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Contactless Measurement of Wafer Lifetime by Free Carrier Infrared Absorption*

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A recent tendency in crystalline silicon solar cell production is that a solar-grade material of medium quality with 0.1 - 10Ωcm is introduced for cost reduction purposes. Subsequently, some contactless method to evaluate substrate is desirable to determine cell performance prior to fabrication. As a means of doing so, minority carrier lifetime can be looked at. It is commonly recognized as a key indicator of solar cell performance. Most contactless carrier lifetime measurements so far utilize μ-wave as a probe. However, it is rather difficult with this approach to measure a wafer having a resistivity lower than 1Ωcm, due to the skin effect. An alternative is the use of an infrared beam as the probe. Schwartz et al.[1] showed the possibility of measuring high injection carrier lifetime by infrared absorption through using a rather slow Xe flash lamp as a light source to inject excess carriers and through curve fitting by computer.

This paper extends this method to a Q-switched Nd:YAG laser to define the initial excess carrier distribution be uniform throughout the sample wafer in a very short time. A practical way to obtain the effective carrier lifetime(τ_{eff}) of a Si wafer directly from the relaxation of transmitted infrared beam, is also described.

The free carrier absorption coefficient for an infrared light has been shown to be proprotional to carrier concentration in the range of interest.[2] If the initial excess carrier concentration, Δn_0, is uniform, transmitted light intensity, I, is expressed by

$$I = I_{t0} \exp[-K\Delta n_0 \exp(-t/\tau_{eff})].$$

Here, I_{t0} is transmitted light intensity when no excitation light is applied and K is the constant including absorption cross section and the surface recombination term.

If the change in I, ΔI_t, is small compared to I_{t0}, the following approximation holds: $\ln(I/I_{t0}) = -\Delta I_t/I_{t0}$. Hence, the relation

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$$\tau_{eff} = t/[\ \ln(K\Delta n_0) - \ln(\ \Delta I_t/I_{t0})\ ].$$

This equation implies that τ_{eff} is determined directly as the relaxation time constant of the transmitted infrared beam intensity after carrier injection.

The experimental set-up where a Si wafer is subjected to continuous CO_2 laser beam penetration, while a repetitive Q-switched Nd:YAG laser beam is applied to the area of interest, is shown in Fig. 1. The CO_2 laser intensity was monitored with an HgCdTe infrared detector whose characteristic time constant was shorter than 50ns.

An example of a decay curve and its logarithmic transformation for a 400μm thick, as cut wafer obtained from a solar-grade material is shown in Fig. 2. The obtained τ_{eff} of 6.2μs agreed reasonablly with the bulk lifetime of 40μs determined by the standard photoconductive decay method when one considers the high(10^4cm/s) surface recombination velocity of the cut wafer. A solar cell of 11.9% efficiency was obtained from this material by a process that produces 13% cells from conventional(τ>200μs) material.

In conclusion, the transient infrared absorption method has been established as a contactless, and even remote measuring tool of carrier lifetime. It is applicable to direct evaluation of solar-grade Si wafer for cell production.

References:

1) R. J. Schwartz et al., Conf. Record of the 13 th IEEE Photovoltaic Specialists Conf., Washington D.C. (1978) pp.83.
2) L. Jastrzebski et al., Solid-State Science and Technology, 126(1979) 260.

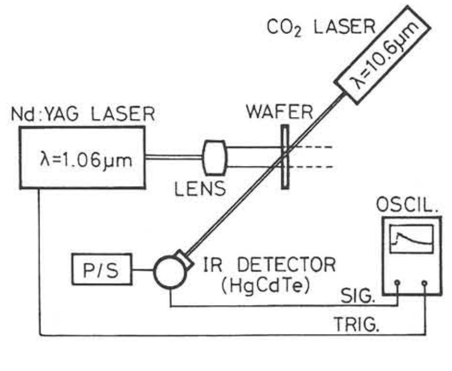

Fig. 1 Schematic diagram of experimental set-up.

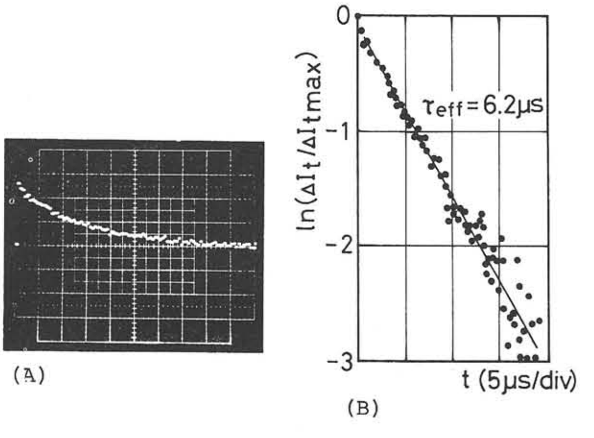

Fig. 2 (A) IR transmission decay cueve measured as voltage change across HgCdTe element under certain bias.
(B) Logarithmic transformation of (A).