Design and implementation of a cryogenic electrical characterization system for organic photovoltaic cells

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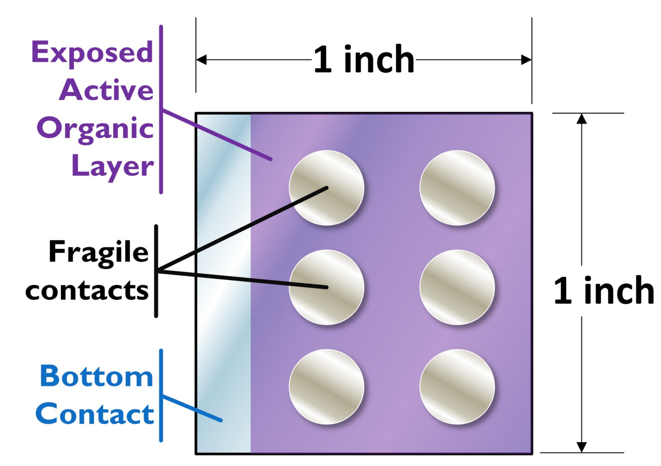
INTRODUCTION

Organic photovoltaic (OPV) cells are a promising future energy technology, but current materials suffer from relatively poor operating efficiencies. One major obstacle to improving this efficiency is the presence of electronic trap- states in the devices due to material defects. Thermally Stimulated Current (TSC) spectroscopy is one possible method used to characterize and understand such defect states, but no dedicated commercial systems exist, and the required equipment is prohibitively expensive. The goal of our project is to design a relatively cheap TSC platform using liquid nitrogen (LN_2) and to develop customizable software for automating TSC experiments. Our system will be used by researchers at the ISU Microelectronics Research Center.

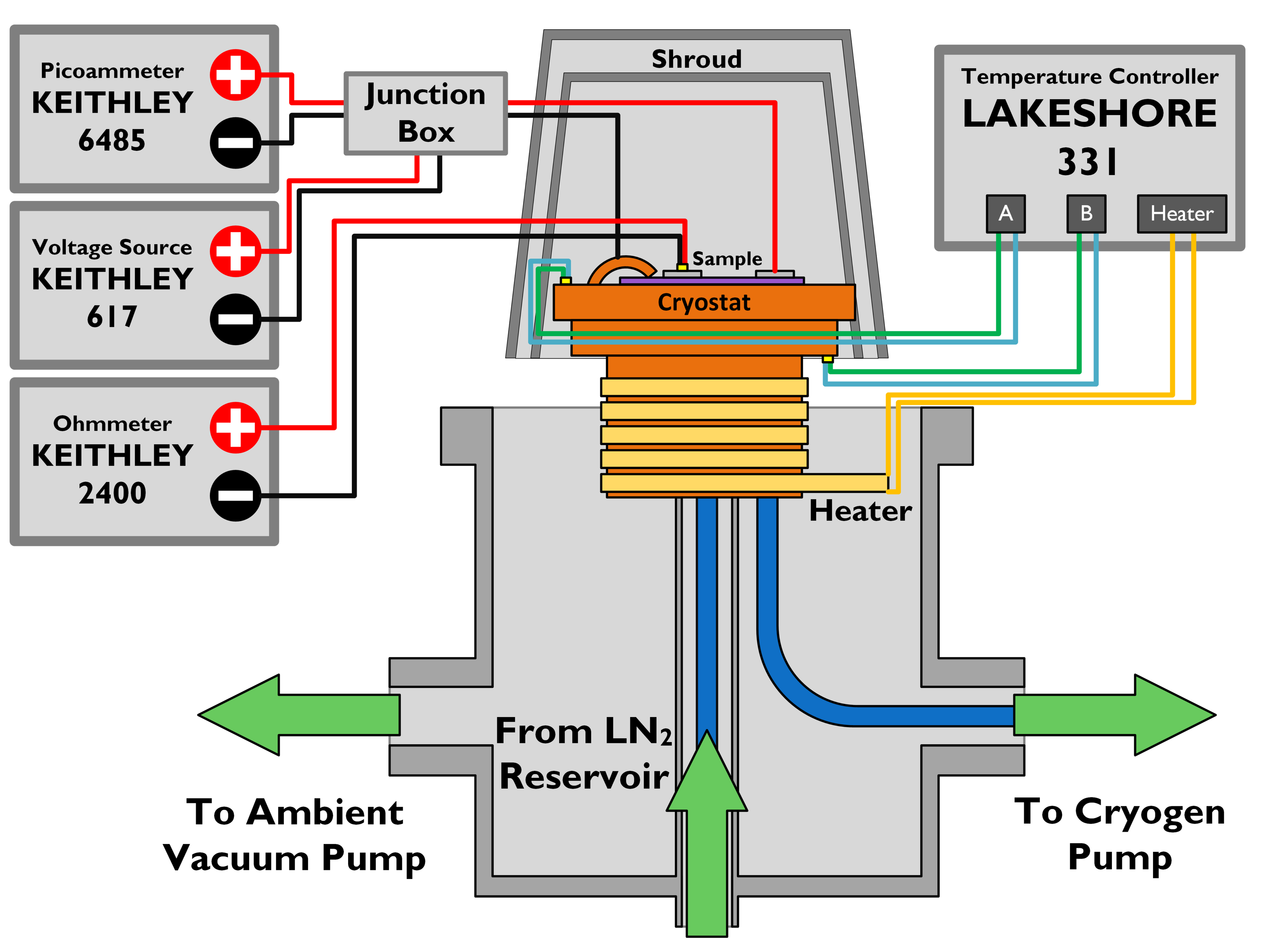
DESIGN REQUIREMENTS

* Make contact to the fragile surface of the standard OPV sample
* Accurately measure the temperature of the sample
* Use LN_2 to bring the temperature of the sample to 80 K
* Measure current signals with pA resolution or better
* Control the temperature ramp rate within 0.1 K/min
* Automate experiment operation and data collection
* Allow for complete experiment customization



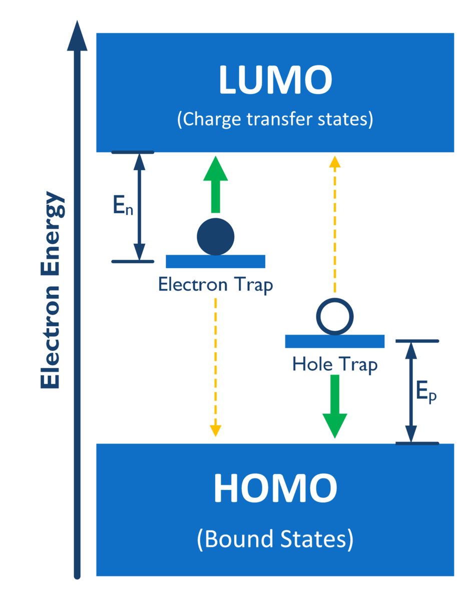
A thin-film OPV cell, mounted to a glass slide

SYSTEM OVERVIEW

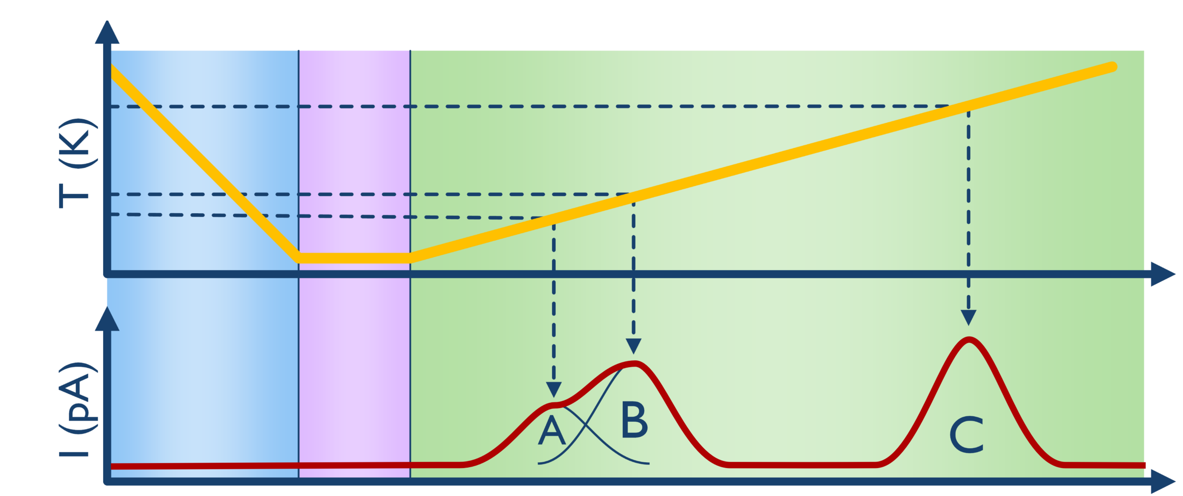


THERMALLY STIMULATED CURRENTS

The method of Thermally Stimulated Currents is a low-temperature technique used in materials characterization. A sample is cooled to cryogenic temperatures, and then electrons are injected into mid-gap defect states, where they become trapped. The sample is then heated slowly, and electrons escape from the traps as the thermal energy becomes large enough. By collecting these electrons and measuring the current, one can see a series of "glow peaks," which quantitatively describe the energies and populations of the trap states.



Band structure of an OPV, showing mid-band trap states. The green arrows denote TSC transitions.



Schematic of a basic TSC experiment. This experiment shows three defect states, labeled A, B, and C.

THERMAL MANAGEMENT

Liquid nitrogen boils at 77 K (-321° F). In order to get a sample down to 80 K, only three K above that temperature, any small leakage of heat into the system must be eliminated, but probes must connect directly to the sample to measure current and determine the exact temperature. Several important features of our design solve both of these problems simultaneously.

* High accuracy Platinum Resistive Temperature Detectors (RTD)
* Thinnest possible wiring to maximize thermal impedance
* Removable shroud creates cold pocket around sample
* Cryogenic varnish to stabilize wiring mechanically and thermally
* Simple clamp holds sample in place and acts as contact point
* Apiezon N cryogenic grease to enhance thermal contacts

An OPV sample in the system, ready for measurement

The layered shroud prevents all kinds of thermal loss

MEASUREMENT INTEGRITY

TSC experiments require high-accuracy, low-noise current measurement, but also require a cascade of connections and instruments. However, making reliable, robust contact to the fragile surfaces of the sample also presents a difficult challenge. Our multifaceted solution addresses all of these issues.

* A custom-built, shielded junction box cleanly routes signals
* Implementation of coaxial and triaxial cabling protects from EMI
* Vacuum chamber grounded to double as a Faraday cage
* Floating "tie-down" contact scheme allows for low-force contact
* New Keithley 6485 Picoammeter proveds 10 fA resolution

The entire assembly, including the LN_2 flask, vacuum hoses, and cabling, is shielded against electromagnetic interference

A custom-built low-noise junction box for the picoammeter and the voltage source

TSC DASHBOARD SOFTWARE

Our system includes a comprehensive, user-friendly, standalone computer-based control program written using National Instruments LabVIEW, which automates experiments with a wide variety of control parameters.

* Allows complete control over the experiment design
* Automates data collection
* Displays data in real-time, and produces intuitive log files
* Presents an intuitive and easy-to-use GUI
* Controls the ramp rate with 0.1 K/min precision