Improving the Reliability and Capability of PARADIM's MBE

Jonathan Ortiz

2019 PARADIM REU Intern @ Cornell

Intern Affiliation: Mechanical Engineering, New Mexico State University

Program: 2019 Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials Research Experience for Undergraduates Program at Cornell University (PARADIM REU @ Cornell)

PARADIM REU Principal Investigator & Mentor: Dr. Darrell Schlom, Material Science and Engineering, Cornell

Primary Source of PARADIM REU @ Cornell Funding: Support for PARADIM is provided under NSF Grant # DMR-1539918 as part of the Materials Innovation Platform Program

Contact: jortiz1@nmsu.edu, schlom@cornell.edu

Website: http://cnf.cornell.edu/education/reu/2019

Abstract:

The Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials, or PARADIM, offers its users a fully automated oxide molecular-beam epitaxy (MBE) system for the growth and characterization of oxide thin films. The goal of this REU project was to design hardware improvements to various components of the PARADIM MBE system, most of which were associated within the effusion cells located towards the bottommost position of the system. The effusion cells serve to evaporate certain elements or compounds to create the molecular beams, which deposit on the substrate located at the center of the MBE system. The challenge of this project is that procedures done in this system are subjected to an ultra-high vacuum (UHV) environment.

Summary of Research:

Molecular-beam epitaxy (MBE) is a thin film growth method, which may be thought of as atomic spray painting, used to grow oxide semiconductors, insulators, and super conductors in an ultra-high vacuum (UHV) environment to avoid impurities. The oxide is ultimately assembled in a very precise and controlled manner layer by layer from one or more atomic or molecular beams originating from effusion cells. The MBE system has eleven such sources that can be used simultaneously without breaking growth chamber vacuum. Each of these effusion cells evaporate the desired element or compound at temperatures in the 300-2000°C range depending on the vapor pressure of the species evaporated.

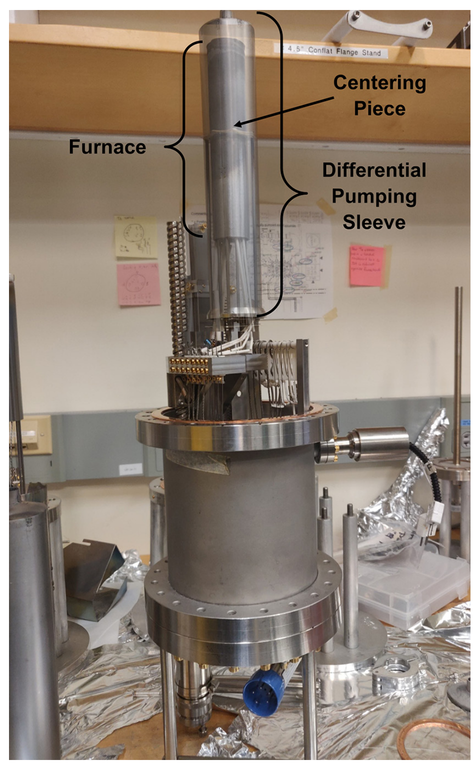

Figure 1: Image of an effusion cell.

The parts of the effusion cell, shown in Figure 1, include the centering piece, crucible, furnace, and the differential pumping sleeve which covers all of these parts. Surrounding each effusion cell is a fence that serves to prevent cross contamination from one source to the next. In addition, the MBE system also contains a retractable quartz crystal microbalance (QCM) for the purpose of flux measurement and calibration prior to and after growth.

The current differential pumping sleeves being used, shown in Figure 2, suffer from an extremely low life span. This problem arises from the way this part is currently being manufactured and assembled. Therefore, to increase the life span of this part we looked into changing the manufacturing and assembling process.

Our solution was to laser beam weld the seams of the part to create a continuous connection that limits the possibility of the part failing due to stress concentrations or buckling caused by continuous exposure to elevated temperatures.

Figure 2: Old vs. new differential pumping sleeve.

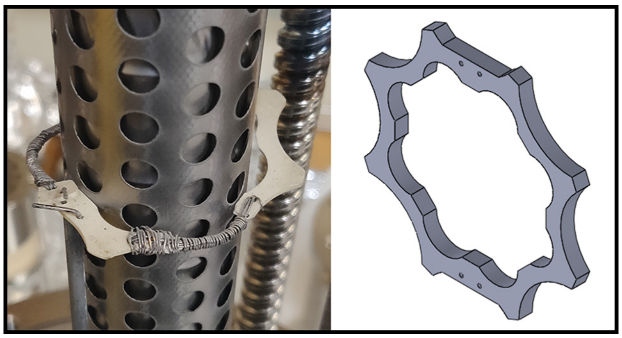

Figure 3: Old vs. new centering piece.

The improved differential pumping sleeves that will be manufactured by an outside company are shown in Figure 2.

The next design challenge can be found in the centering piece shown in Figure 3. This piece currently suffers from not having the most optimal life span, however, this time the cause is attributed to how it is made out of pyrolytic boron nitride. While expensive, this material is relatively easy to machine and is a good material to be exposed to high temperatures due to its low vapor pressure and excellent chemical stability. Nonetheless it does suffer in that it flakes over time as the material is weakly bonded together, similar to graphite. In addition, this current design is not optimal due to how it currently consists of two overlapping sections, which has shown to create failures at the attachment points where the two sections overlap. Therefore, to address these design issues the centering piece will be changed, as shown in Figure 3, to be one single piece instead of two and the material will now be yttria stabilized zirconia (YTZP).

The reasoning behind this material change is due to how YTZP is currently one of the strongest commercially available ceramics, it resists crack propagation, and it has a low thermal conductivity.

One of the most significant accomplishments was the design of an automated shadow mask. The shadow mask will allow PARADIM users to use the MBE system to deposit specific patterns of materials while still remaining in UHV. This mask, shown in Figure 4, will for example enable users to deposit gold contacts onto the corners of their thin film, which would potentially allow them to more accurately measure resistivity vs. temperature.

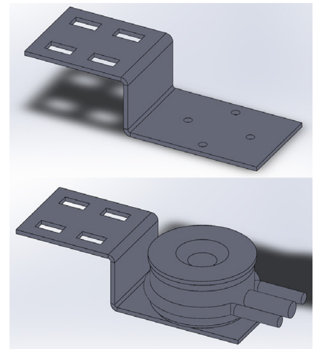

Figure 4: Solidworks model depicting the shadow mask.

When attempting to improve any system the designer or engineer must take into account any existing constraints which the system might impose. In this case the constraints were the dimensions of the housing of the QCM, due to how the only available attachment point for the shadow mask was the underside of the QCM. In addition, it is imperative that the designed improvement be easily manufactured. This is shown in Figure 4 by the design not having any complex geometry in addition to the part not being too large and remaining in close proximity to the QCM.

Present Status and Future Directions:

The design for the differential pumping sleeve has been completed and sent to an outside company to be manufactured. Next, the centering piece design is also completed but manufacturing is on standby until the new differential pumping sleeves are manufactured. The shadow mask template has been completed, except for the design to include all of the various specific patterns it will have. In addition, there are also other designs completed with new crucibles of various sizes, new fences for the MBE system, and a titanium liner required when atomizing pure titanium in the MBE. All of these designs are in the process of being sent to outside companies to be manufactured.

Acknowledgements:

I would like to thank Dr. Darrell Schlom for giving me the opportunity to expand and improve the capabilities of the hardware found within the PARADIM labs. I gratefully acknowledge support by the National Science Foundation for PARADIM funding provided under NSF Grant # DMR-1539918 as part of the Materials Innovation Platform Program.

References:

[1] D.G. Schlom, L.Q. Chen, X.Q. Pan, A. Schmehl, and M.A. Zurbuchen, "A Thin Film Approach to Engineering Functionality into Oxides," J. of the American Ceramic Society 91 (2008) 2429–2454.