among neighboring nanoparticles. The "elevated" properties make the cavity or bowtie decouple from the substrate, which is expected to enhance near-field intensity. However, such "elevated" nanocavity array is limited to the weak tunability of plamonic resonance and complicated fabrication processes, such as electron-beam lithography (EBL) and focused ion beam (FIB) milling. Their main disadvantages of high cost and slow throughput are not practical for SERS applications. In this work, periodical silicon nanowires (SiNWs) integrated with metal-insulator-metal (MIM) layers are employed as SERS substrates. Laser interference lithography (LIL) combined with reactive ion etching (RIE) is used to fabricate large-area periodic nanostructures, followed by decorating the MIM layers. Compared to MIM disks array on Si surface, the SERS enhancement factor (EF) of the MIM structures on the SiNWs array can be increased up to 5 times, which is attributed to the enhanced electric field at the boundary of the MIM disks. Furthermore, high density of nanoparticles and nanogaps serving as hot spots on sidewall surfaces also contribute to the enhanced SERS signals. Meanwhile, SiNWs array boosts the adsorption of probing molecules within the detection volume and light scattering within the SiNWs. It is also found that the calculated electric field enhancement demonstrates a periodic variation of pillar height, which is due to the constructive or destructive interference between the incident and reflected light. Via changing the thickness of the insulator layer, the plasmonic resonance can be tuned. These factors contribute to the enhanced SERS signals. This 3D platform with large area, good periodicity and pillar height dependent electric field enhancement can provide guidance for further optimizing and engineering such "elevated" plasmonic nanostructures for practical SERS applications.

Keywords: surface-enhanced Raman scattering; nanostructure fabrication; plasmonics; metal-insulator-metal
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