

GLM™-2000 Recombination Lifetime Measurements

PROBLEM

Carrier recombination lifetime is an important semiconductor property that strongly influences the characteristics of devices built with these materials. These lifetimes are a sensitive indicator of the quality of semiconductor materials and they are strongly and negatively impacted by the presence of impurities and defects. In the case of photovoltaic materials, carrier lifetimes directly correlate with the conversion efficiency of solar devices produced using the material. An effective tool is therefore needed that can rapidly and accurately measure recombination lifetimes without damaging completed or in-process devices. The tool must be easily integrated into PV device production lines to provide recombination lifetime measurements for use in the quality control procedures of photovoltaic device manufacturing lines.

Two conventional methods are available for carrier recombination lifetime determination: the flash lamp method and the microwave detection method. Neither is entirely adequate as a quality control metrology tool. The flash lamp method is a “quasi” steady state due to the need for lamp ramp-up and ramp-down. Thus, true steady state minority carrier lifetimes cannot be measured. As well, the flash lamp approach cannot measure the dark resistivity. Microwave/laser methods suffer in that they can only measure small regions on a wafer (~1 mm diameter) and calculations do not, therefore, provide a truly representative measure of the wafer properties.

BACKGROUND

Figure 1 shows a schematic that can aid in understanding the principle of photoconductance and carrier recombination. In a photovoltaic material, carriers are generated when light photons impinge on the material. Short wavelength photons have limited penetration and generate carriers near the surface of the PV wafer. Longer wavelength photons penetrate deeper into the material and produce carriers in the bulk of the wafer. Recombination (i.e. loss) of those carriers generated near the surface is proportional to the quality of the surface passivation and any damage that may be present on the surface. Poorly passivated or damaged surfaces result in shorter carrier lifetimes. Carriers generated in the bulk migrate to the surface prior to recombination and the lifetime of these carriers is influenced by diffusion lengths and defects within the PV layer along with those factors influencing surface recombination. Recombination lifetimes within a PV wafer are thus determined by the combined influences of material surface conditions, material bulk contaminants, material bulk and surface defects. Experimental measurements of the recombination lifetimes in a PV material are influenced by the choice of photon wavelength and the light intensity impinging on the surface.

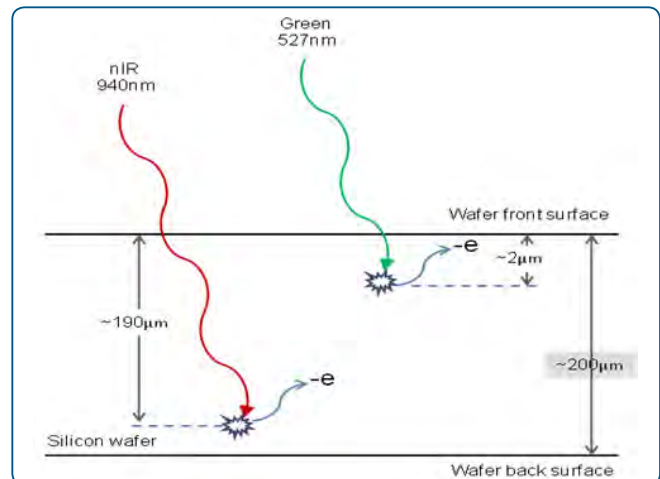


Figure 1

BACKGROUND (CONT.)

Recombination lifetimes can be determined experimentally using the Gtau method. Gtau is just the carrier generation rate multiplied by the lifetime time constant. Figure 2a helps to understand the definition of Gtau. In the (relative) absence of light, the measured conductivity at the surface of a PV wafer is the sheet resistance. In the presence of light, the measured conductivity in a PV wafer rises with a characteristic rise time and rate. When light is removed, the measured conductivity falls in at characteristic rate. Gtau is simply the absolute difference between the “light on” and “light off” conductivities. Rate of rise in the photoconductivity determines PCR (photoconductivity rise) time while the rate of fall when the light is removed determines the PCD (photoconductivity decay) time (Figure 2b).

The sheet resistance of the material provides a means of determining dopant concentration and degree of activation along with process uniformity and wafer-to-wafer variations. The magnitude of Gtau is indicative of the relative abundance of defects, damage, metal contaminants, etc. in partially fabricated PV devices. PCR and PCD lifetimes provide indications of material purity, crystal quality, cleaning effectiveness, surface damage and the quality of surface passivation.

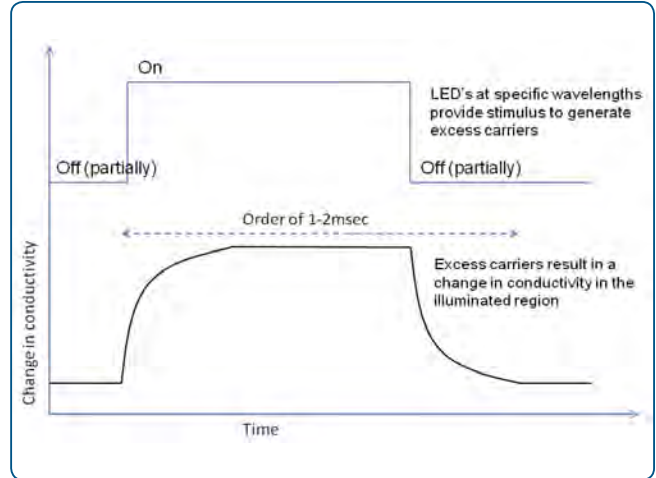


Figure 2a

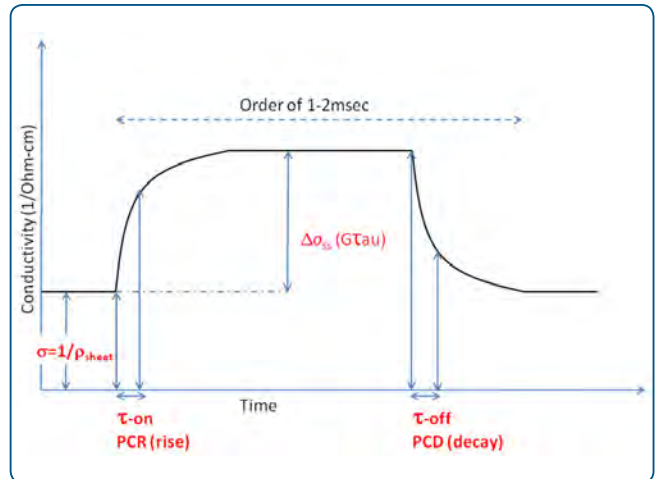


Figure 2b

SOLUTION

The MKS GLM™-2000 PV Wafer and Silicon Monitor (Figure 3) provides a unique non-contact RF detection technology for photoconductance determinations in PV and silicon wafers. This metrology tool measures the quality of PV and silicon feedstocks and partially processed cells using a novel implementation of the current RFPCD measurement technique. Using the GLM-2000 it is possible to obtain contactless measurements of Gtau, PCR, PCD and sheet resistance.

The GLM-2000 is essentially a novel implementation of a transformer. The primary coil is driven with a constant RF voltage. When a wafer is inserted in the slot, it acts as the secondary coil of the transformer. Variations due to differences in conductivity of the wafer induce differences in the primary coil. These differences can be detected by providing a balancing circuit that maintains a constant voltage on the primary coil. Without illumination and with a wafer inserted in the GLM-2000, the measured losses can be related to the base sheet resistance of the wafer. When the wafer is exposed to a light source, changes are induced in the conductivity that can be measured as Gtau, PCR and PCD. Figure 4 shows the simplicity of a typical output of the GLM-2000. It can be seen that the output simply and clearly displays the graphical representations of the measured parameters.

The GLM-2000 allows successive measurements at various injection levels. The recombination lifetime is a function of the injection level and the GLM-2000 can selectively choose a given constant injection level using a programmable LED illuminator (by setting a constant power in software or by a sweep in power). As well, the user can access ultra low level light conditions to measure minority carrier lifetimes by a bias light methodology. This ability to choose different injection levels permits the user to hold an absolutely constant power level with the programmable LED illuminator. The GLM-2000's proprietary bias lighting also permits testing low light injection levels in the presence of shallow trapping effects. Moreover, a combination of the PCR and PCD, as compared to the true state minority carrier lifetime, gives additional insight to the shallow trapping behavior (Reference: MKS-GLM 2000 Applications Note on measurements for multicrystalline Si wafers).

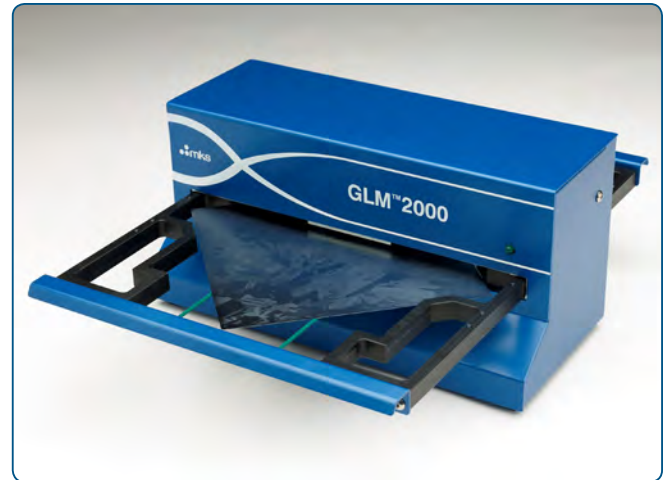


Figure 3

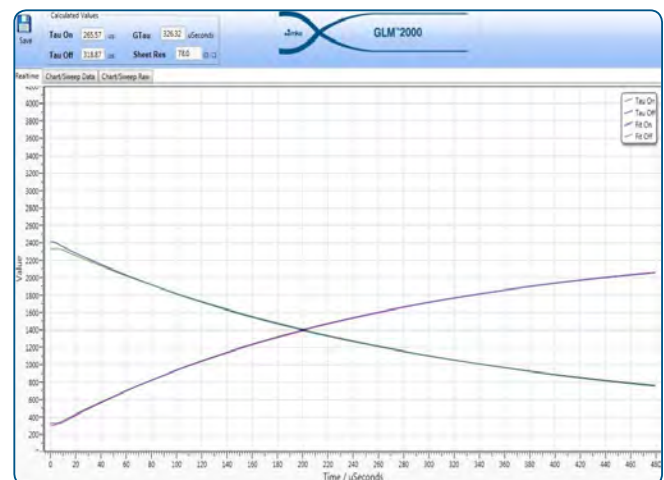


Figure 4

SOLUTION (CONT.)

Figure 5 shows data taken from a case study that monitored partially fabricated c-Si solar wafers over a series of different lifetime values. In this study, the measurements obtained using the GLM-2000 were compared against those determined by flash lamp and microwave detection methods. The recombination lifetimes measured were performed using the two alternative techniques and the GLM-2000 to measure the same set of wafers exhibiting a very broad range of lifetimes. It can be seen that in all cases the values determined using the GLM 2000 were comparable with those obtained by the conventional techniques.

The GLM-2000 Gtau method is the only technique that uses constant light conditions with steady state exposure periods significantly greater than recombination lifetimes under test. Such conditions are more typical of real world solar cell operation. The recombination lifetime measurements performed using the GLM-2000 can be used to distinguish shallow trap effects that are inherent to small grain semiconductors. The instrument provides for unique bias lighting compensation through the use of a proprietary illuminator. Furthermore, upon request, it can be configured to monitor the differences between bulk and surface effects by tuning the illuminator color. The GLM-2000 creates an alert when the items being evaluated are out of specification and defective items can be binned without further processing, immediately increasing yield.

CONCLUSION

The GLM-2000 is an “at line” measurement instrument that monitors the quality of partially fabricated solar cells, either in process or post process, without contact and at high speed. Using unique illumination hardware and on-chip signal processing, the GLM-2000 collects an inductively coupled conductivity measurement to monitor sheet conductance (resistance), photoconductance, and recombination lifetime at high speed (16.6 ms per datum). These metrics provide a highly specific evaluation for the product quality at many stages of manufacturing.

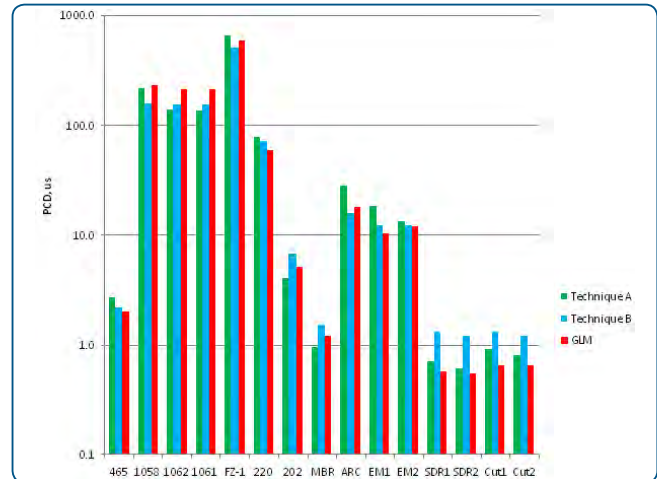


Figure 5 - Measurements comparing PCD values determined using the GLM-2000 with those of Technique A (flash lamp) and Technique B (microwave) for the same sample.

For further information, call your local MKS Sales Engineer or contact the MKS Applications Engineering Group at 800-227-8766. GLM™ is a trademark of MKS Instruments, Inc., Andover, MA.