Injection Dependent Lifetime Spectroscopy with a Varying Pulse Length

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Abstract. The versatile capabilities of MDP (microwave detected photoconductivity) measurements, facilitating injection dependent measurements with a varying exciting laser pulse width, are demonstrated. With these measurements new opportunities arise for the investigation of carrier dynamics in defects at different depths inside the sample. Additionally the possibilities to measure very thin layers are demonstrated. In this study several measurements onthin epitaxial layersare presented which demonstrate the numerous information that can be gained with injection and pulse dependent measurements.

Keywords: lifetime, injection, epitaxial layers, MDP, silicon

INTRODUCTION

The minority carrier lifetime is one of the key parameters for material quality and hence device performance. The carrier lifetime is very sensitive to all kinds of electrically active defects in the material, such as impurities and crystal defects such as dislocations. Hence it is an ideal parameter for research applications as well as large volume inline material quality characterization. For those inline applications the lifetime measurements have to be contactless, destruction free and with high measurement speed and resolution.

An important factor, particularly for comparison and the correct interpretation of lifetime results, is the measurement strategy for the carrier lifetime. The lifetime data should quantitatively reflect either the surface or bulk recombination lifetime, according to the material property to be investigated. For samples with different layers, such as epitaxial layers even more recombination sites must be considered and it is desirable to distinguish, which recombination site is predominantly determining the measured lifetime, e.g. the surface, the interface or the recombination in the epitaxial layer itself. Figure 1 shows a scheme of a typical sample with an epitaxial layer and the recombination sites that have to be considered. Keep in mind that often even more layers are present, such as e.g. a buffer layer.

FIGURE 1. Scheme of the recombination sites of a sample with an epitaxial layer

It was already shown in former publications that the pulse length of the exiting light source influencesthe measurement depth in thick samples critically and hence also the lifetime results [1, 2]. If a short pulse length of only 200 ns is used the surface recombination is much more dominant, since the developing carrier profile is very near to the surface. On the other hand, if a steady state regime is applied the carriers diffuse deeper into the sample and also bulk information can be gained. The same effect can be used to investigate epitaxial layers and the different recombination sites therein by using smaller wavelength and by comparing injection dependent measurements with a varying pulse length and hence a varying measurement depth.

This calls for a measurement system that is able to measure with short pulses and with long pulses as well in order to establish a steady state regime, with different wavelengths, and a broad injection range. The carrier lifetime measurement method MDP [3] in combination with recent state of the art improvements in apparatus technology meets these requirements. Results are presented based onthe latest developments in sensitivity andnew measurement options.

EXPERIMENTAL

Different thin film samples of 6 … 50 µm thick silicon epitaxial layers on a highly doped silicon substrate were investigated. The thin films were either passivated using a thermal oxide oramorphous silicon. P doped as well as n doped samples were measured.

The applied method MDP measures the time dependence of the photoconductivity during and after a rectangular laser pulse by microwave (9 … 10 GHz) absorption via a resonant cavity as part of an integrated microwave electronic. The width of the exciting laser (980 nm) pulse can be varied from 0.1 µs to several ms. Hence measurements in a short pulse regime as well as at steady state with respect to the generation and recombination of carriers are enabled. This has a crucial influence on the carrier profiles that develop in the sample. Figure 1 shows the simulated carrier profiles that develop in a 300 µm thick sample with a surface recombination velocity of 1000 cms^{-1} after a short pulse and a steady state excitation. For short pulse measurements with a pulse length $t_{pulse} << \tau$ the carrier profile is very inhomogeneous and the highest carrier concentration occurs at depthsbelow 50 µm. Hence the main influence on the measurement result arises from the recombination in this area of the sample. For samples with an epitaxial layer this means that the recombination at the surface and in the epitaxial layer is much more emphasized. For steady state measurements, the carriers have time to diffuse into the sample and hence the carrier profile is more uniform and also the recombination in the interface and in the substrate as well influences the measurement result.

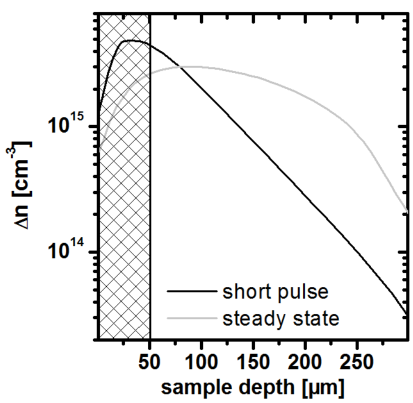

FIGURE 1. Simulated carrier profiles in a 300 µm thick sample that developed after a short pulse (200 ns) excitation and a steady state (200 µs) excitation; the carrier profile right after switching off the light is shown

Since the carrier profiles in the samples are not uniform, especially for short pulse measurements, the injection was determined via the simulation of the carrier profiles as it was described in detail in [1].

The advanced MDP setup provides superior detection sensitivity compared to conventional setups. This enables injection dependent measurements over eight orders of magnitude with one and the same apparatus, allowing for detailed studies of traps as well as recombination centers in the material. In contrast to e.g. photoluminescence techniques, MDP data are a priori quantitative.

RESULTS

First of all, the new developed high sensitivity setup especially for thin layer measurements is presented. Figure 2 shows a measurement of a 50 µm thick silicon epitaxial layer on a highly doped silicon substrate that was measured with the formerly used standard setup and with the enhanced sensitivity setup. A signal-to-noise improvement by about a factor of 100 could be achieved. Hence a lower laser power could be used for the measurements and much more contrast in the lifetime map is now observable.

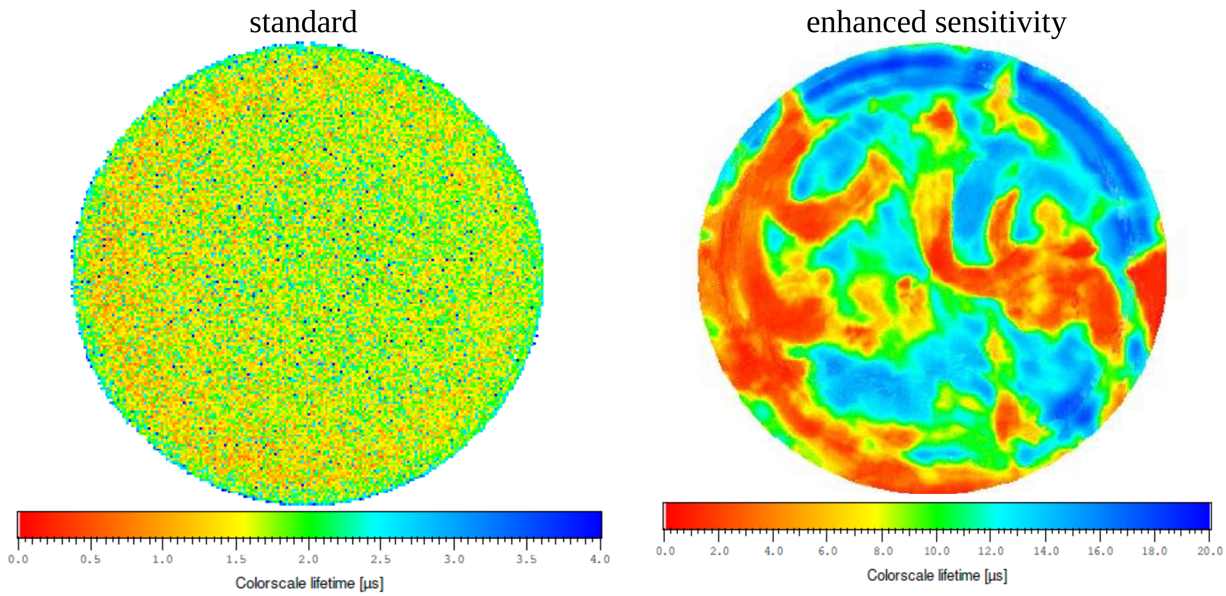

FIGURE2. Example of enhanced sensitivity by a factor of 100; 50 µm p-doped silicon epilayer on highly doped silicon substrate, passivated with thermal oxide

Figure 3 shows the results of injection dependent measurements with a varying laser pulse width on two different samples with epitaxial layers. The 6 µm thick n-Si epilayer which was passivated with a thermal oxide, shows no difference in the injection dependent lifetime curve for different laser pulse widths. This is probably due to the very thin epitaxial layer and a very good surface recombination velocity, hence with IR light not much difference can be observed. For more information the sample has to be measured with a shorter wavelength e.g. 532 nm. The second sample has an approximately 30 µm thick n-Si epilayer which was passivated with amorphous silicon. In this case a considerable increase in the measured lifetime over the complete injection range is observed, which indicates that also the trapping effect in the low injection range changes with pulse width. This, in turn, points to different trapping densities in the samples' different layers. Furthermore, the lifetime seems to be mostly limited due to the recombination at the surface, and hence the lifetime decreases strongly with short laser pulses and the corresponding carrier profiles near to the surface. Again even more information can be gained, if additional measurements with shorter wavelengths are performed. Such measurements are underway and will be presented in a forthcoming paper.

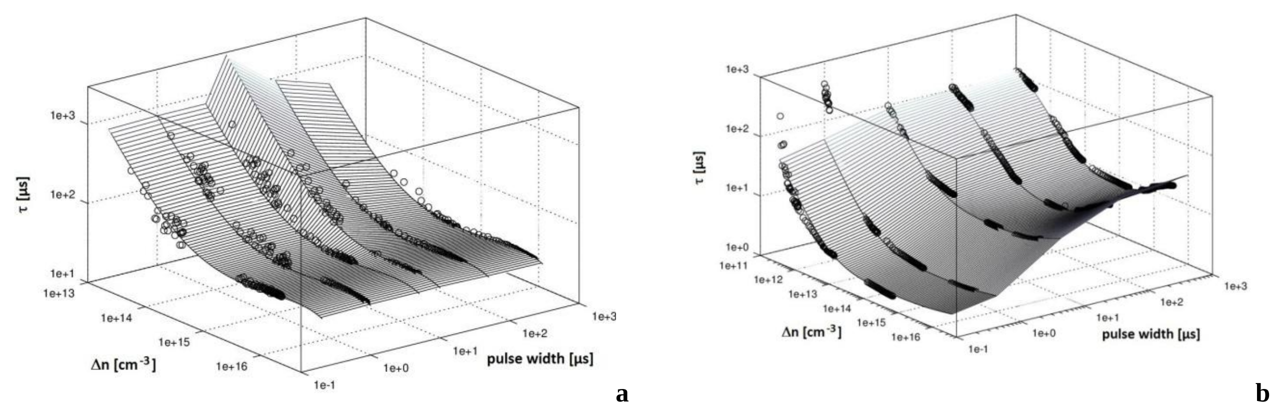

FIGURE 3. Injection dependent lifetime curves with different pulse widths of a 6 µm n-Si epitaxial layer passivated by a thermal oxide (a) and of a 30 µm n-Si epitaxial layer passivated by amorphous Si (b). The drawn lines are just to guide the eye.

CONCLUSION

In this study the improved sensitivity of MDP measurements was demonstrated on various epitaxial layers. Furthermore it was shown that with MDP measurements the exciting laser pulse width can be adjusted continuously from only 200 ns to several ms and hence it is possible to measure in a short pulse (similar to µPCD [4]) or steady state (similar to QSSPC [5]) regime with the same measurement system. Thus it is possible to gain information about the dominant recombination processes in different depths of a sample which is especially interesting for samples with thin epitaxial layers. It was demonstrated that, due to different carrier profiles developing in the sample, different effective lifetimes are measured which furnish valuable pieces of information on the depth distribution of recombination centres.

Further studiesemploying different laser wavelengthsare currently in progress and will be published soon.

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