Characterization of photocarrier properties and their associated trap-state transport parameters of CdZnTe using heterodyne lock-in carrierography imaging and deep level photothermal spectroscopy

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Backgound. –The wide use of CdZnTe in detector and solar cell fabrication makes imperative the non-destructive characterization of its transport and defect properties. Homodyne and heterodyne photocarrier radiometry (Ho- and HePCR) as well as deep level photo-thermal spectroscopy (DLPTS) demonstrate high capability for evaluating recombination times, kinetic parameters of traps such as capture and emission coefficients, trap densities, emission/capture relaxation times, and defect level energetics [1-3]. Recently the He-PCR method was extended to camera based heterodyne lock-in carrierography (He-LIC) imaging for constructing images of lateral distribution of optoelectronic parameter in CdZnTe using an InGaAs NIR camera [4].

Methodology. -The method presented here used two spread and homogenized 808-nm laser beams with modulation frequencies $f1$ and $f1 + \Delta f$. The beams were sine-waveform modulated using a two- channel function generator in the range 0.1 -100 kHz. Lock-in demodulation was performed at a beat frequency of Δf =10 Hz. The DLPTS measurement was carried using a cryogenic chamber and an InGaAs single detector in the frequency range 25 – 700 kHz. The evaluation of transport and defect parameters was performed on the basis of a two trap/defect state theoretical model developed using nonlinear rate equations for *p*-type carrier kinetics [1] and various excitation intensities.

Results. –The DPLTS investigation clearly showed the presence of two bandgap traps in our CdZnTe wafer (Fig. 1a). The activation energies were found to be 0.148 and 0.175 eV through fitting to Arrhenius plot of e/T^2 vs. 1/kT. The HeLIC images show inhomogeneous distribution of defects over the wafer (Figs. 2a,b). The kinetics of trap carriers produced a pronounced notch ('dip') phenomenon in the HePCR/HeLIC amplitude frequency response (Fig. 2c) and a phase jump (Fig. 2d). The spatial distribution images of parameters such as recombination lifetime, capture coefficients, emission rates, and concentrations of both traps (Figs. 2e,f) were evaluated from a theoretical dynamic nonlinear rate-equation model with two bandgap traps. HeLIC imaging was used to discuss dynamic photocarrier interactions with CdZnTe traps. Relaxation time images were derived from the kinetic optoelectronic quantities and can be used for optoelectronic characterization of entire CdZnTe wafers.

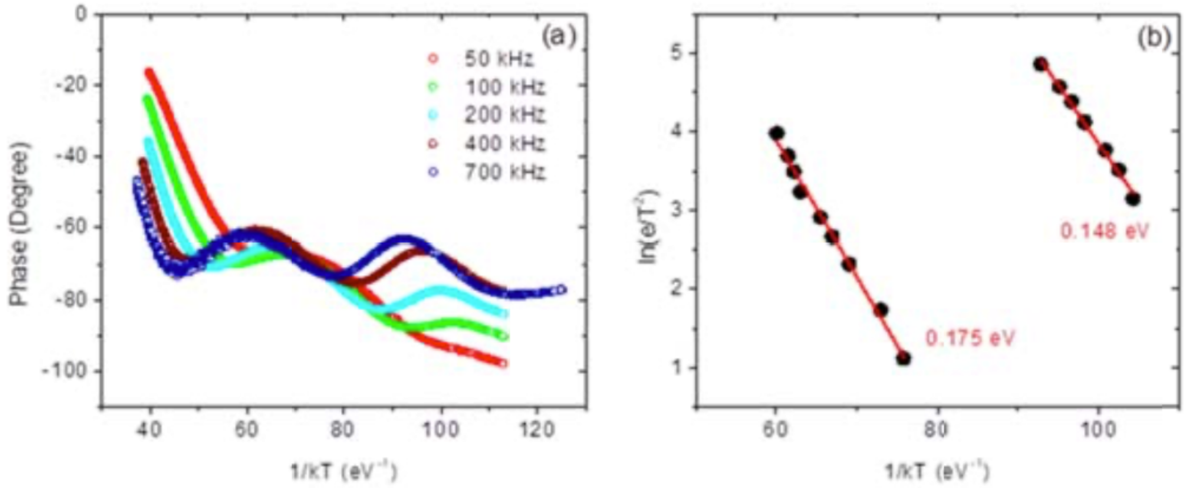

Fig. 1. (a) Homodyne PCR phase of CdZnTe vs. 1/kT at various frequencies; and (b) Arrhenius plots with extracted activation energies. Thermal emission rate at each peak was estimated using $e_n(T_{peak})f = 2.86\pi f$.

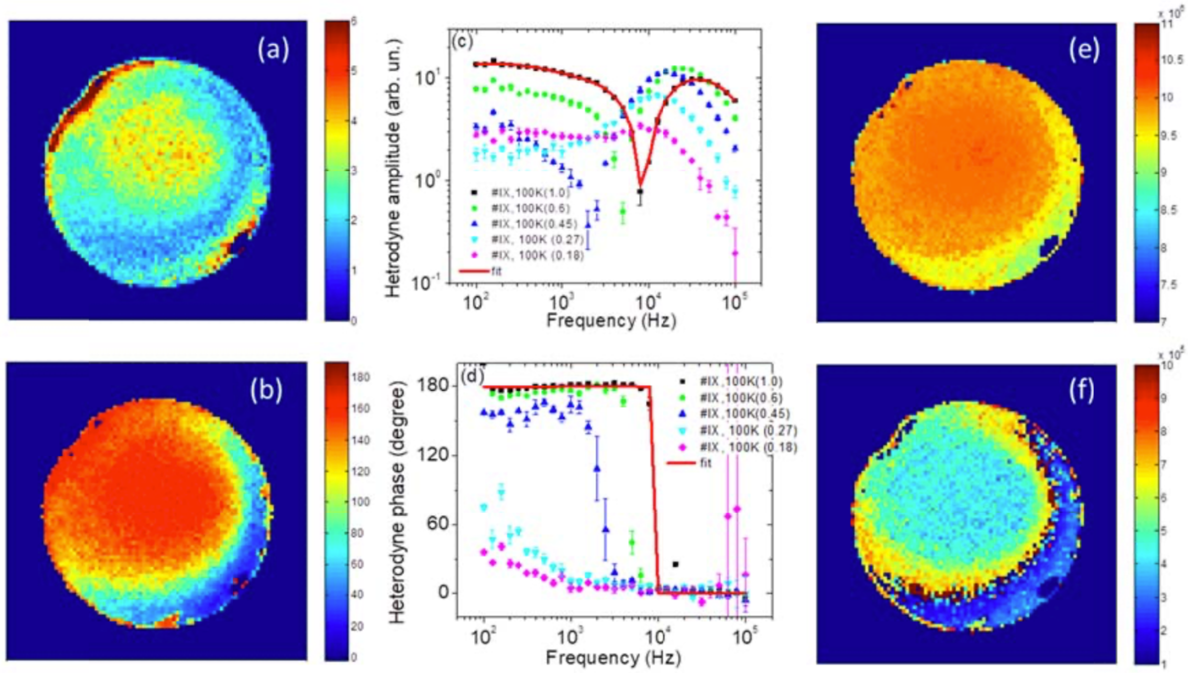

Fig. 1. HeLIC amplitude **(a)** and phase **(b)** image of CdZnTe at 0.25 kHz and intensity $0.45 \cdot I_{max}$, I_{max}=1.9W/cm^2; and amplitude **(c)** and phase **(d)** near-center pixel dependence on frequency at several intensities. Measurements were carried out at 100K. Derived trap #1 **(e)** and trap #2 **(f)** density images at intensity $0.45 \cdot I_{max}$.

Conclusions. –Dynamic radiative HeLIC imaging of CdZnTe wafers coupled with deep level photothermal spectroscopy can be effectively used for kinetic and defect characterization toward quality control of photovoltaic devices and detectors fabricated on this type of substrate.

References

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