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Temperature Dependence of Electron Yield in Low-Density Polyethylene

Jordan Lee
Utah State University

U.R.C.O. Grant Proposal

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Temperature Dependence of Electron Yield in Low-Density Polyethylene

Jordan Lee, Principle Investigator

JR Dennison, Faculty Mentor

Gregory Wilson, Graduate Student Mentor

Materials Physics Group
Physics Department
Utah State University

UtahStateUniversity
MATERIALS PHYSICS GROUP

Narrative

The objective of this work is to measure electron yield profiles for low-density polyethylene (LDPE) at varying temperatures in a high vacuum environment. This information will provide a window into how the material charges when submitted to varying temperature in space-like environments with electron fluxes. With a large enough temperature range, insight may be gained on phase transitions of the material as well.

LDPE has a relatively simple branch-like structure of carbon and hydrogen. LDPE has many interesting characteristics such as high electron affinity, water-resistance, durability in extreme temperatures, and radiation resistance [1]. The high durability, low weight, and ease of recyclability are several reasons why this material is so commonly found in packaging today. However, more research into how the material behaves in space-like environments may play a pivotal role in how it can be used in conjunction with spacecraft design. As the simplest organic polymer, LDPE is also the subject of many theoretical studies of how defect structure on the atomic scale is related to electron transport properties and electron emission.

Electron Yield Overview

When a solid material is subjected to an electron beam in a vacuum, the interaction can result in electrons being emitted from the material itself. These electrons are classified in two categories; secondary (δ) and backscattered (η). By comparing these types of emittances with the incident beam, we are able to determine backscattered and secondary yield. The sum of these two yields provides the total electron yield of the material (σ). Over a certain energy range, a profile of the material's electron yield can be determined. This information is essential to understand the charging effects of this material when subjected to a space-like electron plasma environment. There are three fundamental points to consider when looking at a yield profile (Fig. 1). Two of these are called crossover energies which denote the points at which the total electron yield crosses unity. Total electron yields under unity define energy regions in which the material would negatively charge with electron bombardment. Total electron yields over unity define energy regions in which the material undergoes positive charging with said bombardment. The third extreme point denotes the maximum total electron yield. This point highlights the bombardment energy that provides the highest rate of positive charging in the sample.

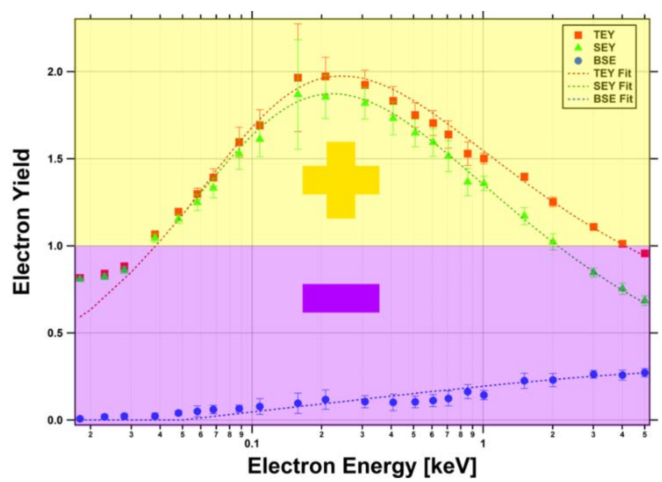

Figure 1: Electron Yield profile of Tungsten with charging region overlay. Total, secondary, and backscattered yield data fits are shown in red, green, and blue, respectively.

Two sets of testing are performed on a given material during yield measurements. The first set is a measurement of total electron yield, in which data concerning incident and emitted electrons is recorded through four sensors. The second set of measurements requires that a section of the sensor device be biased to -50 V. Electrons with enough energy to surmount this potential are classified as backscattered electrons. Traditionally this potential has been used as the discriminator between whether an electron emitted from the sample is considered a secondary electron or a backscattered electron.

By assessing the backscattered and secondary emissions in relation to the incident electron beam, we can assess charging mechanisms within the material.

Previous Experiments

High energy yield tests (energies of 5 keV and higher) have been performed on LDPE [2]. The reason for lack of research in this area is due to yield data being difficult to collect from insulators. The difficulty of LDPE, within the class of insulators, is greater still due to its negative electron affinity leading to high yields as well as a high resistivity. These characteristics define a material that can be charged very fast and take long periods of time to discharge. Pulse-yield and Yield Decay methods have been designed by researchers at USU in order to alleviate these issues [3]. I have performed yield measurements on conductors such as gold and tungsten. With the use of charge neutralizers mentioned in the next section, I have also performed yield measurements on insulators such as quartz (silicon oxide), polyimide, and PEEK. Other tests have been performed within the chamber such as DC spectra and cathodoluminescence.

Currently the Electron Emission Test (EET) chamber is fitted with a Hemispherical Grid Retarding Field Analyzer (HGRFA) [5] and STAIB electron gun. The electron bombardment comes from a STAIB electron gun which allows for manipulation of electron energies within its allowed range (10 eV to 5 keV). A UV LED and low-energy electron flood gun act as charge neutralizers. The very act of taking a yield measurement of an insulator causes it to charge up. The neutralizers ensure that we are taking measurements from a neutral sample at every data point. The combination of charge neutralizers, STAIB gun, and HGRFA allows for yield measurements in lower energies mentioned previously (see Figure 2) [4]. These samples are subject to the chamber's ultra-low pressure range of ~10 nanotorr. The team is currently augmenting this system for automation and noise reduction. These augmentations could allow the conventional data acquisition time of 4-6 hours to be reduced to only 2 hours.

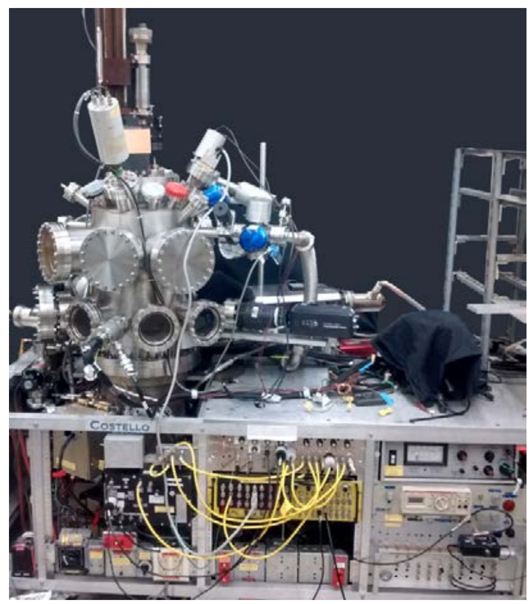

Figure 2: EET Chamber with system components [2].

A cryostat system, previously used by the team for cathodoluminescence experiments [6] has already been shown to work within the EET chamber. The cryostat system allows acquisition of data over a sample temperature range of 40 K to 450 K with temperature stability of ±0.5 K [7]. However, the cryostat system has never used in parallel with the HGRFA and STAIB gun for low energy yield measurement. Combining the yield measurement with the cryostat system is the main focus of my current Blood scholarship for Summer 2017.

Proposed Experiments

With the addition of a stable mounting and thermal isolation of the HGRFA on the cryostat, we could perform low energy yield measurements of temperature controlled samples of LDPE. Using the temperature range of the cryostat system and its small temperature variance, yield profiles could be developed for each designated temperature value. These yield profiles will provide an idea of how the material intrinsically responds to temperature fluctuations in high vacuum environments. Given LDPE has a bandgap ~4 eV, we should expect to see interesting data at temperatures below room temperature. Such a system and the data collected for LDPE is a rarity. There are almost no studies of temperature dependence of yield and no high resolution yield studies on insulators

The intent of this project is to create yield profiles of LDPE in relation to temperature. However, if there is extraordinary success in this area, we may wish to examine yield profiles in a temperature range that has shown anomalies in other experiments. At around 250-300 K LDPE has been exhibited very abrupt and anomalous behavior in regards to radiation induced conductivity [7], steady-state conductivity [8], electrostatic breakdown [10], and permittivity (see Figure 3). These changes in electron transport are believed to be related to a structural glass phase transition for LDPE which occurs in the 250 K to 265 K range. Exploring the electron yield profiles for this range may provide more evidence to support this idea. The ability to correlate changes in electron emission with both a structural phase transition and with changes in electron transport properties are an exciting and novel prospect.

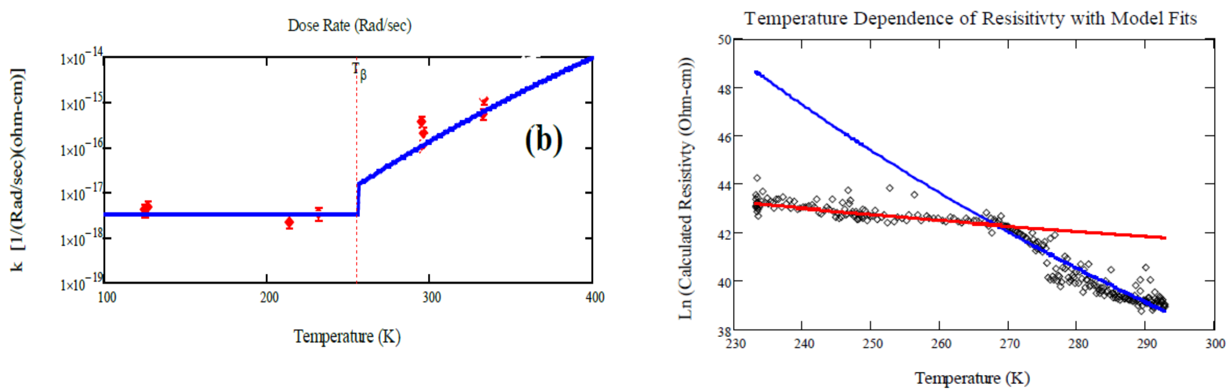

Figure 3: (a) Radiation induced conductivity of LDPE with signature at 250 K [8] and (b) resistivity of LDPE with signature at 270 K [9].

Summary of Effects

There are only a handful of labs around the world that can even attempt high resolution yield testing of insulators, USU having one of them. Electron yield data taken for insulators at these energies is a rarity in the field, but the combination of temperature effects would provide new research. Not only is this project attempting to learn more about electron yields in polymers, but may recover data that supports the idea of yield dependence on structural phase transitions. Successful completion of this project would provide an avenue of research that could be continued and improved upon by the Material Physics Group. Those methods of research would be unparalleled by any other lab in the world.

EDUCATIONAL PLAN

This project is the amalgamation of different apparatuses used in previous research. This experience would offer me the chance to combine these complex systems together. The knowledge gained from this would put me far ahead in the needed tools for graduate studies in experimental Physics.

I plan to submit an abstract to the Spacecraft Charging Technology Conference (SCTC) and present at APS Four Corners Meeting as well as USU's Student Research Symposium. These submissions and presentations will offer me the experience needed to pursue a career of research in Physics. The speaking opportunities, paper writing, and collaboration with others in the field will make me a strong candidate for graduate placement.

Completion of this project may allow me to encourage other students of Physics or engineering to steer this project in the direction of their choosing. Giving them the needed resources and proper machinery to create their own URCO projects.

Personnel Overview

Jordan Lee is a senior undergraduate student pursuing a degree in Physics with a Professional Emphasis, with a minor in Mathematics. He has been a member of the Material Physics Group since the fall of 2016 and has assisted with performing yield measurements, DC spectra, and cathodoluminescence of conductors and insulators within the Costello chamber at USU.

Gregory Wilson received dual B.S. degrees in physics and mathematics from Utah State University in Logan, UT in 2012. He received an MS in physics from Montana State University in Bozeman, MT in 2015. He is currently a PhD student in physics at Utah State University. He has worked with the Materials Physics Group for four years on electron emission and luminescence studies related to spacecraft charging.

J. R. Dennison is a professor in the Physics Department at Utah State University, where he leads the Materials Physics Group. He has worked in the area of electron scattering for his entire career and has focused on the electron transport and electron emission of materials related to spacecraft charging for the last two decades. He will provide project oversight and will work directly with Jordan and Gregory on implementation of the cryostat system and how to interpret data.

Timeline

Current efforts are being made to reduce noise and automate yield testing for the EET chamber. Without these augmentations, low energy yield measurements for insulators can take anywhere between 4 and 6 hours. With these augmentations, time needed for yield measurements could be reduced to 3 hours. Analysis of these measurements is quite a bit shorter and can take less than an hour to perform. There will only be one sample of LDPE in the cryostat sample holder for a given test. Breaking vacuum, switching samples, and reducing chamber pressure can take days to perform and will denote the bulk of time taken for sample preparation. The main focus of this project is the yield data taken in September, which will provide novel data for LDPE research. Tests performed in October and November will take up the bulk of yield testing time at over 45 hours.

Table 1: Project Timeline

URCO Project Time Line

Objective	Completion
• Design, testing, and implementation of the cryostat with the STAIB and HGRFA system (Blood Scholar Project).	May / August 2017
• Sample preparation: secure and cut sample sheets, bakeout samples, and store in nitrogen-rich sample box • Verify STAIB and HGRFA are working properly • Test cryostat setup functionality • Perform gold yield test for calibration	August, 2017
• Begin LDPE yield testing at 120 K • Analyze yield profile at 120 K • Assess any errors or malfunctions • Fix errors and malfunctions	September, 2017
• SCTC abstract submission • APS Four Corners • Begin LDPE yield testing at 150 K • Continue yield testing in steps of 10 K up to 300 K • Analyze yield profiles for every temperature step • Begin writing for the URCO report	October / November, 2017
• Submit final URCO report	December, 2017

Budget

Table 2 describes the budget summary for the project. LDPE with given thickness is the material necessary for experimentation. The HGRFA will need to be attached to the cryostat, but kept thermally isolated from the samples. This will require that the HGRFA have an appropriate mount for the cryostat.

Table 2. Budget Summary

URCO BUDGET SUMMARY		
EXPENSES:	**VENDOR**	**AMOUNT:**
Supplies		
Vacuum supplies, gaskets, filaments	MDC Vacuum	$185
HGRFA Mount: Materials	McMaster-Carr	$150
HGRFA Mount: Machining Costs ($65/hr x 7 hr)	Mountain Valley Machining	$455
LDPE Samples 150 mm x 150 mm x 2.3 mm 5 pcs	GoodFellow	$221
Stipend		
Jordan Lee		$1000
TOTAL BUDGET:		$ 2011
VP for Research URCO Funds		$1250
Materials Physics Group Matching Funds (A07563)		$761
TOTAL FUNDING SOURCES		$2011

REFERENCES

[1] International Atomic Energy Agency. "Stability and stabilization of polymers under irradiation." Vienna: IAEA, 1999.

[2] Song, Z. G., C. K. Ong, and H. Gong. "Secondary and backscattered electron yields of polymer surface under electron beam irradiation." Applied Surface Science, 1997: 169-175.

[3] Ryan Hoffmann, JR Dennison, "Methods to Determine Total Electron-Induced Electron Yields Over Broad Range of Conductive and Nonconductive Materials," *IEEE Trans. on Plasma Sci.*, **40**(2), 298-304 (2012).)

[4] Christensen, Justin, "Electron Yield Measurements of High-Yield Low-Conductivity Dielectric Materials," MS Thesis, Utah State University, Logan, UT, 2017.

[5] Ryan Hoffmann, JR Dennison, Clint D. Thomson, and Jennifer Albretsen, "Low-fluence Electron Yields of Highly Insulating Materials" *IEEE Transaction on Plasma Science*, **36**(5) October 2008, 2238-2245.

[6] Evans Jensen, Amberly, "Modeling the Defect Density of States of Disordered SiO_2 Through Cathodoluminescence," MS Thesis, Utah State University, Logan, UT, 2014.

[7] Justin Dekany, Robert H. Johnson, Gregory Wilson, Amberly Evans and JR Dennison, "Ultrahigh Vacuum Cryostat System for Extended Low Temperature Space Environment Testing," *IEEE Trans. on Plasma Sci.*, **42**(1), 266-271, 2014.

[8] JR Dennison, Jodie Gillespie, Joshua Hodges, RC Hoffmann, J Abbott, Alan W. Hunt and Randy Spalding, "Radiation Induced Conductivity of Highly-Insulating Spacecraft Materials," in Application of Accelerators in Research and Industry, *American Institute of Physics Conference Proceedings Series*, Vol. **1099**, ed. Floyd D. McDaniel and Barney L. Doyle, (American Institute of Physics, Melveille, NY, 2009), pp. 203-208.

[9] JR Dennison and Jerilyn Brunson, "Temperature and Electric Field Dependence of Conduction in Low-Density Polyethylene," *IEEE Transaction on Plasma Science*, **36**(5), 2246-2252, 2008.

[10] Allen Andersen, JR Dennison, Alec M. Sim and Charles Sim, "Electrostatic Discharge and Endurance Time Measurements of Spacecraft Materials: A Defect-Driven Dynamic Model," *IEEE Tran. Plasma Science*, **43**(9), 2015, 2941-2953.

Curriculum Vita

EDUCATION

H.S. Diploma — May 2005
Beaver High School, Beaver, UT

B.S., Psychology — May 2010
Biology Minor, — GPA 3.3
Southern Utah University, Cedar City, UT

B.S., Physics, Professional Emphasis — Dec 2017
Math Minor, — GPA 3.8
Utah State University, Logan, UT

TECHNICAL WORK EXPERIENCE

Research Assistant — 11/16 - current
USU Materials Physics Group — Logan, UT

- Operated high vacuum testing facilities
- Performed electron yield measurements
- Performed data analysis using Igor
- Currently implementing the cryostat system

COMPUTER SKILLS

Python DataThief Igor Pro Microsoft Office LabVIEW

AWARDS

- Blood Scholar — Summer 2017
- Sigma Pi Sigma: Physics honor society member — 2017
- Undergraduate oral presentation award (SRS) — 2017

ACHIEVEMENTS & ACTIVITIES

Society of Physics Students: Physics outreach activities — 2015 – current
Physics Day at Lagoon: Physics outreach — 2015 – current
USU Observatory Night: Physics outreach — 2015 – current

PRESENTATIONS

Vanessa Chambers and **Jordan Lee**, “Analysis of Holography Methods,” *Student Research Symposium*, Utah State University, Logan, UT, April 13, 2017. [Oral Presentation]

Vanessa Chambers, **Jordan Lee**, and America Wrobel, “Analysis of Holography Methods,” *Student Research Symposium*, Utah State University, Logan, UT, April 13, 2017. [Poster]

URCO Matching Funds Commitment

Student Name ____Jordan Lee______________________________ whose A# is __A00388645__.

The title of the project is Temperature Dependence of Electron Yield in Low Density Polyethylene

1 SCHOLARSHIP MATCHING FUNDS COMMITMENT

As part of the URCO program, a scholarship match is required. This letter serves as JR Dennison's commitment to meet the matching funds requirement for this URCO scholarship.

JR Dennison (name of faculty mentor/Department/College) will provide support in the form of **F&A or E&G funds** for this scholarship. The index these funds will come from is A07563 (index number). An additional account may be used to provide matching support from the Physics Department (index number TBD).

If this URCO application is approved, I authorize the Research and Graduate Studies (RGS) office to transfer $250 in funds from this index to match the $750 in funds from the RGS office to award the student a $1,000 scholarship.

Sincerely, John Robert Dennison

2 EQUIPMENT MATCHING FUNDS COMMITMENT

As part of the URCO program, a 1:1 match is required for equipment/supplies/research travel funds. This letter serves as JR Dennison's commitment to meet the matching funds requirement.

The total request for the equipment/supplies/research travel funds is $1011. Of this request $511 will be provided by JR Dennison. The index for these matching funds will be A07563. An additional account may be used to provide matching support from the Physics Department (index number TBD).

If this URCO application is approved these matching funds will be made available for this URCO project expenses. The faculty mentor's department will be responsible for overseeing the expenditures for this URCO project. RGS's funds will be transferred to the department

Sincerely, John Robert Dennison