γ-Radiation "Aging" of Gallium Oxide

1. Proposal Narrative

A. Abstract

While Gallium Oxide shows great promise for applications in high power electronic devices, flat panel displays, and photovoltaic devices due to its wide bandgap, optical transparency, and relatively high thermal conductivity, little is know about how its material properties change upon long term exposure to high energy photons as would be found in many photovoltaic application. This project seeks to use gamma radiation as a proxy for extended deployment of gallium oxide based photovoltaic devices. By characterizing changes to the optical, electrical, and structural properties of sputter deposited gallium oxide films as a function of radiation dose we will gain fundamental insight into how the material properties are altered though aging. Such results are the basics for engineering designs which utilize gallium oxide as a fundamental material.

B. Background/Statement of the Problem/Significance of the Project

The last several decades have seen a slow but steady improvement in both efficiency in photovoltaic, (PV), devices and in their affordability. Today, there exist several large scale PV plants scattered across the globe. Applications of solar cell technology are also seen domestically on tops of homes and around properties. Additionally, solar cells are the fundamental power sources for satellites, and space vehicles. Therefore, understanding how material properties change over time is of paramount importance for extended spaceflight.

In order to conclude that a transparent conductive oxide layer, (TCO for short), is required for modern PV devices, it is useful to understand the fundamentals of PV operations. PV cells work by converting the energy of light into electrical energy. This happens when a photon of light is absorbed by an electron within the PV device. The energy acquired from the photon may excite the electron enough for it to cross the bandgap of the absorbing medium and enter the conduction band where it is extracted. Once extracted, the electron is used in an external circuit before returning to the unexcited state within the cell. To jump the gap an electron must gain energy from an outside source. For PV devices, this is from photon absorption. If the photon absorbed has energy at least as large as the bandgap, an electron may be promoted to the conduction band where it can then be sent through an external circuit [1]. This conducted electron is known as a photocarrier.

Current PV technologies have limited room for improvement without the use of a TCO layer. A known issue with the TCO layer is that it acts as a filter for incoming light. Photons carrying energies equal to or greater than the TCO band gap will be absorbed similar to that of photons in the absorption layer. Unlike the absorption layer, the TCO is often subjected to photons with enough energy to reconfigure or even remove atoms entirely from the TCO, particularly in space-like environments. Over time these reconfigurations and atom removals alter optical, electrical, and structural properties. Knowing specifically how the TCO is altered by radiation over time and its resistance to change (so-called “radiation hardness”) should be studied before commercial application.

UW-L’s 137Cs irradiator emits characteristic gamma(γ)-radiation of 661.8 keV, which is comparable to the exposure in an un-shielded environment (such as space). The Ga_2O_3 films will be exposed to the γ-radiation within the Cs irradiator to mimic the energies of non-earth environments. Further aging and radiation hardness studies of the film should be conducted. The γ-radiation seen in space is far greater than the peak ultra-violet (UV) radiation typical on earth. In order to determine information about aging within a period of time less than the expected life span of the material, higher energy photons may be used. We can conduct a semi-accurate age modeling of the life span of a Ga_2O_3 thin film (15-20) years, by bombarding the sample with γ-radiation for a period of a few months rather than UV radiation for the full life expectancy.

The absorption of each type of photon by a material is ultimately dictated by the absorption cross sections (the probability that a photon of a given energy will be absorbed by an atom). Using the average power flux of UW light in North America (approximately 40 W/m2 [2], calculating the power flux of the Cs irradiator at UW-L (10,600 W/m2), and compensating for the respective absorption cross sections, it is estimated that the aging ratio of the Cs source to the UV experienced by a PV device on Earth is approximately 300:1. Thus, a six month exposure to UW-L's source of γ-radiation can effectively model the approximate 15 years expected lifespan of a PV device.

Within the Ga_2O_3 crystal, there is a higher probability that a high energy photon will dislodge an O atom rather than a Ga atom. This difference in dislocation may be because Ga has a larger mass than oxygen (roughly three times as large). Therefore, the main defects in the Ga_2O_3 will come from the production of O vacancies in the material. More descriptively, the O atom will be displaced from its energetically favorable bonding location by breaking its bond with the surrounding Ga which weakens the overall structure of the crystal.

In the recent past, Dr. Wonderful and his research group at UW-L observed a different promising oxide that could replace indium in the TCO layer, Zinc Oxide (ZnO). His research concluded that the radiation had little effect on over-all transmittance, optical constants, or optical bandgap of the irradiated films. Resistivity did decrease over continued exposure along with data suggesting that O-vacancies were acting as donors to dope the irradiated films [3]. It is unclear whether similar results are to be expected from the same test on Ga_2O_3 .

C. Objectives / Specific Aims

- Understand how γ-radiation affects the optical properties of Gallium Oxide.
- Determine how aging affects optical transmittance and index of refraction
- Determine how aging affects the structural and optical properties of the film

D. Methods

Before beginning the radiation process, Ga_2O_3 thin films must be grown on sight and analyzed for all the properties that will be iteratively tested after radiation treatments. Important physical properties which must be measured include the lattice constant (average atomic spacing), optical transmittance and reflectance, optical band gap, surface morphology, and the quantification of any O or Ga-vacancies in existence within the crystal before any sample is exposed to radiation.

Samples will then be exposed to the Cs irradiator for varying amounts of time consistent with values needed to understand the radiation ageing process. If the life expectancy of a PV device is 20 years, we will expose the samples corresponding to 1, 3, 5, 10, 15, and 20 years.

These year ratings correspond to 18, 80, 146, 292, 438, and 548 hours of exposure respectively. Samples will again have their material properties fully tested and characterized once specified exposure times have been completed.

The PI will have access to a materials science lab that provides many tools and instruments needed to characterize the samples. When a TCO layer discolors due to Oxygen vacancies which scatter, rather than transmit, the incident light, its functionality is compromised. The O vacancies, acting as electron traps can also increase the intensity of the light reflected from the surface of the material. The PI will use a UV–Vis near-IR spectroscopy system optimized for solid sample analyses to quantify the changes in transmittance and reflectance that have occurred since being irradiated. Measurements in the optical band gap will be made in the UV region along with the percent of visible light which is transmitted through the Ga_2O_3.

A transparency curve can be drawn when transmittance values are compared across the entirety of the samples. A slight reduction from the initial 100% transmittance of the pre-irradiated samples is expected. Ideally, samples remain above 80% for the duration of the study with little reflectance changes being measured. These results would suggest that despite continuous damage, the electron hole traps are not in large enough quantities to further hinder transparency of the material. We would like to correlate this data to atomic changes within the crystalline lattice. The correlating data will be taken using a combination of microscopy and spectroscopy techniques which can probe the crystal at an atomic level.

The combined iterative data obtained from the above mentioned test will allow the PI to obtain valuable information pertaining to the properties of Ga_2O_3 as it is continuously aged with radiation exposure. This knowledge will add to the fundamental knowledge of Ga_2O_3 and aid in the future of Ga_2O_3 based PV device engineering.

E. Final Products and Dissemination

The results of this project will be presented at the 2021 UWL Research and Creativity Symposium, and at the Wisconsin Space Conference.

F. Budget justification

Early June 2020 - Fabricate and characterize gallium oxide films deposited on fused silica. This will take approximately one week, and will establish the baseline material properties for as-deposited gallium oxide in an unaged condition.

Mid-June thru Mid-August 2020: Films will be placed in the Cs irradiator and exposed to radiation for various duration. Approximate exposures will be 80 hours, 12 hours, 24 hours, 48 hours, 96 hours, 192 hours, 382 hours, and 768 hours. The longest exposure period requires approximately one month in the irradiator. After each exposure period the film will be removed from the irradiator and characterized for comparison to the initial as-deposited material.

September 2020 thru April 2021: Analyze collected data, and prepare poster presentation for the 2021 Research and Creativity Symposium

We will need 3 pieces of UV grade fused silica to use as substrates ($230).

We will also need a 5g bottle of Gallium oxide powder to prepare the films ($67.00).

Total supplies request: $297.00, Our total budget is $1297.00

*VII. **Bibliography***

[1] *K-S Choi, Band Gap Tuning of Zinc Oxide Films for Solar Energy Conversion,* ***2011****, 6-8.*

[2] *A. I. Kudish, et al., Internation Journal of Climatology,* ***1997,*** *17, 1697-1704*

[3]
http://iamdn.rutgers.edu/downloads/pec-2015-1/284-final-pec-2015-program-abstract-book-v3/file