Cathodoluminescence Spectroscopy - A means of Studying Gallium Oxide Micro and Nanocrystals

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Abstract

Currently, our lab is designing a system that allows us to leverage cathodoluminescence spectroscopy to study the optoelectronic properties and morphology of gallium oxyhydroxide and gallium oxide. This system would allow us to place our samples within a vacuum chamber and irradiate it with a high-energy electron beam, causing light emissions that are then collected by a fiber optic cable. This optical system allows us to capture the emissions and investigate them as its characteristics are dependent on the material properties of the sample. Furthermore, since we are working in ultra-high vacuum conditions, the components of the system have to be designed with careful consideration, in addition to allowing several degrees of freedom in order to precisely position our sample within the vacuum chamber.

What is Cathodoluminescence (CL)?

- Electrons produce optical transitions upon hitting material
- Spatial resolution on the nanometer scale
- Signature atomic and crystal structure of material is studied and correlated to chemical and electronic compositions
- Lower energy electrons in the valence band are excited by the electron beam, creating free electron-hole pairs
- They decay back to the ground state, but can do so in various ways
- Differences in energy between the states are emitted as a photon - this is what is captured in CL

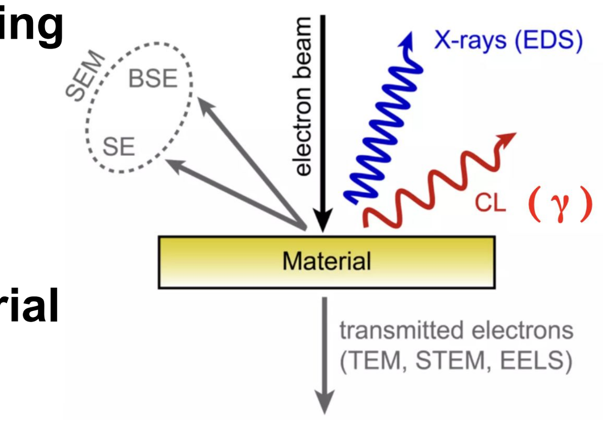

Fig. 1: Host of scattering processes as a result of high energy electron beam

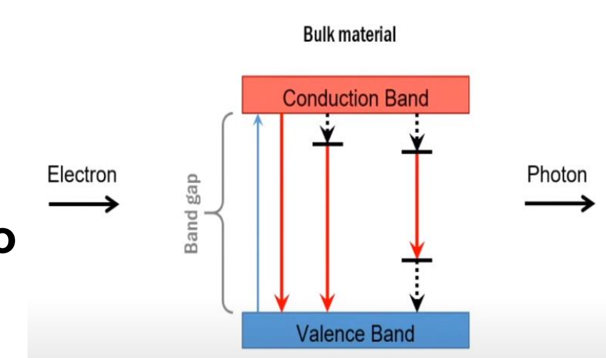

Fig. 2: Intermediate states within materials result in a specific wavelength of photon

Computer-Aided Design of Fiber Arm for CL

In order to utilize this technique, we need to construct both a fiber optic cable to collect the emitted photons and an assembly to position this fiber above our samples for collection and move it out of the way of other systems in our vacuum chamber

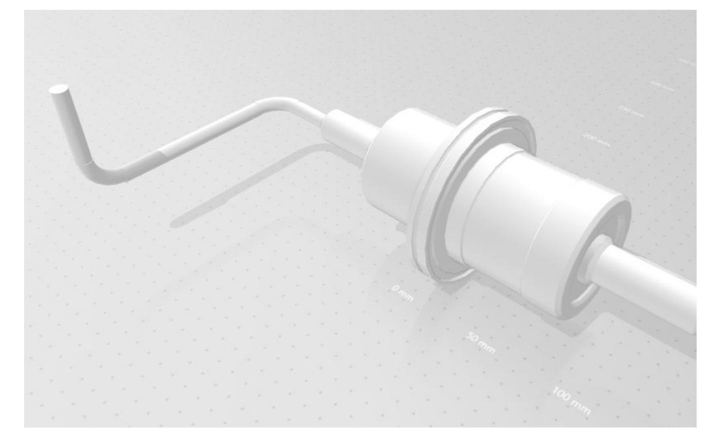

Fig. 3: Initial model of arm connecting it to the rotary feedthrough

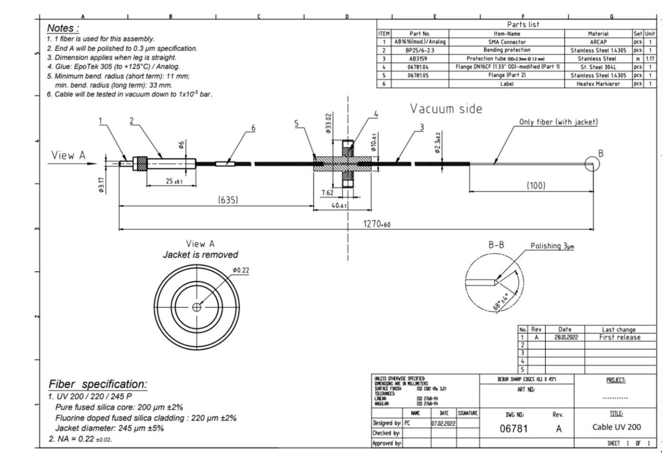

Fig. 4: Optical fiber setup for cathodoluminescence

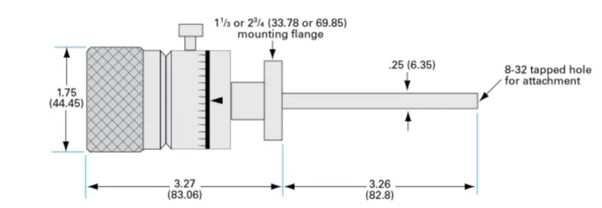

Fig. 5: Dimensions of rotary feedthrough

3D Modelling took place in AutoCAD and models were 3D printed (Polyprinter) for dimension tests and further modification

Design and Implementation of Assembly

- The arm, extending into the vacuum chamber, has minimal parts and junctions
- Rotary motion feedthrough from the outside provides the sample inside with rotational freedom
- A total of 6 degrees of freedom with L-bracket - fiber optic cables needs to be adjusted for focal point of light emission. This allows us to collect the emitted photons

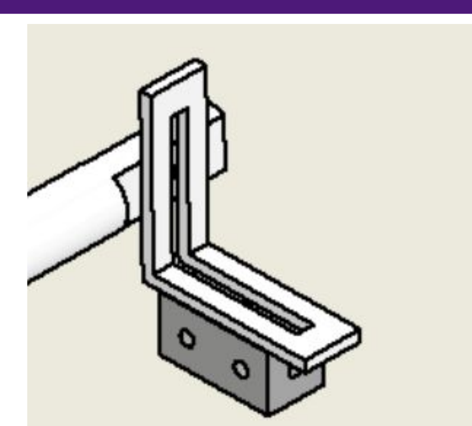

Fig. 6: L-bracket can be adjusted on arm prior to being placed in the vacuum chamber. The sample and the optic cables are held by the mount underneath

Ultra-High Vacuum System Considerations

- A vacuum environment allows us to reduce interactions with the electron beam and its possible effects on excitation process
- Reduction of contaminants such as gas and water molecules in air in the chamber
- While minimal moving parts on arm is a constraint, so is welding pieces together
- Possible air pockets when bending have to be considered
- We need to utilize non-magnetic, corrosion-resistant materials. Stainless steel fits these and is also a relatively low-vapor pressure alloy
- Vented screws instead of regular screws are to be used to reduce contamination and leaks

Fig. 7: Exterior of vacuum chamber where irradiation of electrons will take place

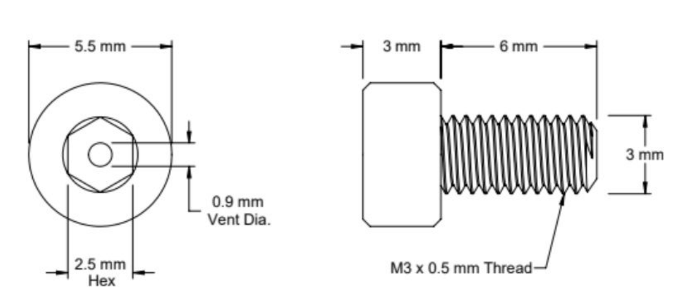

Fig. 8: Dimensions of vented screws

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CL spectroscopy is a powerful non-destructive experimental technique allowing characterization of optical and electronic surface properties of various materials. In particular, it allows us to investigate microscopic defects and impurities within those materials which are critical to performance in emerging technologies. We will use CL to study materials such as metal oxides that are used for applications in electronics, biomedical technologies, industrial chemistry, etc. In our design of the CL spectroscopy setups, we take into account the environments needed to extract the spectroscopic information from our materials.

Conclusion and Further Studies

- Manufacturing the proposed designs and testing them in vacuum conditions
- Conduct CL tests to be able to correlate defect intensity with penetration depth of the electron beam
- SEM (scanning electron microscope) can compliment CL tests as both use electron beams
- Having studied the effects of pH on the morphology of gallium oxyhydroxide and its subsequent effect on antibacterial action, we want to use CL to probe the the relationship between morphology and luminescence.