SPS Chapter Research Award Proposal

Project Proposal Title	From Ideas to Orbit: Fabrication and Assembly of Custom Satellite Hardware
Name of School	Rhodes College
SPS Chapter Number	5940
Total Amount Requested	$2,000

Abstract

Rhodes College's 1U CubeSat satellite, RHOK-SAT, is nearing the final stages of development. RHOK-SAT is scheduled to launch to the International Space Station in approximately one year. The payload team has finished prototyping designs and must now proceed with the fabrication and assembly of the custom satellite hardware.

Proposal Statement

Overview of Proposed Project

RHOK-SAT is a 1U CubeSat satellite collaboration between Rhodes College and the Photovoltaic Materials and Devices Group at the University of Oklahoma to characterize the behavior, performance, and degradation of novel perovskite solar cells in Low Earth Orbit (LEO). The perovskite solar cells show qualities that could potentially outperform today's standard solar cell technology. Furthermore, perovskites possess a unique self-healing capability, making them a good candidate for deep space missions. RHOK-SAT will be one of the first missions to test and conduct in-situ measurements of perovskites.

The primary responsibility of the RHOK-SAT payload team is to integrate all of the satellite's experimental hardware. RHOK-SAT's experimental hardware includes six perovskite devices, a control Copper Indium Gallium Selenide (CIGS) solar cell, a custom-built sun sensor, eight Resistance Temperature Detectors (RTDs), and eight independent microcontrollers. Each perovskite device (figures 1a and 1b) contains six individual cells, called pixels, for a total of 36 perovskite cells. Perovskite technology is still in the early stages of development and there are some properties that make them more delicate than industry-standard solar cells. The main challenge of the payload development team is to create a way to electrically connect to the cells without solder or a conductive paste and to carefully secure the cells to the satellite.

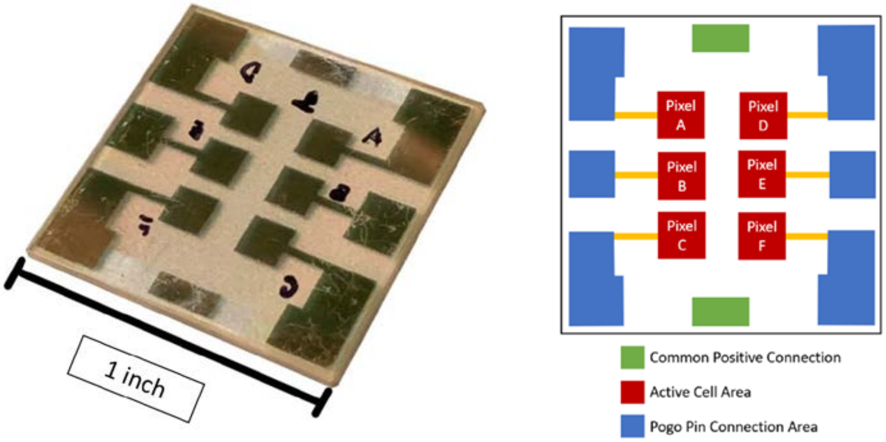
To mechanically mount the perovskites to the satellite, an aluminum face plate was designed using 3D CAD software. To test the designs, the face plate prototypes were printed using a resin 3D printer. Using the resin printer allowed for fast and inexpensive production of the parts while the designs were still being developed and modified. After about a year of design, revision, and improvements the final model of the face plate was ready for fabrication.

Over the summer of 2022, the students on the payload team were trained to operate the CNC mill on campus. Students worked to develop a fabrication process for the custom face plate as they learned how to use Computer-Aided Manufacturing (CAM) software to generate cutting operation programs. With these new skills, the first custom-fabricated parts for the project were made (figure 2).

The parts for the flight model (FM) of the satellite must be precisely machined to tight tolerances out of aerospace-grade aluminum. The FM parts need to be made out of aluminum 6061, an aluminum alloy known for its high machinability and corrosion resistance (1). All of the parts need to be precision machined with tools specifically designed for high precision aluminum machining. The tools used to fabricate the first faceplate were worn from prior use and not treated with proper coatings for machining aluminum. Using aerospace grade aluminum and the proper tools is essential for the fabrication process.

In order to get quality data from the experimental perovskite cells, accurate temperature measurements of each cell must be made. Temperature can change the performance of the cells and without accurate temperature readings of a cell before taking a measurement it is impossible to correctly analyze the results. Eight RTD devices will be used to measure the temperature of the six perovskite devices, CIGS, and the aluminum face plate. An RTD is a device that linearly increases in electrical resistance as its temperature increases. This relationship allows for an accurate characterization of the temperature of each part of the satellite. Each RTD will be nested into the faceplate along with the six perovskite devices. Before each on-orbit solar cell measurement, RHOK-SAT will record the temperature of each cell and the faceplate by measuring the resistance through each RTD.

As Rhodes is a small liberal arts school without a formal engineering program, this CubeSat project provides a uniquely valuable opportunity to students, especially those in SPS. RHOK-SAT is closely connected to the Rhodes chapter of SPS. Nearly all students involved in the RHOK-SAT team are members of SPS and several of the faculty act as advisors to the Rhodes chapter. SPS's mission of increasing accessibility and interest in physics is at the core of the RHOK-SAT project in the form of legitimate aerospace engineering experience.



Figures [1a. and 1b.]: Perovskite slide and diagram of the cell layout

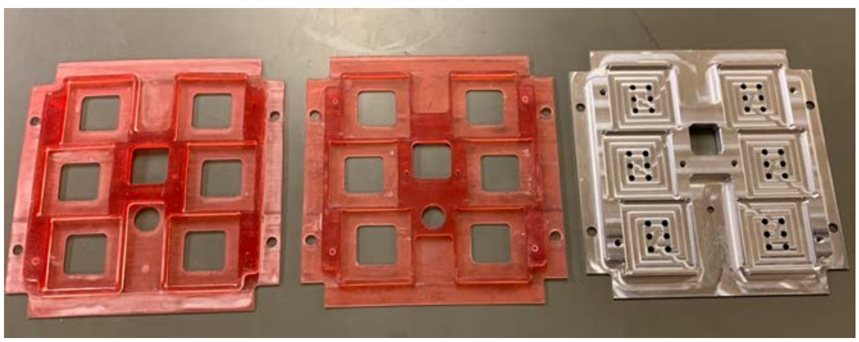


Figure [2]: Three different faceplate designs, two resin-printed and one fabricated from aluminum

Background for Proposed Project

RHOK-SAT is a joint 1U CubeSat satellite project between RHodes College and the University of OKlahoma to characterize the performance and degradation of novel perovskite solar cells in space. These perovskite cells are different from typical solar cells and require special mounting and connection hardware to ensure reliable data can be obtained. The RHOK-SAT team has developed a custom electro-mechanical harness to mount the perovskite cells to the satellite. This harness assembly consists of a machined aluminum faceplate and a printed circuit board (PCB). The faceplate houses the six perovskite devices and seven of the eight RTDs. The RHOK-SAT team has completed extensive research and training in machining techniques and can efficiently fabricate all necessary parts of the satellite. The cell performance and thermal data will provide valuable information to drive solar cell innovation forward.

Expected Results

Currently, the RHOK-SAT payload team is working towards two main goals:

- Successful fabrication and anodization of the aluminum faceplate.
- Successful integration of eight temperature sensors on the satellite, each of which will monitor the temperature of either the top plate itself, the CIGS cell, or one of six perovskite cells.

Description of Proposed Research - Methods, Design, and Procedures

The satellite's payload faceplate was developed using SolidWorks CAD software and is imported into Autodesk Fusion 360 CAM software for the machining process. The machining process begins with a plain, 4" x 4" x ¼" rectangular piece of stock. In Fusion 360, each cutting operation is precisely planned with cutting tool dimensions, cutting types, cutting speeds, and cutting paths. The operations are sequentially executed to cut away the stock revealing the part. The faceplate is machined in two separate setups. First, the top half of the part is cut (figure 3). To machine the bottom half of the part, the piece must be flipped upside down. The second set of cutting operations can now be programmed and executed (figure 4).

The HAAS Mini-Mill is used to machine all parts for RHOK-SAT. The mill, located in the Rhodes College machine shop, is a 3-axis mill that allows for cutting operations to be performed in the x, y, and z planes. The fabrication process takes a total of around 3 hours from start to finish for one faceplate from raw aluminum bar to finished product. Many of the cutting operations must be performed in slow cutting paths to protect the part from harmful vibrations and warping that can occur during the machining process. Another way to protect the part and the cutting tools is to use the right tool made from the right material. A cutting tool's material and coating can make or break a cutting operation. Cutting tools are generally made from two types of material, high-speed steel (HSS) and carbide. Carbide tools are much harder than HSS and can be used to make much more precise cuts. To prolong the life of cutting tools, they can be coated in materials such as titanium nitride (TiN) and titanium carbonitride (TiCN). These coatings increase the durability of the cutting tools, allow for a faster cutting speed, and produce a finer cut in the aluminum. The tools required for the precise machining of the aluminum are carbide tools coated in TiCN.

Fabrication of the faceplate requires 12 different tools:

1. 2" face mill
2. ½" flat end mill
3. ⅜" flat end mill
4. ⅛" flat end mill
5. 1/16" flat end mill
6. ½" chamfer mill
7. #29 drill
8. 2.8 mm drill
9. 2.5 mm drill
10. #3 center drill
11. 7/64" drill
12. M3 right hand tap

After the faceplate is fabricated, it must be sent to be anodized. The process of anodizing creates a strong layer on the surface of the aluminum that increases its corrosion resistance that cannot be chipped off. The parts are placed in a liquid medium and a charge is sent through the medium from a cathode.

Oxygen atoms are released from the medium and form an oxide layer on the surface of the aluminum (2). All of the exposed metal on the satellite must be anodized to protect it from the conditions in space.

Currently, the Rhodes machine shop does not have all of the proper toolings to produce a flight-ready faceplate. Most of the current tools used to produce the first version of the faceplate are either worn down from use over the years or improperly coated. The proper fabrication of the faceplate will allow for seamless integration of the perovskite cells, RTDs, and necessary circuitry into the satellite and ensure a safe ride to space.

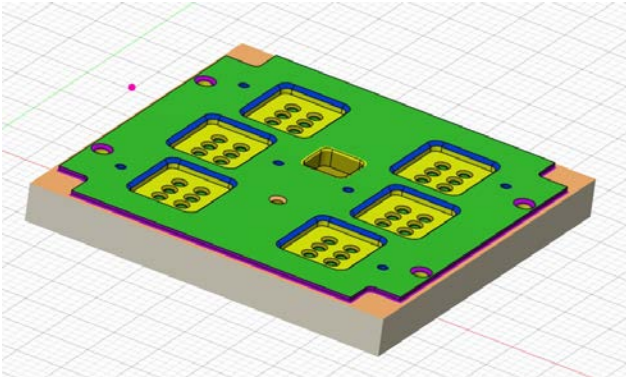


Figure [3]: Top plate setup 1

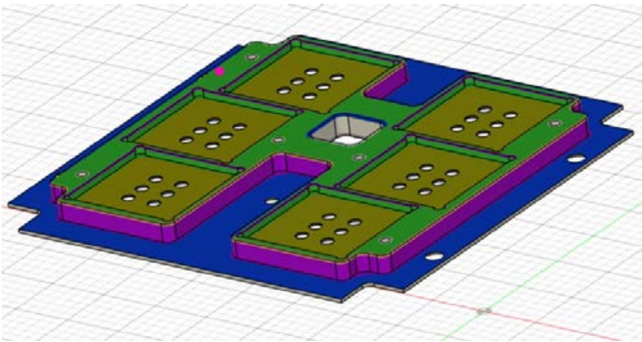
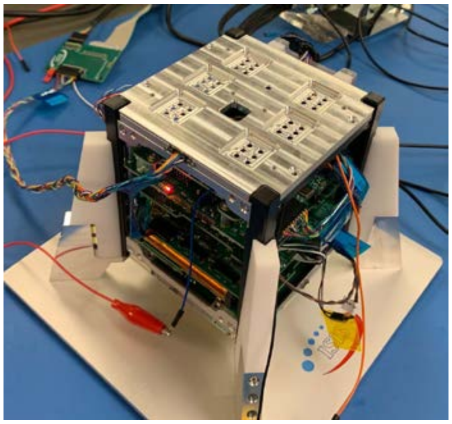


Figure [4]: Top plate setup 2



Figure[6] First model of the faceplate integrated into the RHOK-SAT engineering model

Plan for Carrying Out Proposed Project

The plan for the proposed project will continue approximately until the end of 2023. The required temperature sensor is in stock and can be shipped from the manufacturer with minimal lead time. Aluminum 6061 is available to ship from the distributor. The RHOK-SAT project involves SPS members with oversight from the physics department faculty and staff.

SPS students involved in the payload fabrication and temperature sensors are as follows:

- Ben Wilson: a class of 2023 Physics and Computer Science double major. He is RHOK-SAT's lead student researcher and is responsible for the design and fabrication of all custom hardware. Ben is also the co-founder of the Aerospace Engineering Club at Rhodes College.
- Olivia Kaufmann: a class of 2023 Physics major and the current SPS chapter President at Rhodes. Olivia is the team lead for the characterization of experimental photovoltaic technology using a dedicated microcontroller. Her work includes the integration of payload microcontrollers with RHOK-SAT's onboard computer.
- Jess Hamer: a class of 2023 Physics major, Zone X AZC, and our SPS Demonstration officer. Jess is the team lead for the design and implementation of electronic hardware. Jess's work includes the design of all custom circuit boards for the project.
- Damian Nguyen: a class of 2025 Physics major, and the current Rhodes Aerospace Engineering Club treasurer. He is responsible for the rapid prototyping of payload parts, developing test devices, space and launch environment testing, and 3D design.
- Other students involved with the flight software aspect of the project are : Kairos Wong '24 (SPS Member), Marouf Mohammad '24, and Anas Matar '25

Physics faculty members involved with the project include:

- Dr. Bentley Burnham, Assistant Professor of Physics, and RHOK-SAT project manager. Dr. Burnham oversees the progress of the project and handles administrative communications between the Rhodes team, the University of Oklahoma, NASA, and outside collaborators.
- Dr. Ann Viano, Associate Professor of Physics and Sigma Pi Sigma (SPS) chapter advisor. Dr. Viano oversees the design and integration of electronics for the project as well as the educational outreach portion of the project.
- Dr. Brent Hoffmeister, Professor of Physics, SPS chapter advisor, and Rhodes Physics department chair.

RHOK-SAT payload development has a dedicated laboratory on the fourth floor of Rhodes Tower. The fabrication of the top plate, among other parts, is done in the machine shop on the ground floor. These spaces have all the necessary equipment, computers, and resources to effectively carry out the proposed project.

Project Timeline

- Jan 2023: Acquire the material and equipment needed to prepare for the fabrication and integration process.
- Feb-May 2023: Receive the Flight Model (FM) from ISISPACE (hardware provider in The Netherlands) and start final assembly. Hold critical design review.
- May 2023: Write the interim report, detailing the project's progress of the fabrication process and the integration of the RTDs, as well as any changes to the plan in the latter half of the year.
- June 2023: Conduct environmental testing and troubleshooting to fix any last problems before handing over the satellite six months later.
- July-Oct 2023: Complete all software development and licensing.
- November 2023: Hand over the satellite to NASA to prepare for launch.

- December 2023: Write the final SPS report of the year.

Budget Justification

The manufacturing and assembly of high-precision parts require fresh, undamaged cutting tools. New milling tools and drill bits must be purchased to replace the worn and damaged tools currently available at Rhodes. Each tool will be purchased from Kodiak Cutting Tools, a high quality tool manufacturing company. Each tool purchased will have the necessary TiCN coating to improve the life of the tool. The machining process is demanding on tools and will naturally cause wear, but with proper machining techniques the tools will rarely break. However, human error is a possibility, and tools occasionally break. For these reasons, a replacement tool must be on standby ready to complete the machining process of a part. Two of each tool must be purchased to limit production delays.

Anodizing metal parts is not safe to do in-house. All of the fabricated faceplates must be sent to a company to be anodized. K&L Plating, Inc. performs aerospace grade aluminum anodizing for low cost and quick turnaround time.

The most expensive elements of the assembly are the RTDs. These RTDs from Honeywell are high quality, reliable temperature sensors that will provide the RHOK-SAT team with valuable data about the satellite. Without reliable temperature readings, the data received from the solar cells is worthless. It is imperative that the temperature sensors take accurate measurements.

A total of 28 RTDs are needed to produce two identical models of the satellite. The flight model and engineering model will each contain 8 sensors. Redundancy is one of the most important factors in aerospace engineering. There must always be a backup plan. For redundancy and safety measures, a complete, working assembly of the payload hardware must be available in case components are damaged or faulty. The last four RTDs will be used for an experimental perovskite temperature detection assembly that is currently being developed. Each RTD will be secured to its designated surface with a thermally conductive space-grade epoxy.

The fabrication process creates a large amount of heat in the parts and cutting tools that must be removed to protect the equipment. The Haas Mini-Mill sprays coolant onto the tool and workpiece to maintain safe operating temperatures.

Bibliography

- (1) 1st Choice Metals. “Aluminum 6000 Series.” https://www.1stchoicemetals.co.uk/aluminium/grades-guide/6000-series/#:~:text=Grade%206061&text=Aluminium%20grade%206082%20is%20slightly,H20
- (2) Aluminum Anodizers Council. “What is Anodizing?” https://www.anodizing.org/page/what-is-anodizing