**MATERIALS ENGINEERING SEMINAR**

# "Morphology Tuning of Oxide-Metal Vertically Aligned Nanocomposites for Hybrid Metamaterials"

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## ABSTRACT

Metamaterials are artificially engineered nanoscale systems with a three-dimensional repetitive arrangement of certain components, and present exceptional optical properties for applications in nanophotonics, solar cells, plasmonic devices, and more. Self-assembled oxide-metal vertically aligned nanocomposites (VANs), with metallic phase as nanopillars embedded in the matrix oxide, have been recently proposed as a promising candidate for metamaterial applications. However, precise microstructural control and the structure-property relationships in VANs are still in high demand. Thus, by employing multiple approaches for structural design, this dissertation attempts to investigate the mechanisms of nanostructure evolutions and the corresponding optical responses.

In this dissertation, the precise control over the nanostructures has been demonstrated through morphology tuning, nanopillar orderings, and strain engineering. Firstly, Au, a well-known plasmonic mediator, has been selected as the metallic phase that forms nanopillars. Based on the previously proposed strain compensation model which describes the basic formation mechanism of VAN morphology, two oxides were then considered: $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) and $CeO_2$. In the first two chapters of this dissertation, LSMO was considered due to its similar lattice ($a_{LSMO}$ = 3.87 Å, $a_{Au}$ = 4.08 Å) and its enormous potential in nanoelectronics and spintronics. Deposited on $SrTiO_3$ (001) substrate through pulsed laser deposition (PLD), LSMO-Au nanocomposites exhibit ideal VAN morphology as well as promising hyperbolic dispersions in response to the incident illuminations. By substrate surface treatment of annealing at 1000°C, and variation of STO substate orientations from (001), to (111) and (110), the improved and tunable in-plan orderings of Au nanopillars have been successfully achieved. In the third chapter, a new oxide-metal VAN system of $CeO_2$-Au ($a_{CeO2}$ = 5.411 Å, and $a_{CeO2}/\sqrt{2}$ = 3.83 Å) has been deposited. The intriguing 45° rotated in-plan epitaxy presents an unexpected update to the strain compensation model, and tuning of Au morphology from nanopillars, nanoantennas, to nanoparticles also shows an effective modulation of the LSPR responses. COMSOL simulations have been exploited to reveal the relationships between Au morphologies and optical responses. In the last chapter, the two VAN systems of LSMO-Au and $CeO_2$-Au have been combined to form a complex layered VAN thin film. Investigations into the strain states, the nature of complex interfaces, and the according hybrid properties, show dramatic possibilities for further strain engineering. In summary, this dissertation has provided multiple routes for highly tailorable oxide-metal nanocomposite designs. And the two proposed material systems present great potential in optical metamaterial applications including biosensors, photovoltaics, super lenses, and more.

**Date: Thursday, July 20, 2023**
**Time: 1:00 P.M.**
**Place: ARMS 1021 or via this link:** https://purdue.webex.com/join/hwang00

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