Undergraduate Research Training Boot Camp Using Thin-Film Optics Technology

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ABSTRACT

We conduct a five-week research boot camp each summer for King Abdullah University of Science and Technology (KAUST) STEM students. Undergraduates carry out independent research regardless of their discipline. Each boot camp contains sessions on overview of topics relevant to thin film optics as well as skills needed for conducting research. The key learning goal of the challenge optics problem is to demonstrate the applicability of research skills across modeling, research design, fabrication process, and testing exercise. Here we present our findings from the past five boot camps, assessments of the students using responses in the workshop evaluations, and their research outcomes. We also share a curriculum aimed at broader adoption.

Keywords: Undergraduate, Thin film, Optics

1. INTRODUCTION

Rose-Hulman Institute of Technology is a private engineering & science college founded in 1874 as Rose Polytechnic Institute, which changed the name to Rose-Hulman Institute of Technology in 1964. There are eighteen degree science and engineering programs with 2,200 undergraduate students and 50 graduate students at the school. The number of full-time faculty is over 210.

We conduct a five-week research boot camp each summer for King Abdullah University of Science and Technology (KAUST) STEM students. The majority of KAUST students are freshmen or sophomores attending some of the top U.S. universities. Undergraduates carry out independent research regardless of their discipline. The goal of our research training boot camp is to make the invisible world of research visible to undergraduate researchers, through a set of seminars on essential topics and optics project activities. Each boot camp contains sessions on overview of thin film optics, photonic bandgap structures, plasmonic effect, research planning, experimental design, data collection and visualization, writing technical paper, and other appropriate topics. The key learning goal of the challenge optics problem is to demonstrate the applicability of research skills across modeling, research design, fabrication process, and testing exercise. Here we present our findings from the past five boot camps, assessments of the students using responses in the workshop evaluations, and their research outcomes. We also share a curriculum aimed at broader adoption.

2. THE BOOT CAMP

2.1 From Inception to Present

The concept for the undergraduate boot camp started in a faculty Book Club & Discussion Group in 2012 during the discussion on the book "The Craft of Research." In 2013, a proposal was submitted to the institute for obtaining an Innovation Fund. The 1st pilot program was in 2014 where seminar details for Engineering Management graduate students were worked out. The first Workshop announcement was sent out to freshmen and sophomores in March 2015. The first Workshop was held on with 22 students (FR and SO), May 9th, 2015. The second Workshop was conducted Feb. 26, 2016. The first KGSP proposal was submitted to IIE, March 2017,

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for summer 2017. Two more KAUST-RHIT RTI bootcamps (2018 and 2019) were conducted before COVID-19. The RTI for KAUST-KGSP was resumed in summer of 2022.

We conduct a five-week research boot camp each summer for KAUST STEM students. The majority of KAUST students are freshmen or sophomores attending some of the top US universities. Each bootcamp contains sessions on: Fundamentals of optics, overview of thin film optics, photonic bandgap structures, and plasmonic effect, Research planning, experimental design, data collection and visualization, Writing technical paper, and other appropriate topics.

In each research bootcamp, interdisciplinary teams of students, typically six to eight science/engineering majors, create a plan for research and execute it, concluding their work with a poster presentation and submission of a technical paper. It provides a Collaborative Learning Environment Through Teamwork The key learning goal of the challenge optics problem is to demonstrate the applicability of research skills across modeling and design, fabrication process, experimental design, and testing exercise.

2.2 Students Learning Outcomes

After completion of the bootcamp, students learn to:

- Model multi-layer films and metal or alloy Plasmonic films
- Operate fabrication/deposition instrumentations (sputtering or e-beam evaporator) safely
- Operate thin film metrology instrumentations
- Design an optics experiment
- Maintain a research diary
- Give technical presentation
- Do data analysis, error propagation, plot data
- Write a technical paper and do a peer-review
- Make a poster

2.3 Program Overview

The program consists of Five Weeks Schedule, Four Progress Reports, Six Workshops, Seven Milestones, and Four deliverables. The details of workshops and milestones are provided in the following.

2.3.1 Workshops

Workshop 1: Program Overview Introduction, Program Syllabus, Team selection, Problem Statement or Statement of Work, Plan of Study guidelines, What is research?, Keeping a research dairy or research notebook, Microfabrication, cleanroom etiquette, and process flow.

Workshop 2: Technical Lessons Project Proposal and Plan of Study, Discuss and refine project proposal plan and schedule, Technical Lesson1: Introduction to Nature of light, Technical Lesson2: Fundamentals of light-matter interaction, Technical Lesson3: Fundamentals of multi-layer dielectric thin films and photonic bandgap structures,

Workshop 3: Modeling and Simulation Technical overview, Review of modeling and simulation techniques, Simulation tools - MATLAB, Maple, Lumerical Experimental Design, Preliminary list of research articles and resources.

Workshop 4: Data and bibliography Taking Data and Error Analysis, Graphs and Plots, Writing a bibliography, Finding Library Databases and resources.

Workshop 5: Preparing a Manuscript Writing a science or engineering paper, Constructing an abstract and conclusions, Peer review Giving a good quality presentation, Make and present a research poster

Workshop 6: Professional Development Speaker from industry, Graduate school as a career path, Create professional resume, and How to build relationships and request letters of recommendation.

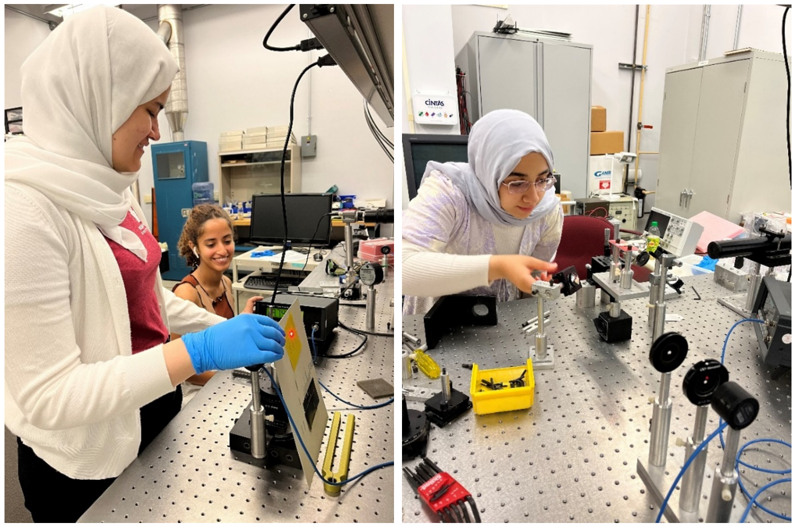

Figure 1. Students characterizing their fabricated devices in the lab.

2.3.2 Milestones

There are seven objectives associated with each bootcamp, each of which requires a milestone requirement as listed with their descriptions in the following:

Milestone-1: Research Proposal and Plan of Study Students will propose a research plan, including what problem they are trying to solve, and what techniques they will use to investigate. A draft of the proposal will be shared with peers at the 1st Progress Report session, and it should be completed, including a planned outline of work, milestones, and work schedule.

Milestone-2: Literature Review Research occurs in the context of others work and therefore, students are to collect relevant research articles (and other resources) to write a literature review and bibliography. The review will include a paragraph summarizing each source in the bibliography and describing its relevance to this project. Students should have at least 4 relevant research articles plus book(s) or online resources. This paper should be at least 3 pages.

Milestone-3: Progress Reports These informal presentations will describe what has been accomplished in the modelling portion of the project, fabrication or testing experiment(s), and will provide a detailed outline of the problem-solving strategies. Included in this will be an outline of the "methods", the algorithms, and techniques in the modelling, experimentations, as well as a plan for the analysis of how well the modelling and/or simulations (which may not be completed yet) compares with the experimental data.

Milestone-4: Peer Review Components While each research project will be done by a student team, peers can provide useful feedback on one another's work, and seeing other students' work can bring new ideas about a student's own project. To that end, students will be asked to share their work with their peers, to prepare feedback for peers, and to meet to discuss their progress and feedback. Students are expected to participate in Progress Report sessions, and to prepare a quality peer review form for each peer. Students will discuss preliminary research plans during the 1st and 2nd Progress Report sessions. Between the 1st and 2nd Progress Report sessions, students will exchange research plans and literature reviews, and will arrange a time to meet to discuss their research. Student teams should come prepared to talk about their own projects, and also to provide helpful feedback on peers' projects. During Workshop 5 session, student teams should provide the current draft of their final papers to each other and should complete the Peer Review Feedback Form for each peer. Students are encouraged to meet outside the regularly scheduled meetings to discuss their feedback.

Milestone-5: Final Design and Model Every project will involve making a device model and writing a mathematical codes or program that solves a given problem, or serves as a proof-of-concept, or illustrates some component of a program to solve the problem. Students must submit any mathematical codes/files required to

Figure 2. Students being trained in the cleanroom.

model and to generate plots, graphs, and simulations. This must be well-organized with descriptive comments to make it readable and comprehensible.

Milestone-6: Fabrication and Characterization in MiNDS Cleanroom All projects require a sample that will be fabricated using either electron-beam evaporator or sputtering system. All these unites are located in the MiNDS cleanroom facility in Myers Hall. All fabrication and characterization (Fig. 1) work must be documented by each student in his/her research notebook. There must be an insertion into the research notebook for every task performed in the cleanroom or Optics Lab including all modeling and design work on daily basis. The notebooks will be examined on each Thursday during the Project Review sessions and will be collected at the last Progress Report meeting on week 5.

Milestone-7: Final Paper and Final Project Poster The final paper and project poster should integrate the previously reported work into a coherent whole, adding in introduction and conclusion, figures, including citations and bibliography, and is due by August 5th. Use figures to illustrate the problem and your solution(s). Students must address feedback from instructor, peers, and the research assistant by revising and improving

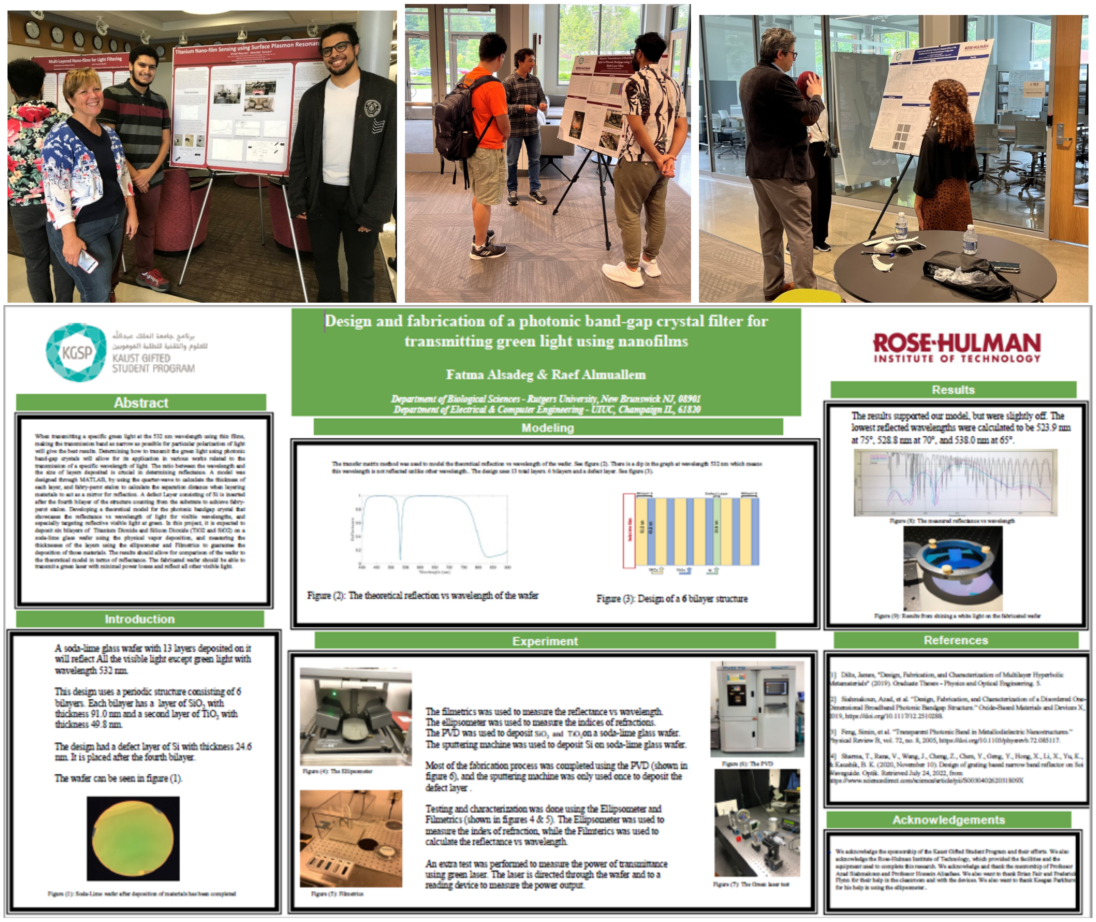

Figure 3. Poster Presentations in Summer 2022

every section of the paper. The final paper should be between 10 to 15 pages long. Use AIP or IEEE style for text, citations, tables and figures.

2.3.3 Microfabrication Training in Cleanroom

Students were introduced to the on-campus Micro-Nanoscale Devices and Systems (MiNDS) cleanroom facility with 2,000 sqft of class 100 clean space. They passed a cleanroom Safety and Etiquette Training. In addition, they were trained on the following topics: Thin Film Fabrication and Testing, Electron-Beam Evaporation, Sputtering Deposition, Optical Thin Film Measurement, and Visible spectrum Ellipsometry (Fig. 2).

2.3.4 Peer Review

Students were trained on the peer review process and asked to review their peer's papers. The students were required to provide comments adhering to the following guidelines: Abstract: Does it contain information on "what, why, how, and significant results"? Introduction: Does it include "research motivation, prior work by others, what's new in this work, paper organization"? Theoretical Modeling: Is the design described fully? Is theoretical model easy to follow and understand? Results and Discussions: Are the tables, graphs and plots have captions that is comprehensible? Are the figures properly described in the text? do the data make sense? are the discussions are valid and understandable? Conclusions: Are the conclusions intelligible, coherent, and complete? are the important results are discussed? Does the author offer a future direction or possible improvement to the methodology? etc. References: Is the format correct? are the references listed in proper order? Is there a reference that is not cited in the text? Is there a recent (last 3 years) paper related to the research? General Review Points: Check the paper for editorial details and accuracy. Is the flow of information

Figure 4. Certification meeting for the participants of Boot camp in 2022.

in the order expected? Are acronyms defined and used appropriately? Do sentences lead from old information to new information? Does the paper instill confidence that the researchers have done a thorough job in this research project? Are there obvious issues that authors ignored to address? Are your questions mostly about communication or mostly about the technical aspects of research?

2.3.5 Poster Presentation

Last Day of the Boot camp is devoted to poster presentation and is open to entire campus. Each poster includes sections on abstract, theory, simulations, experimental details, results, references and acknowledgments. The students stand in front of their posters for a duration of about one hour and discuss their research project with the visitors. Poster presentation session of 2022 is shown in Fig. 3. A sample of the posters is also shown. After the poster session is over, the students are awarded the certificate of completion, which officially marks the end of the boot camp (Fig. 4) .

2.3.6 Evaluations

The student comments and feedback are collected after each boot camp. The majority of students express that the bootcamp exceeded their expectations for learning modeling and hands-on experience. Also, they all indicate that they could use one more week to improve their results and outcomes.

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