# REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188



| 1. REPORT DATE (DD-MM-YYYY) | 2. REPORT TYPE | 3. DATES COVERED (From - To) |
|---|---|---|
| 16-08-2023 | Final Report | 15-Feb-2022 - 14-Feb-2023 |

**4. TITLE AND SUBTITLE**
Final Report: Ellipsometry of Thin Films for Mid-Infrared Optoelectronics

**5a. CONTRACT NUMBER**
W911NF-22-1-0045

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**
611103

**6. AUTHORS**

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAMES AND ADDRESSES**
Louisiana State University and A&M Colleg
Office of Sponsored Programs
202 Himes Hall
Baton Rouge, LA 70803 -0001

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)**
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

**10. SPONSOR/MONITOR'S ACRONYM(S)**
ARO

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
79220-PE-RIP.1

**12. DISTRIBUTION AVAILIBILITY STATEMENT**
Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

**14. ABSTRACT**

**15. SUBJECT TERMS**

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 15. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | Kevin McPeak |
| UU | UU | UU | UU | | 19b. TELEPHONE NUMBER 225-578-0058 |

# RPPR Final Report
as of 17-Aug-2023

Agency Code: 21XD

Proposal Number: 79220PERIP **Agreement Number: W911NF-22-1-0045**
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DUNS Number: 075050765 EIN: 726000848
**Report Date:** 14-May-2023 Date Received: 16-Aug-2023
**Final Report** for Period Beginning 15-Feb-2022 and Ending 14-Feb-2023
**Title:** Ellipsometry of Thin Films for Mid-Infrared Optoelectronics
**Begin Performance Period:** 15-Feb-2022 **End Performance Period:** 14-Feb-2023
**Report Term:** 0-Other

Submitted By: Kevin McPeak Email: kmcpeak@lsu.edu
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**Distribution Statement:** 1-Approved for public release; distribution is unlimited.

**STEM Degrees:** 0 **STEM Participants:** 2

**Major Goals:** - Acquire a multiangle spectroscopic infrared ellipsometer, manufacturer: J.A. Woollam, make: IR-VASE
- Setup the IR-VASE instrument in the LSU Nanofabrication Facility
- Train users on the IR-VASE
- Study the mid-infrared optical properties of HgTe and Ag2Se nanocrystal films provided by our collaborator Ayash Sahu at NYU
- Study the optical properties of noble-transition metal alloy films as a function of temperature. These films are deposited by co-sputtering in the PI's lab.

**Accomplishments:** - A J.A. Woollam IR-VASE was purchased
- The IR-VASE was installed the week of January 23rd, 2023
- Training by Nina Hong from J.A. Woollam was given on January 26 and 27, 2023
- The optical properties of HgTe nanocrystal films and CuPd alloy films have been measured
- Mid-infrared optical properties of humic acid and MS2 virus films have also been measured as preliminary data for another DoD proposal

**Training Opportunities:** - The following users have been trained to use the IR-VASE
-- Dr. Sergi Lendinez, assistant director of the LSU nanofabrication facility
-- Lina Rojas, graduate student in Dr. McPeak's group
-- Cameron Bachar, graduate student in Dr. McPeak's group
-- Dr. Sachith Bhagyashree Mahesha, Postdoctoral Researcher in Dr. McPeak's group

**Results Dissemination:** Nothing to Report

**Honors and Awards:** Nothing to Report

**Protocol Activity Status:**

**Technology Transfer:** Nothing to Report

**PARTICIPANTS:**

**Participant Type:** Staff Scientist (doctoral level)

# RPPR Final Report
as of 17-Aug-2023

**Participant:** Sergi Lendinez
**Person Months Worked:** 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

**Participant Type:** Graduate Student (research assistant)
**Participant:** Lina Rojas
**Person Months Worked:** 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

**Participant Type:** Graduate Student (research assistant)
**Participant:** Cameron Bachar
**Person Months Worked:** 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

**Participant Type:** Postdoctoral (scholar, fellow or other postdoctoral position)
**Participant:** Sachith Bhagyashree Mahesha
**Person Months Worked:** 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

**Partners**
Ayash Sahu
New York, NY USA
4
Prof. Sahu's group is providing us Ag2Se and HgTe nanocrystal film samples to measure in the IR-VASE

I certify that the information in the report is complete and accurate:
Signature: Kevin McPeak
Signature Date: 8/16/23 1:55PM

## Abstract

Developing new materials and devices for improved mid-wave infrared (MWIR) photodetection requires a fundamental understanding of the optical properties of the materials. Variable-angle-spectroscopic ellipsometry is the gold standard for determining the optical properties of thin-film materials. Unfortunately, MWIR ellipsometers are rare, making it challenging to determine the MWIR optical properties of new materials. The requested IR ellipsometer will allow the PI to measure the MWIR optical properties of various candidate materials for high-performance MWIR photodetection. Furthermore, the requested temperature-controlled stage will allow these measurements to occur under real device operating conditions, which is important for optimizing these new materials and integrating them into actual devices.

## Objectives

1. Acquire a multiangle spectroscopic infrared ellipsometer, manufacturer: J.A. Woollam, make: IR-VASE
2. Setup the IR-VASE instrument in the LSU Nanofabrication Facility
3. Train users on the IR-VASE
4. Study the MWIR optical properties of HgTe and Ag2Se nanocrystal films provided by our collaborator, Ayash Sahu, at NYU.
5. Study the MWIR optical properties of noble-transition metal alloy films.

## Findings

### 1. Acquire a multiangle spectroscopic infrared ellipsometer, manufacturer: J.A. Woollam, make: IR-VASE

An IR-VASE was purchased from J.A. Woollam company.

### 2. Setup the IR-VASE instrument in the LSU Nanofabrication Facility

J.A. Woollam set up the IR-VASE in the LSU Nanofabrication facility (NFF) from January 23rd through 25th of 2023. Figure 1 shows the tool installed in the NFF.

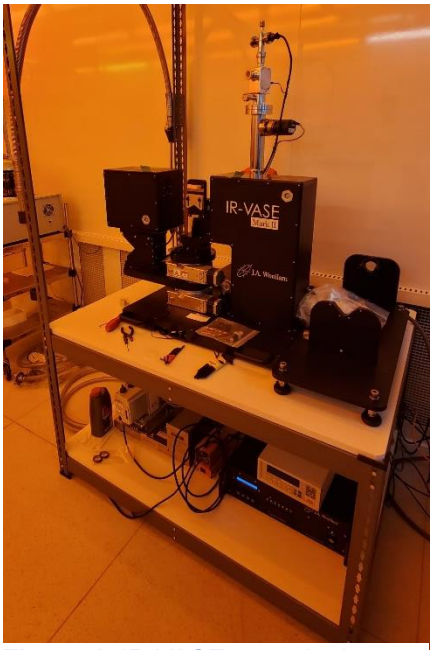


**Figure 1**. IR-VASE setup in the LSU Nanofabrication facility

**Figure 2.** Dr. Nina Hong from J.A. Woollam trains users at the NFF on the IR-VASE.

### 3. Train users on the IR-VASE

Dr. Nina Hong from J.A. Woollam trained users on the IR-VASE in the LSU Nanofabrication facility (NFF) on January 26th and 27th of 2023. Figure 2 shows Dr. Hong during the training event.

### 4. Study the MWIR optical properties of HgTe and $Ag_2Se$ nanocrystal films.

Our collaborator at NYU, Prof. Ayash Sahu, has provided us with thin films of HgTe nanocrystals. The nanocrystals were solution synthesized, and the films were fabricated by dip coating and subsequent ligand exchange. **Figure 3** is an electron micrograph of the HgTe films post ligand exchange. **Figure 4** shows the MWIR ellipsometry properties (ψ and Δ) for the HgTe films measured by the IR-VASE. The HgTe NC films show negligible optical absorption in the MWIR.

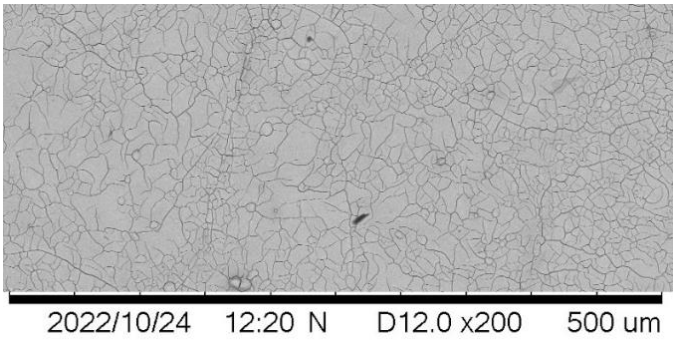


**Figure 3.** Electron micrograph of a 200 nm thick HgTe nanocrystal film post ligand exchange.

**Figure 5** shows the calculated NIR optical properties (n and k) for the HgTe NC films. The PI used a *B*-spline fitting function and a two layer optical model (NC film / Si substrate) to calculate these optical properties from the measured ψ and Δ values Note the increase in n and k around 2200 nm, corresponding to increased NIR absorption in the film. Studies are ongoing to determine the ideal NC growth and ligand exchange conditions. The synthesis and film assembly procedures for the $Ag_2Se$ NC films have not been completely worked out yet. Therefore, the PI has focused on using the IR-VASE to

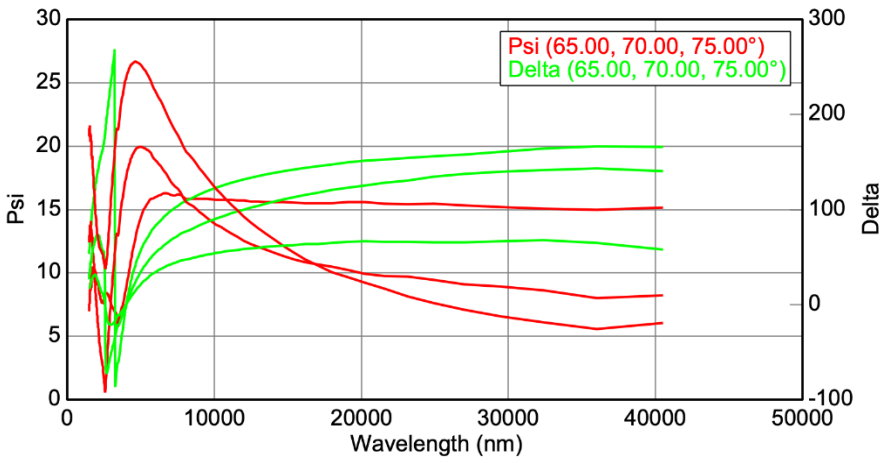


**Figure 4.** ψ and Δ values from 200 nm thick $Ag_2Se$ nanocrystal films measured on the IR-VASE

determine the NIR/MIR optical properties from HgTe NC films and provide feedback to our NYU collaborators.

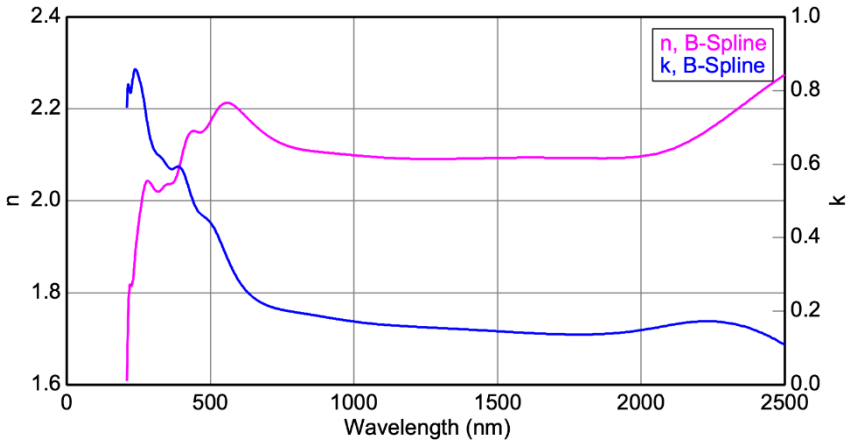


**Figure 5**. Calculated index of refraction (n) and extinction coefficient (k) for HgTe NC films.

## 5. Study the MWIR optical properties of noble-transition metal alloy films.

The PI also uses the IR-VASE to study the optical properties of noble-transition metal alloy thin films. Previously, the PI reported that band hybridization between Cu 3*d* and Pd 4*d* bands resulted in emergent optical properties, which could be observed through NIR ellipsometry. The IR-VASE allows us to extend our studies into the MWIR, probing direct and indirect transitions close to the Fermi level. Currently, the PI is studying binary and ternary alloys of Cu, Pd, Au, and Ni constituent elements. **Figure 6** shows the calculated real part of the permittivity ($\varepsilon_1$) for 100 nm thick $Cu_xPd_{1-x}$ alloy films with three stoichiometric ratios. The feature at 15 μm in the $Cu_{50}Pd_{50}$ $\varepsilon_1$ requires more investigation but indicates the emergent properties of these alloy materials even in the MWIR.

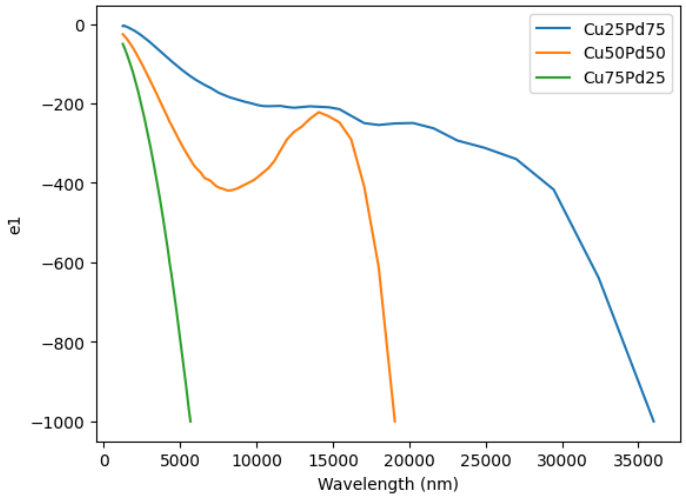


**Figure 6.** Real permittivity ($\varepsilon_1$) at mid-infrared wavelengths for 100 nm thick CuPd alloy films on silicon. Values were calculated based on measured ψ and Δ values from the IR-VASE.