EILERS GRADUATE STUDENT FELLOWSHIP
FINAL REPORT

EILERS FELLOW: Agust Olafsson

FACULTY ADVISOR: Jon Camden

REPORT PERIOD: Feb 2021 – Aug 2021

PROJECT TITLE: Infrared nano-spectroscopy of plasmonic materials using high-resolution STEM-EELS

CONNECTION TO ND ENERGY’S
RESEARCH AREAS
(CHECK ALL THAT APPLY):

- [X] Energy Conversion and Efficiency
- [X] Smart Storage and Distribution
- [ ] Sustainable Bio/Fossil Fuels
- [ ] Transformation Solar
- [ ] Transformational Wind

The percentage completed for each goal is indicated in the table below.

MAJOR RESEARCH GOALS

<table>
<thead>
<tr>
<th>MAJOR RESEARCH GOALS</th>
<th>ACTUAL PERFORMANCE AND ACCOMPLISHMENTS</th>
<th>% OF GOAL COMPLETED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examine dopant concentration effects on NC plasmons</td>
<td>Measured the effects of dopant concentration on hybrid plasmon modes in the infrared regime.</td>
<td>75</td>
</tr>
<tr>
<td>Image NC-NC plasmon hybridization</td>
<td>Analyzed the hybridized modes of indium tin oxide nanocrystal (NC) dimers at various tin dopant concentrations.</td>
<td>100</td>
</tr>
<tr>
<td>Measure NC optical constants</td>
<td>Used electron energy loss (EELS) to measure optical constants of ITO with varying tin dopant and simulate monomer and dimer plasmon modes.</td>
<td>25</td>
</tr>
</tbody>
</table>

RESEARCH OUTPUT:

Please provide detailed information below regarding any output resulting from your research project.

CATEGORY                              INFORMATION

EXTERNAL PROPOSALS                     (Sponsor, Project Title, PIs, Submission Date, Proposal Amount)
Air Force Office of Scientific Research, “Direct Observation of Infrared Energy Transfer Using Focused Electron Beams”, Jon Camden and David Masiello, March 2021, $550,118.00

EXTERNAL AWARDS                       (Sponsor, Project Title, PIs, Award Date, Award Amount)
Air Force Office of Scientific Research, “Direct Observation of Infrared Energy Transfer Using Focused Electron Beams”, Jon Camden and David Masiello, March 2021, $550,118.00

JOURNAL ARTICLES                      (Journal Name, Title, Authors, Submission Date, Publication Date, Volume #, Page #s)

BOOKS AND CHAPTERS                   (Book Title, Chapter Title, Authors, Submission Date, Publication Date, Volume #, Page #s)
N/A

PUBLIC PRESENTATIONS, SEMINARS, LECTURES      (Event, Presentation Title, Presentation Date, Location)

AWARDS, PRIZES, RECOGNITIONS            (Purpose, Title, Date Received)
N/A

INTERNAL COLLABORATIONS FOSTERED       (Collaborator Name, Organization, Purpose of Affiliation)
N/A

EXTERNAL COLLABORATIONS FOSTERED       (Collaborator Name, Organization, Purpose of Affiliation)
Daniel R. Gamelin, University of Washington, Synthesis of Semiconductor Nanocrystals

WEBSITE(S) FEATURING RESEARCH PROJECT  (URL)
N/A

OTHER PRODUCTS AND SERVICES (e.g., media reports, databases, software, models, curricula, instruments, education programs, outreach for ND Energy and other groups)  (Please describe each item in detail)
N/A
MAJOR GOALS AND ACCOMPLISHMENTS
(Additional Details, Technical Results, Charts and Graphics)

Figure 1: Surface plasmon hybridization of ITO NC dimers. The hybridization diagram (a) depicts the collinear in-phase ($\alpha$), perpendicular in-phase ($\beta$), perpendicular out-of-phase ($\gamma$), and collinear out-of-phase ($\delta$) coupled modes. TEM images of the 10% Sn$^{4+}$ (b) and 2% Sn$^{4+}$ (d) doped ITO NC samples studied. Experimental EEL point spectra (c,e) collected at the aloof positions of the monomer (red), dimer end (green), and dimer gap (blue) together with corresponding simulated EEL spectra (black dash). The rising feature at low energy is the zero loss peak tail (SI).

Figure 2: EEL spectrum images displaying IR plasmon hybridization in a 10% ITO NC dimer. The experimental (a) and simulated (b) images demonstrate each of the four hybrid dipolar modes ($\alpha, \beta, \gamma, \delta$). The subtle difference between perpendicular modes $\beta$ and $\gamma$ is indicated by the node of low probability in the $\beta$ mode junction that is absent in the $\gamma$ mode junction.

Figure 3: Simulated electric field enhancement in ITO NCs as a function of tin dopant concentration. Line scans show the maximum field enhancement for an ITO monomer (a) and dimer (b) compared to silver, all computed at their respective resonance energy. For both ITO monomers and dimers, the maximum field enhancement (c) occurs at 5% tin doping. Error bars indicate the standard deviation from the mean.\textsuperscript{24}