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ND*nano* Summer Undergraduate Research 2018 Project Summary

1. **Student name & home university**: Evan Gies, University of Notre Dame

2. **ND faculty name & department**: Ryan K. Roeder, Aerospace and Mechanical Engineering, and Anthony J. Hoffman, Electrical Engineering

3. **Summer project title**: Synthesis of zinc oxide and titanium dioxide nanoparticles for phononic resonance in the mid- and far-infrared

4. **Briefly describe new skills you acquired during your summer research**:

Through my research on nanoparticle synthesis, I have learned many new nanoparticle synthesis and characterization methods. I have also improved my ability to keep a detailed notebook on my research notes.

5. **Briefly share a practical application/end use of your research**:

The field of phononic resonance has a potential 50-fold improvement on plasmonic resonance detectors. One possible improvement is in the field of analytical chemistry, where phononic resonance in the mid- and far-infrared region of the electromagnetic spectrum can be used to identify potentially harmful trace compounds in a specimen.

6. **50- to 75-word abstract of your project**:

Phononic nanoparticles (PhNPs) are a new class of materials that interact with light in the mid- and far-infrared region of the electromagnetic spectrum. The optical properties of nanoparticles in this region have not yet been investigated. Zinc oxide and titanium dioxide were synthesized by a variety of methods with the goal of preparing spherical monodispersed nanoparticles suitable for optical characterization.

7. **References for papers, posters, or presentations of your research**:

[1] J. D. Caldwell, L. Lindsay, V. Giannini, I. Vurgaftman, T. L. Reinecke, S. A. Maier, and O. J. Glembocki, “Low-Loss, Infrared and Terahertz Nanophotonics Using Surface Phonon Polaritons,” Nanophotonics 4, 44–68 (2015). doi:10.1515/nanoph-2014-0003
[2] K. Feng, W. Streyer, Y. Zhong, A. J. Hoffman, and D. Wasserman, “Photonic Materials, Structures and Devices for Reststrahlen Optics,” Opt. Express 23, A1418 (2015). doi:10.1364/OE.23.0A1418
[3] Pourrahimi, A. M., Liu, D., Pallon, L. K., Andersson, R. L., Abad, A. M., Lagarón, J., . . . Olsson, R. T. (2014). Water-based synthesis and cleaning methods for high purity ZnO nanoparticles – comparing acetate, chloride, sulphate and nitrate zinc salt precursors. RSC Adv., 4(67), 35568-35577. doi:10.1039/c4ra06651k
[4] Choi, S., Kim, E., Park, J., An, K., Lee, N., Kim, S. C., & Hyeon, T. (2005). Large-Scale Synthesis of Hexagonal Pyramid-Shaped ZnO Nanocrystals from Thermolysis of Zn−Oleate Complex. The Journal of Physical Chemistry B, 109(31), 14792-14794. doi:10.1021/jp052934l

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[5] Pauly, M., Pichon, B. P., Albouy, P., Fleutot, S., Leuvrey, C., Trassin, M., . . . Begin-Colin, S. (2011). Monolayer and multilayer assemblies of spherically and cubic-shaped iron oxide nanoparticles. Journal of Materials Chemistry, 21(40), 16018. doi:10.1039/c1jm12012c

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One-page project summary that describes problem, project goal and your activities / results:

Phononic nanoparticles (PhNPs) are a new class of materials that interact with light in the mid- and far-infrared region of the electromagnetic spectrum. This light-matter interaction is similar in principle to that which occurs with plasmonic materials, but while plasmonics is enabled by oscillations of free-carriers, phononics is possible due to vibrations of the crystal lattice, called phonons [1]. When a polar crystal is exposed to light of the correct frequency, coupling to the oscillations of the lattice results in a spectral region of negative permittivity, acting similar to a metal when the incident light is in a specific region of visible or infrared wavelengths. This region of negative permittivity is called the *Reststrahlen* band of the material. The *Reststrahlen* band therefore defines the region that phononic resonance can be tuned to achieve low-loss optical interactions useful in biomedicine, analytical chemistry, and environmental science [2]. The potential of phononic engineering has been realized in thin film semiconductors, but the optical properties of nanoparticles in the mid- and far-IR region have not yet been investigated. Zinc oxide (ZnO) and titanium dioxide (TiO_2) were selected from a compilation of candidate materials identified by analytical models. Multiple synthesis methods were explored with the goal of preparing spherical, monodispersed nanoparticles suitable for optical characterization [3,4]. An oleic-acid-based synthesis involving a metal-oleate precursor provided reliable synthesis of phase pure, monodispersed NPs, of 12.5±2.9 nm in diameter (Fig 1), as determined by x-ray diffraction (XRD) and transmission electron microscopy (TEM), respectively [4]. Monolayer films of PhNPs were prepared on gold substrates for optical characterization using both as-prepared and commercially-available nanoparticles. The NPs were coated onto the substrates using 11-mercaptoundecanol and an oleic acid coating as binding agents [5]. The conditions of the coating were optimized to create a uniform, monodispersed coating of NPs which allows for the optical properties of individual NPs to be measured. The substrates were imaged under scanning electron microscopy (SEM) to confirm the uniformity (Fig 2). Future studies of the PhNPs will further characterize the optical properties of these particles using Fourier transform infrared spectroscopy, among other methods. The results from this characterization will contribute to the foundational understanding of how NPs interact with light in the mid- and far-IR, and it will reveal potential uses for nanoparticle-based detectors.

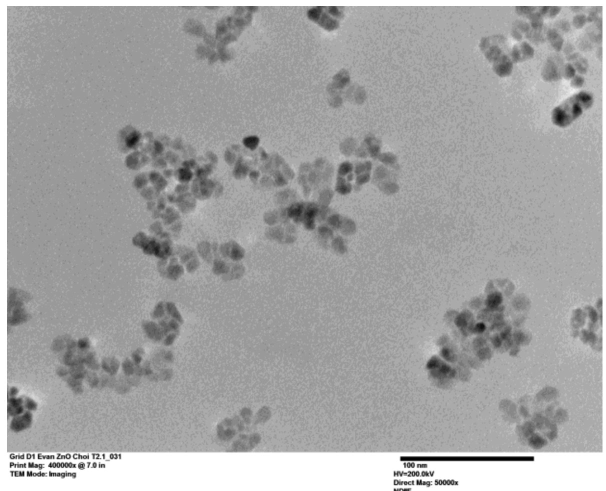

Fig 1. TEM micrograph of as-prepared ZnO NPs. The mean size of the NPs was 12.5±2.9 nm.

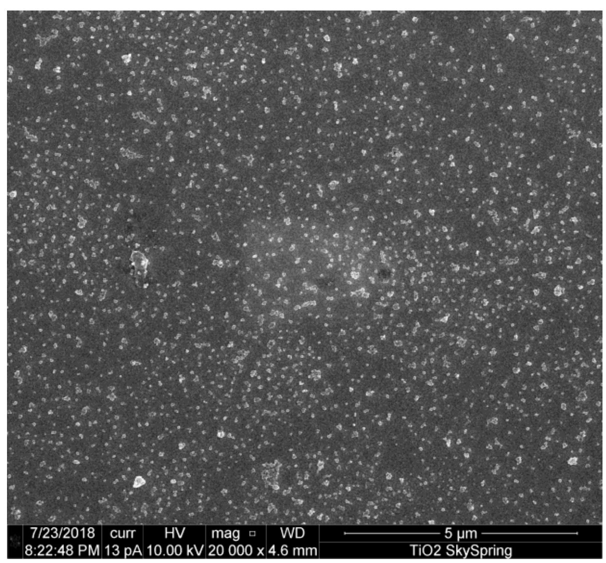

Fig 2. SEM micrograph of TiO_2 NPs on a gold substrate. The particles are uniform and monodispersed.