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Imaging infrared lifetime spectroscopy

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Minority carrier lifetimes in photovoltaic materials are commonly derived from transient microwave-detected photo conductance decay (µW-PCD) measurements. The µW-PCD detector scans across the wafer surface to obtain a mapping. Measurement times of 30 min to several hours are typical for a high resolution scan. Three years back we introduced the infrared camera lifetime mapping (ILM) technique that determines the lifetime from the infrared absorption or emission of light-generated free carriers as imaged with an infrared camera [1]. With ILM, the measurement time is reduced from hours to seconds due to the parallel use of the $3x10^6$ detectors in the focal plane array of the IR camera. In this contribution we report on a sensitivity enhancement of the ILM technique by three orders of magnitude as well as on the first realization of lifetime measurements at variable temperature. The combination of fast and highly sensitive lifetime measurements by an infrared camera with the possibility to measure at variable temperatures facilitates imaging lifetime spectroscopy with high spatial resolution.

Measurement setup

Figure 1 shows the experimental setup of the ILM technique. The wafer under test is placed on a heated gold mirror. An infrared camera that is sensitive in the long wave range (peak sensitivity at wavelength of 8 µm, frame rate 38.9 Hz, focal plane array with 640 x 486 detectors) observes the wafer that is heated to a temperature T_W. We generate a trigger signal from the clock of the camera. This trigger alternatingly turns the excitation light (wavelength 940 nm) on and off after a preset number of frames. The excitation light generates excess carriers which modulate the infrared emission. The emission is detected with a lock-in technique as described in Ref. [2]. The conversion of the camera signal to effective minority carrier lifetimes τ_{eff} follows the procedure we proposed earlier [1].

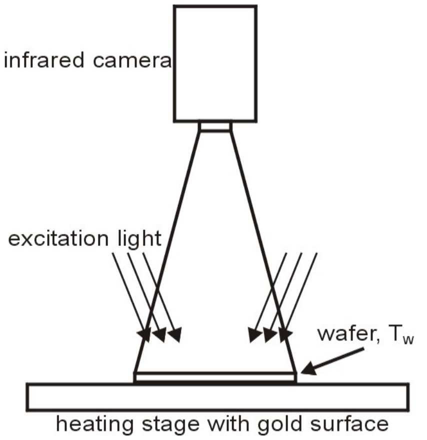

Figure 1: *Experimental setup for infrared lifetime mapping (ILM) in the emission mode. The wafer is heated to a temperature T_W by a heater of low IR emissivity. The modulated excitation light cause a modulated infrared emission by photogenerated free cariers that is observed with the camera.*

The advantage of the mirror is twofold: It doubles the sensitivity by re-directing the IR light emitted through the back towards the camera and it suppresses IR emission from the heater. The experimental setup is thus much simpler than our earlier suggestion to cool the background [1, 3].

Comparison with conventionally measured lifetimes

Imaging lifetimes in the ms range

We demonstrate the image quality of our ILM-Emission technique on a high lifetime boron-doped FZ wafer. The wafer is p-type, 300 µm thick and has a resistivity of 1.4 Ωcm. Both sides of the wafer are surface-passivated with a 50 nm thick amorphous Si-layer. Figure 2 shows a lifetime mapping of a quarter of a 4"-Si wafer as measured by ILM in comparison with a lifetime mapping by µW-PCD. The ILM-measurement took 30 s while the µW-PCD measurement took 2 h despite a slightly poorer pixel resolution. Measurement times in the sub second range are easily feasible. Both measurements were taken under low level injection conditions. Good agreement is achieved. The agreement is not exact since ILM determines an actual lifetime at 70° while µW-PCD determines a differential lifetime at room temperature.

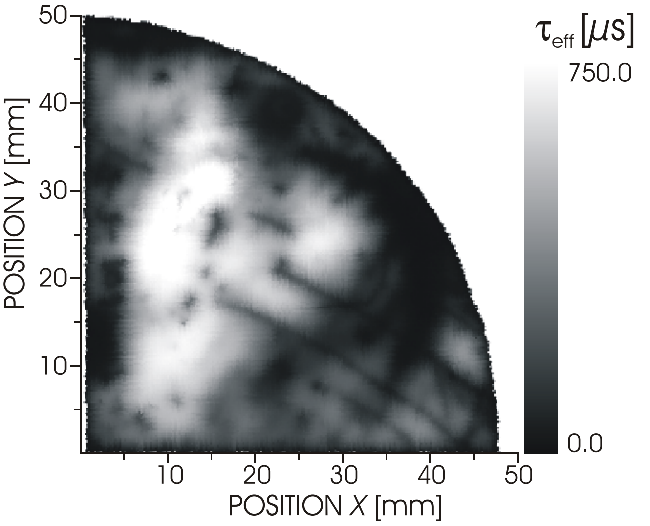

Figure 2a) Measurement by *ILM emission at 70 °C of a surface-passivated silicon wafer with a lateral resolution of 200 µm and a measurement time of 30 s.*

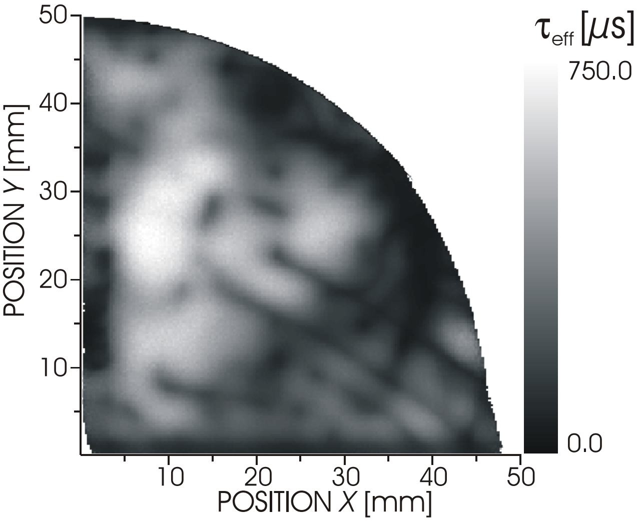

Figure 2b) *Measurement by µW-PCD at room temperature of the sample shown in Fig.2 a). The lateral resolution is 250 µm and the measurement time is 2 h.*

Temperature-dependent lifetimes in the µs range

In order to check the ILM technique in the range of short lifetimes we investigate an Al-doped Czochralski Si wafer with a resistivity of 2.0 Ωcm. The lifetime in this material is known to be dominated by an Al-related defect [4]. Both wafer surfaces are passivated with 80 nm of silicon nitride.

The squares in Figure 3 show the lifetimes we measure by ILM at temperatures T_W ranging from 70°C to 150°C. The lifetimes vary from 2 µs to 50 µs for an illuminating photon flux of 1.3 x10^{17} cm^{-2}s^{-1}. In order to check these results the sample was also measured with the quasi steady state photo conductance technique (QSSPC) at

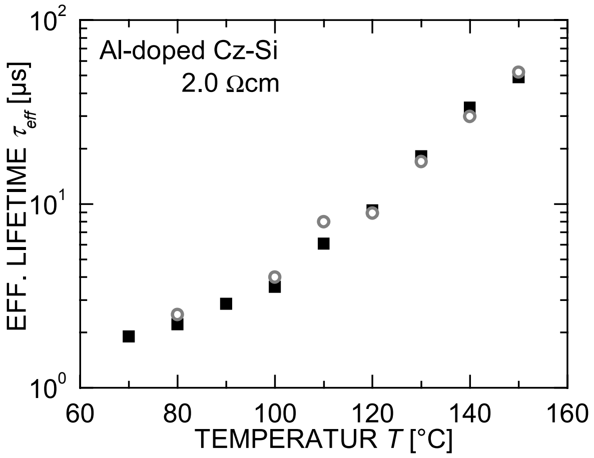

Figure 3: *Effective minority carrier lifetime of an Al-doped Si wafer with surface passivation. Squares: Infrared lifetime mapping (ILM). Circles: Quasi steady state measurements (QSSPC).*

various injection levels and temperatures. Both methods yield the same carrier lifetimes with a deviation of 11 % when averaged over all measurement temperatures. A spatial image of the trap energy may be plotted, after evaluating the energy level of the lifetime killing defect as a function of position on the wafer.

Sensitivity analysis

We quantify the sensitivity of the ILM technique by the noise equivalent lifetime (*NEL*). By definition the *NEL* is the minority carrier lifetime a sample has to have in order to yield a signal to noise ratio of unity with an ILM measurement [1]. In order to determine the *NEL* experimentally, we selected an area on the wafer with a spatially homogeneous lifetime. We measure an average lifetime of 3.7 µs ± 0.4 µs in this area by µW-PCD. In this area we perform ILM measurements at various temperatures. The *NEL* is then deduced from the *spatial* fluctuation of the lifetime determined by ILM.

Figure 4 shows the experimental *NEL* as a function of the number of evaluated image frames for a measurement at 70 °C. As expected [1], the NEL decreases with the square root of the number of frames. After 10,000 images and a measurement time of 4.3 min the *NEL* decreases to a value of 0.1 µs. Further noise reduction is achieved for measurements above 70°C [1].

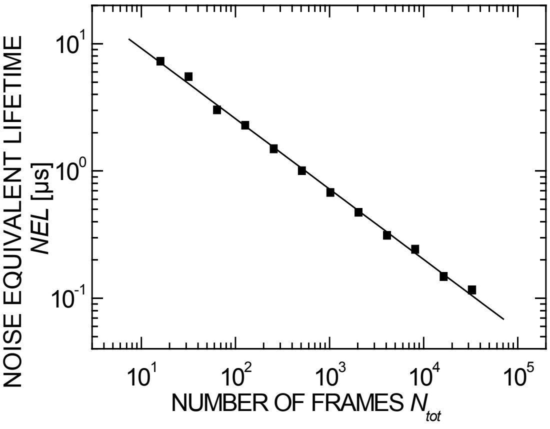

Figure 4: Squares: *Experimental noise equivalent lifetime NEL as measured by ILM on a sample with* τ_{eff} *= 3.4 µs. Line: Linear fit to measured data.*

Acknowledgement

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References:

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