Area: Crystalline and Thin Film Silicon PV

IMPACT OF TRANSIENT TRAPPING ON STEADY STATE PHOTOCONDUCTANCE LIFETIME MEASUREMENTS

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Quasi-steady-state photoconductance\textsuperscript{2} (QSSPC) based injection-dependent lifetime measurement is one of the mostly used characterization techniques for crystalline silicon material. However, artificially high lifetime is often observed at low injection due to carrier trapping. The current understanding and correction methods\textsuperscript{2} of trapping effects are based on the model proposed by Macdonald \textit{et al.}\textsuperscript{3} which assumes that the measurement is done under a quasi-steady-state (QSS) regime. Nevertheless, from both simulations and experimental data, it can be seen that in some cases carrier trapping is better described by the transient regime, even though the dominant recombination process via a Shockley-Read-Hall (SRH) defect is under QSS condition. Therefore, the current commonly-accepted model may lead to misinterpretations and inaccurate correction of the trapping effect.

In the most widely used Sinton Instruments’ lifetime tester, the photoconductance (PC) of the sample is measured inductively when sample is excited by a Xenon lamp pulse flash with a decay time constant ($\tau_0$) of 2.3 ms. To investigate the impact of traps in this measurement condition, a simulation program that numerically solves the SRH rate equations of carrier concentrations was developed using the backward differentiation formula (BDF) method.

\begin{figure}[h]
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\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{(a) Simulation of the PC measurement with various illumination decay time constants; (b) measurement and simulation result of an $n$-type wafer with a strong trapping effect.}
\end{figure}

The simulated PC lifetime for an $n$-type sample with a recombination active defect and a trap-like defect is shown in Fig. 1(a). The black solid line represents the steady state PC lifetime. The blue dashed line indicates the true transient PC lifetime. The transient lifetime shows a much stronger trapping effect, with an apparent low injection lifetime two-order higher than the steady state lifetime. The doted-dashed lines in between display the PC lifetime obtained by changing the decay time constants of the light source. The 2.3 ms decay time, the time constant of the standard Sinton Instruments system, results with lifetime very close to the transient lifetime. This indicates that the trapping should be analyzed as in transient, rather than as being in steady state, if measured with a standard lifetime tester. Figure 1(b) shows the PC lifetime measurement of an $n$-type Czochralski mono-crystalline silicon wafer. The measurement was done with a Xenon lamp of a standard Sinton lifetime tester. As a comparison, the lifetime measured by photoluminescence (PL), which is hardly impacted by trapping, is also presented. Both measurements were fitted by solving the rate equations with great agreement being obtained. The plateau value of the PC lifetime at low injection indicates a trap decay time constant of around 100 seconds, which is significantly slower than the illumination decay. This confirms that this trapping is under a transient condition, and not under the widely assumed steady-state condition.

In summary, we have demonstrated for the first time that under common measurement conditions traps are likely to be under transient condition and not under the more widely-accepted steady-state condition. This finding provides a new and important insight into carrier trapping in PC measurements; it also opens a wide range of new applications. The difference between trapping effect under steady-state and transient conditions will be explained in detail using the developed model. Temperature-dependent lifetime measurements using different illumination conditions will be provided to support the simulation results.

