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# Trapping in multi-crystalline silicon wafers: The impact of firing and laser treatment

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## Introduction

Minority carrier traps (termed 'traps' in this study) in silicon are defect levels where emission of minority carriers from them happens at a much faster rate compared to the recombination rate. Such behavior can result in an artificially high apparent lifetime at low and even medium injection levels when measured by photoconductance (PC)-based methods [1]. Understanding trap is critical as it allows us to perform more accurate lifetime measurements and enhances our understanding of defects in silicon and their impact on solar cell efficiency.

Traps in multi-crystalline silicon (mc-Si) have been previously investigated under steady-state condition [1]. However, recent studies on mono-crystalline silicon wafers have shown that the steady state assumption might not be valid, as the PC decay time constant in samples with traps can be much longer than the decay time of the flash used for quasi steady-state (QSS) measurements [2], [3]. Despite decades of research, there is a gap in our knowledge on the properties of traps in multicrystalline silicon and the impact of defect engineering processes on such traps. In this study, we investigate traps in mc-Si. We show, for the first time, that PC of samples with traps in mc-Si can have long decay time constant of ~600 ms. We also investigate the impact of firing and laser treatment on traps. Interestingly, it is shown that laser treatment can eliminate the trapping effect which has not been observed before.

## Method

A set of p-type mc-Si sister wafers with resistivity of 1.6 Ω.cm is used in this study. After saw damage etch and RCA (Radio Corporation of America) cleaning, silicon nitride ($SiN_x$) was deposited onto both surfaces using an industrial plasma-enhanced chemical vapor deposition (PECVD) system (MAiA; Meyer Burger). The $SiN_x$ layers were then etched off from one of the samples. To investigate the impact of the firing process on the traps, several $SiN_x$-passivated samples were fired at *actual* wafer's peak temperature of 815 °C using an industrial belt furnace (SCHMID). To investigate the impact of laser treatment on the traps, a few fired samples were illuminated by a 932 nm laser (45 kW/m$^2$) for 100 seconds, while kept at 140 °C as *in-situ* monitored by an infrared sensor (PC301HT-0, Calex).

Photoconductance (PC) measurements are performed using our customized lifetime tester[4] using a xenon flash (identical to the flash used in standard Sinton lifetime testers) as a light source. The flash is used in 1/64 mode, which is usually used for measuring samples with lifetime above 200 us in transient condition. The decay time constant of the flash light intensity using this mode is measured to be ~35 μs.

## Result and discussion

Figure 1 presents the PC as a function of time for a sample with and without $SiN_x$ passivation. In both cases a sharp decrease in the PC is observable, immediately after flash cut off (~0.5 s). This is due to the strong recombination in these wafers. Interestingly, after this first decay, a second decay with a much longer time constant can be observed. This decay can be explained by trapping of minority carriers. However, another possible explanation for such behavior can be depletion region modulation (DRM) formed by an inversion layer imposed by the positive charge within the $SiN_x$ layer [5]. Since similar long time constant is observed for the un-passivated sample (630 ms for the non-passivated wafer and 641 ms for the passivated sample), DRM can be excluded as the cause of this effect. To our knowledge, this is the first observation for traps with such a long de-trapping time in mc-Si. This observation highlights possible limitations of previous trap analysis that assumed QSS conditions.

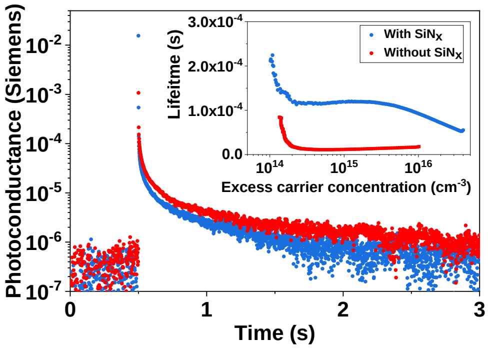


**Fig. 1. Photoconductance as a function of time for a wafer with and without $SiN_x$**

Figure 2 presents the PC as a function of time for (a) non-fired and fired samples and (b) for a sample before and after laser treatment. We now investigate the impact of firing on the trap. Comparing the non-fired and the fired wafers of Fig. 2(a), no significant change can be noticed between the PC decay of these samples. Fitting the decays to a single exponential function indicates only a minor change in the time constant: 625 ms for the non-fired sample and 675 ms for the fired one. The slight difference can be explained by the uncertainty in the measurements. It also can be due a slight change in trap parameters during the firing process.

The impact of laser treatment on the PC and the lifetime of wafers is shown in Fig. 2(b). A dramatic change can be seen: the effect of traps on PC has been eliminated after the laser treatment. The slow decay of PC in the sample that has been laser treated disappeared. The lifetime curves of these samples are shown in the inset of Fig. 2(b). Here we observe a significant reduction of the lifetime accompany with elimination of the traps. It seems to be the first demonstration of the impact of the laser treatment on traps.

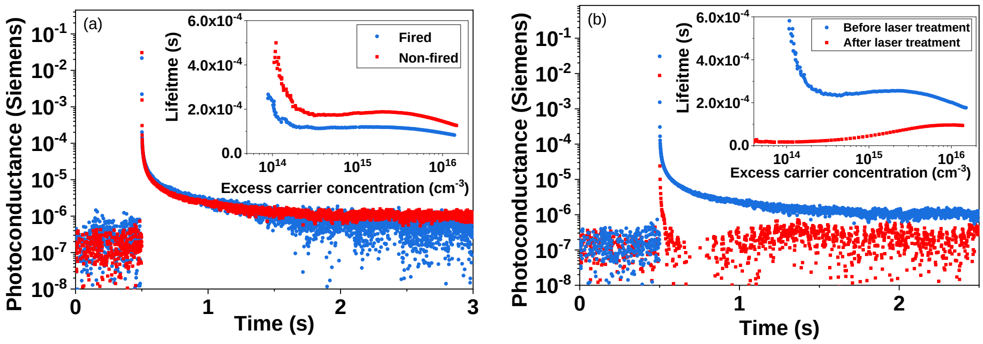


**Fig. 2. Photoconductance as a function of time for (a) fired and non-fired wafers, and (b) before and after laser treatment. Inset: effective lifetime of the wafers as a function of Δ*n*.**

In conclusion, we observed for the first time, traps with a time constant exceeding 625 ms in mc-Si, highlighting possible limitations of previous studies that assume QSS conditions. We also showed that firing has a negligible impact on traps, while a laser treatment can eliminate their effect completely.

## References

[1] A. Cuevas, M. Stocks, D. McDonald, M. Kerr, and C. Samundsett, "Recombination and trapping in multicrystalline silicon," *IEEE Trans. Electron Devices*, vol. 46, no. 10, pp. 2026–2034, 1999.

[2] Y. Hu, H. Schøn, Ø. Nielsen, E. Johannes Øvrelid, and L. Arnberg, "Investigating minority carrier trapping in n-type Cz silicon by transient photoconductance measurements," *J. Appl. Phys.*, vol. 111, no. 5, p. 053101, 2012.

[3] Y. Zhu, M. K. Juhl, G. Coletti, and Z. Hameiri, "Reassessments of minority carrier traps in silicon with photoconductance decay measurements," *IEEE J. Photovoltaics*, vol. 9, no. 3, pp. 1–8, 2019.

[4] C. Vargas *et al.*, "Recombination parameters of lifetime-limiting carrier-induced defects in multicrystalline silicon for solar cells," *Appl. Phys. Lett.*, vol. 110, no. 9, p. 092106, 2017.

[5] P. J. Cousins, D. H. Neuhaus, and J. E. Cotter, "Experimental verification of the effect of depletion-region modulation on photoconductance lifetime measurements," *J. Appl. Phys.*, vol. 95, no. 4, pp. 1854–1858, 2004.