High-frequency heterodyne lock-in carrierography (HeLIC) and thermography (HeLIT) imaging of optoelectronic materials

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Background – Camera-based photothermal imaging has been widely used for qualitative and quantitative thermographic characterization of wide spectra of materials. However, the relatively low frame rate of mid-infrared (MIR) cameras strongly restricts the benefits of high frequency imaging. The new photocarrier diffusion-wave modality of heterodyne lock-in carrierography (HeLIC) allows for the elimination of this limitation for high-frequency dynamic imaging of (opto)electronic kinetic phenomena using a near-infrared (NIR) InGaAs camera [1, 2]. The ability to use frequency imaging scans over wide ranges raises the possibility of evaluating the lateral and spatial distributions of various kinds of defect in semiconductor materials with high spatio-temporal resolution. The possibility of heterodyne photothermal radiometry (HePTR) with a single detector was also recently demonstrated [3].

Methodology – The method presented here used two excitation beams with frequencies *f1* and *f1* + 5 Hz. Lock-in demodulation was performed at a beat frequency of 5 Hz. The low beat frequency allowed the use of a low-frame-rate MIR camera to produce images of fast (high-frequency) dynamic thermoelectronic processes. The appearance of signals and images at the beat frequency is due to the nonlinear character of the photothermal response across the illuminated area. Also the NIR InGaAs camera was used in experiment for comparison HeLIC and HeLIT imaging results.

Results – HeLIT imaging was investigated in the frequency range 100 Hz-10 kHz. An example of HeLIT amplitude image of CdZnTe at 10 kHz is presented in Fig. 1a and the corresponding dependence on frequency of one pixel in Fig. 1b. The HeLIC frequency dependence shows a clearly pronounced notch ("dip") at a resonance frequency where the trapping rate into a trap state of a carrier-density-wave matches the trap thermal emission rate superposed on the non-linear electron- hole recombination interactions. The absence of the notch phenomena from the PTR and LIT data may be due to the fact that these modalities are only sensitive to non-radiative kinetics with the thermal field obliterating the phase sensitivity of carrier motion that gives rise to the dip in LIC when opposing trap filling / emptying rates become equal.

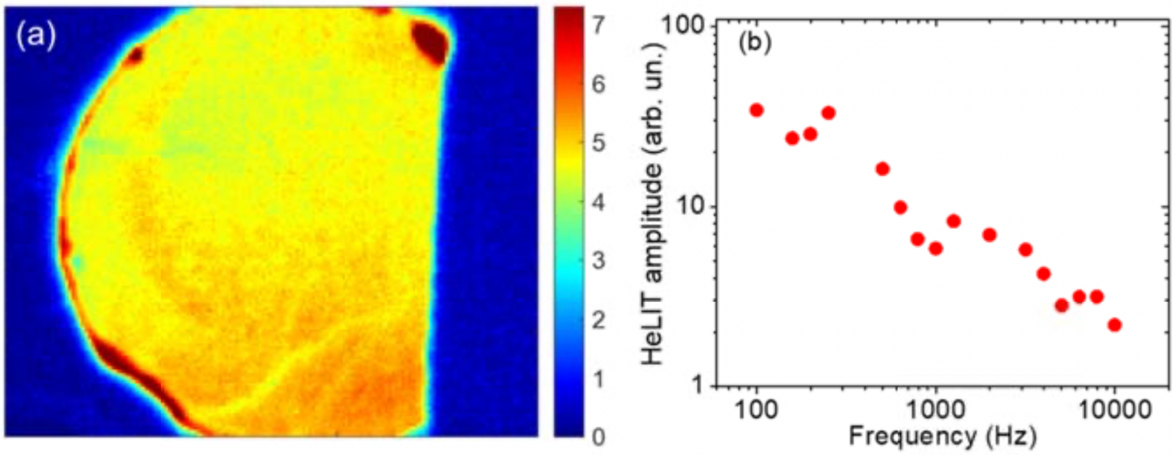

Fig. 1. **(a)** MIR camera HeLIT amplitude image of CdZnTe at 10 kHz; and **(b)** amplitude dependence on frequency of one pixel near the center of the sample. Measurements were carried at 100K.

The same sample was measured using HeLIC. The corresponding HeLIC dependencies are shown in Fig. 2.

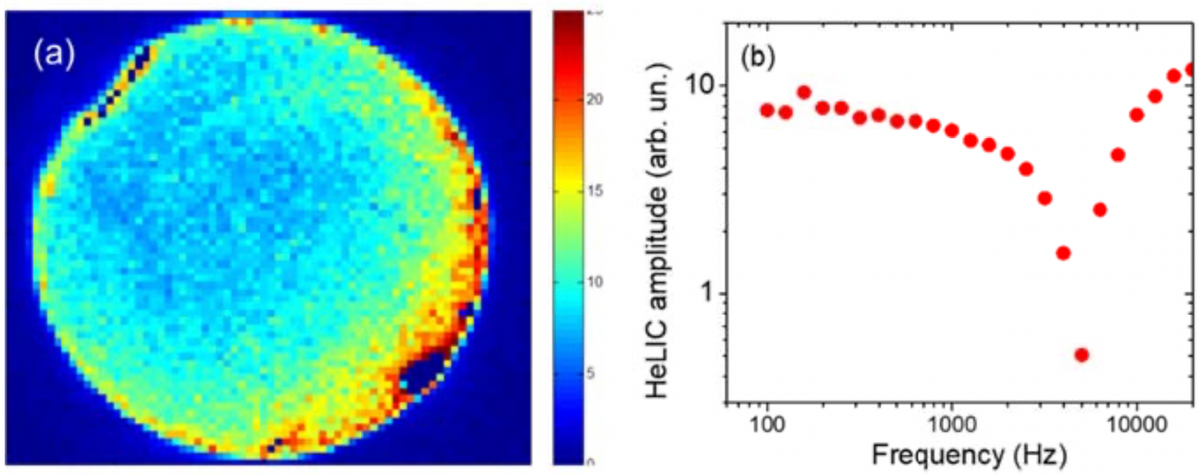

Fig. 2. **(a)** NIR camera HeLIC amplitude image of CdZnTe at 10 kHz; and **(b)** amplitude dependence on frequency of one pixel near the center of the sample. Measurements were carried at 100K.

Conclusions – Dynamic non-radiative (LIT) and radiative (LIC) images of CdZnTe wafers with intraband-gap trap densities were compared for their sensitivity to defect states and photocarrier kinetic effects. Although HeLIT is less sensitive to defect state kinetics, this imaging method allows the exploration of dynamic photothermal imaging of non-radiative photocarrier kinetics at modulation frequencies much higher than accessed by conventional mid-infrared camera frame rates. As a result, spatial distributions of defect topologies shown in Fig. 2(a) are matched with higher resolution details of the same kinetic processes in Fig. 1(a).

References

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