Non-contacting and non-destructive characterization of optoelectronic materials and devices

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Introduction / Overview

Among the various electronic material non-destructive imaging (NDI) methodologies, photoluminescence (PL) imaging has been widely adopted as it allows extracting material and device parameters depending on the PL modality used. More specifically, PL imaging is a versatile technique for the characterization of semiconductor substrates (wafers) and devices spanning almost the entire optoelectronic chain such as solar cells, detectors, light emitting diodes. Photocarrier Radiometry (PCR) and Lock-in Carrierography (LIC) as advanced dynamic PL metrologies allow for the simultaneous determination of electronic Carrier Density Wave (CDW) transport parameters in substrates and devices through best-fitting the amplitude- and phase-frequency responses to appropriate CDW theoretical models by means of suitable multi-parameter fitting procedures. To overcome the near-infrared (NIR) camera speed limitation and poor signal-to-noise ratio (SNR) at high frequencies, heterodyne lock-in carrierography (HeLIC), an extended dynamic range LIC imaging modality pioneered at UofT, was used. This method enables ultrahigh-frequency full images up to several MHz and provides possibilities for the simultaneous imaging of several transport parameters that appear in the kinetics of photocarrier (de)excitation between free energy bands and intraband-gap trap states.

Methods/Experimental Approaches

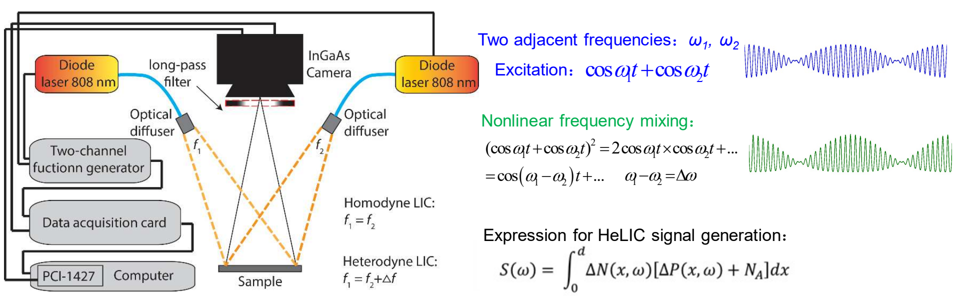

Figure 1. HeLIC experimental setup.

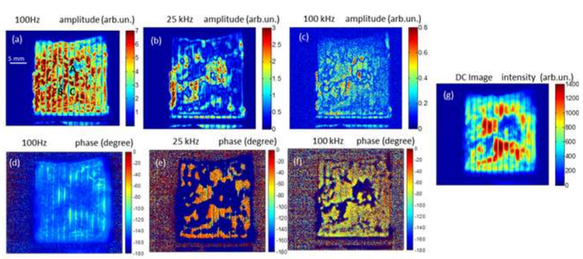

Figure 2. HeLIC InGaAs camera measurements of Silicon solar cell at 100 Hz, 25 kHz, and 100 kHz (a-c) amplitude images. (d-f) phase images. (g) photoluminescence image under DC illumination.

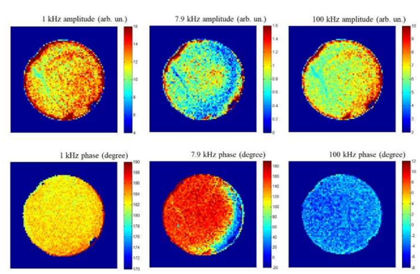

Figure 3. InGaAs camera HeLIC amplitude and phase images of CdZnTe at 1 kHz, 7.9 kHz, and 100 kHz at 100 K .

Major Outcomes/Results/Impact

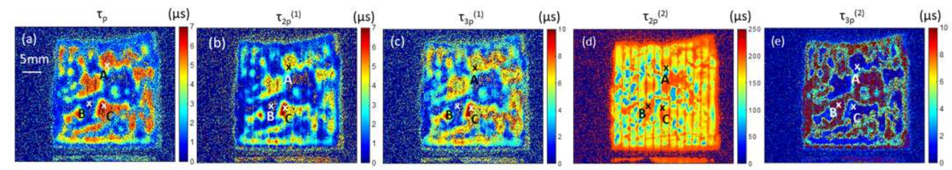

Figure 4. Relaxation time images of CDW traps in Silicon solar cell. (a) carrier lifetime τ_p, (b) $\tau_{2p}^{(1)}$, (c) $\tau_{3p}^{(1)}$, (d) $\tau_{2p}^{(2)}$, (e) $\tau_{3p}^{(2)}$. The $\tau_{2p}^{(j)}$ values represent the capture rate and is a function of the trap concentration, while $\tau_{3p}^{(j)}$ also involve the trap emission rate. j=1, 2 corresponds to the 1st and 2nd intraband-gap defect, respectively.

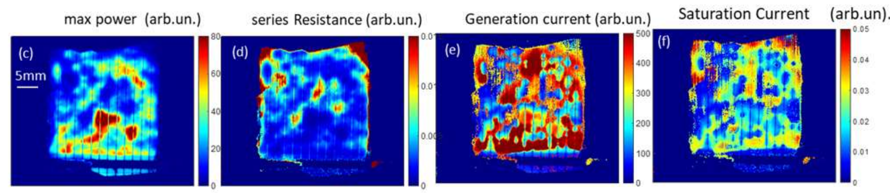

Figure 5. Electrical parameter images of a Silicon solar cell (c) maximum power, (d) (Rs) series resistance, (e) (Ig) generation current, (f) (Io) saturation current.

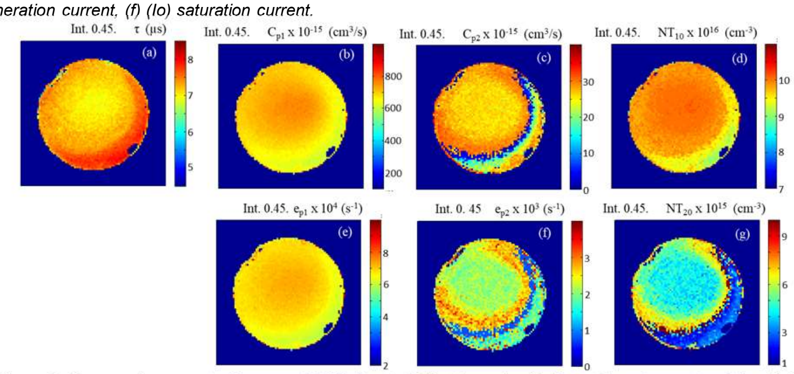

Figure 6. Measured parameter images of CdZnTe at 100K: (a) carrier lifetime, (b) capture rate of the 1st defect, (c) capture rate of the 2nd defect, (d) concentration of the 1st defect, (e) emission rate of the 1st defect , (f) emission rate of the 2nd defect , (g) concentration of the 2nd defect.

The Future: Opportunities

Apply the developed quantitative imaging method (experimental technique and theoretical model) to the non-contact, non-destructive determination of transport and electrical parameter distributions across optoelectronic substrates and fabricated devices which determine their performance.

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