L.14: Development of thermally stimulated current measurement setup for characterizing photovoltaic materials

Study of charge carrier traps due to chemical or structural defects in photovoltaic materials is important as they reduce photocurrent and hence limit the efficiency of photovoltaic devices. Therefore, the knowledge about the nature of traps and their activation energy are important for fabricating efficient devices. Thermally stimulated current (TSC) measurement is one of the most commonly employed methods to probe electronic trap states in semiconductor materials. In this regard, a TSC measurement set up has been developed and also used for investigating electronic trap states in methyl ammonium lead iodide (MAPI), an organic-inorganic hybrid perovskite based photovoltaic material used for solar cell applications.

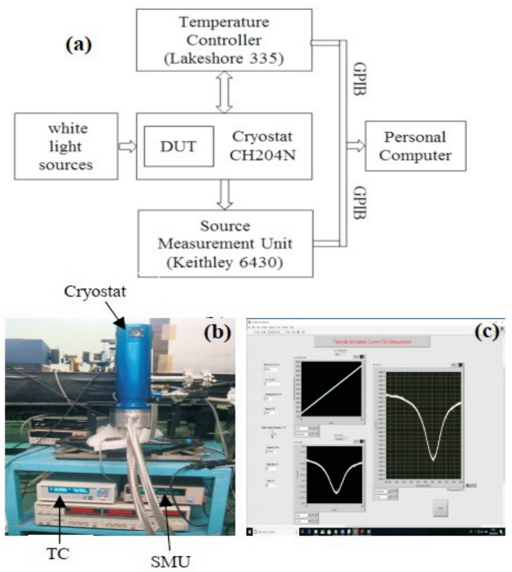

Fig. L.14.1: (a) Block diagram of TSC setup, (b) experimental setup of TSC measurement system, and (c) display of results on front panel graphical user interface (GUI) software.

Figure L.14.1 shows the schematic of the TSC measurement setup, which consists of cryostat, temperature controller (TC), source measurement unit (SMU) and white light source. To perform TSC measurement, charge carriers are photo-generated in the sample using white light after cooling it down to cryogenic temperature (~20 K). The generated carriers diffuse and get trapped in the various traps present in the material. Using TC, the sample temperature is slowly ramped at a constant rate to room temperature. As temperature is ramped, the trapped charge carriers gain thermal energy and they are sequentially released from trap levels, depending upon associated activation energies of the trap sites. This constitutes a current flow, i.e., TSC in the device, which is accurately measured using SMU. The plot of current vs temperature provides the information about the nature of various traps present in the material and their activation energy. The output of the TC and SMU should be accurately measured during the temperature ramping, which requires automation and synchronization between these instruments. General Purpose Interface Bus (GPIB) protocol is adopted for the automation, along with a GPIB-to-USB adapter. An automation software, developed using LabVIEW, provides desired synchronization, data handling, monitoring and control of the instruments during the experiment. Software also stores the data in ASCII format for further analysis. On initiation, the software initializes and configures all the instrument parameters as per the settings provided by the user in the front panel. The software acquires data from both the SMU and TC and provides their real time display, as shown on the front panel of GUI software (refer Figure L.14.1). Two plots on the left side of front panel show the variation of current and temperature with time (100 ms is represented by 1 count) while the plot on the right side is the TSC curve. The TC and SMU readings are averaged before further processing.

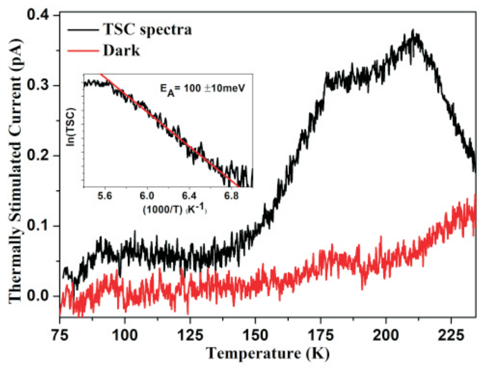

Fig. L.14.2: TSC spectra of MAPI. Inset shows the estimation of the activation energy.

Figure L.14.2 shows the TSC spectra of MAPI recorded at a ramp rate of 5 K/min. TSC is in the range of 0.05 to 0.4 pA, which demonstrates the current sensitivity of the developed setup. TSC spectrum after background correction shows two peaks at 175 K and 212 K, respectively. The peak at 175 K is also present under dark condition and it is attributed to the phase transition induced current, which arises due to the movement of ionic species upon transformation from orthorhombic to tetragonal structure. Analysis using the initial rise method indicates presence of deep traps at activation energy of ~100 meV in the perovskite material.

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