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Investigations of the Implanted Layer in Silicon Based on the Modulated Free Carrier Absorption Phenomenon

Introduction

Modulated free carrier absorption technique uses the effect of absorption of the infrared light by free electrons. In this method free electrons are generated by the modulated in intensity beam of light of the energy of photons bigger than the energy gap of the semiconductor. As a result a periodical concentration of electrons is observed in the conduction band. At the same time the same spot of the sample is illuminated by the constant in intensity infrared (IR) beam of light. Periodical changing concentration of electrons modulates transmission of the IR beam of light. These changes of the intensity of the transmitted light are detected by the photodiode. Voltage signal of the photodiode is amplified and measured by the lock-in amplifier. Typically amplitude and phase frequency characteristics of this signal are measured and from the fitting of the theoretical characteristics to the experimental ones the lifetime of the optically generated

carriers is measured. Such a method was applied for example for investigations of the lifetime of carriers in silicon and the results published in papers [2, 3]. Basics of the MFCA method are described in paper [4]. Different modifications of the MFCA method are described in papers [5-8]. The characteristic feature of these papers is that they deal with the measurements of the life time of carriers in silicon and they describe uniform samples e.g. nonimplanted which can be analyzed in the single layer model. The paper is the attempt of the application of the MFCA method for investigations of the implanted silicon samples. In this case the physical model is a two layer one: a thin implanted layer of the thickness d on a substrate of the thickness L. Thickness of the implanted layer is much smaller than the thickness of the sample. In this paper a comparison of the frequency amplitude characteristics of the MFCA signal of the nonimplanted and O^{+6} and Ar^{+8} implanted samples is presented. The aim of the investigations was to check the influence of the implantation on the frequency characteristics of the MFCA signal. In this paper a possible explanation of the observed effect is given in the model of a damaged layer.

Sample Preparation and Experimental Set Up

The investigated samples of silicon were both of the n and p type nonimplanted and implanted. Si – p type samples were nonimplanted and implanted by Ar^{+8} ions with the energy of 120 keV and implantation doses $5 \cdot 10^{13}$ ions/cm^2, $5 \cdot 10^{14}$ ions/cm^2 and $5 \cdot 10^{15}$ ions/cm^2. The thickness of the samples l=280 μm, resistivity ρ=5000 Ωcm.
Si – n type samples were nonimplanted and implanted by O^{+6} ions with the energy 90 keV and implantation doses $5 \cdot 10^{13}$ ions/cm^2 and $5 \cdot 10^{14}$ ions/cm^2. The thickness of the samples l=410 μm, resistivity ρ=3-5 Ωcm.
The experimental set up for investigations of the implanted silicon samples consisted of 150 W halogen lamp as a source of the probe light, 660 nm red laser diode as a source of the pump light, beam splitter, adapter for the sample mounting which was connected through the fiber with a detector, lock-in type amplifier and the computer which controlled the measuring process. The schematic diagram of experimental set up is presented in Fig.1. All measurements were performed in the room temperature.
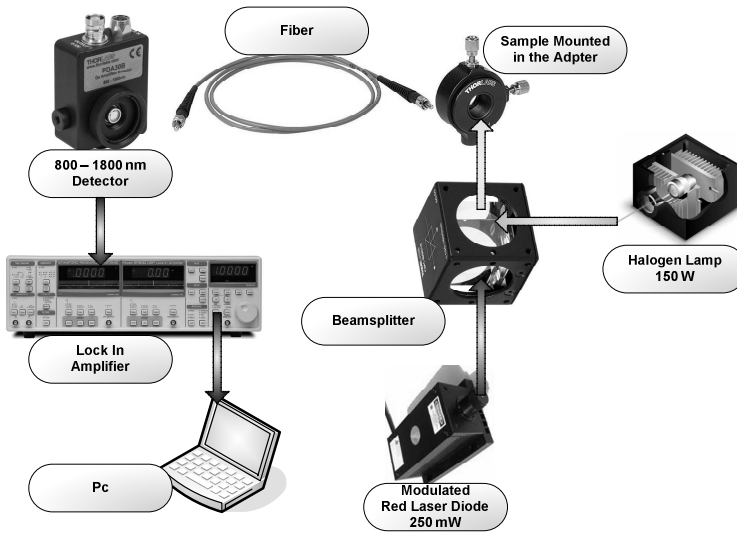
Fig. 1. The experimental set up used for investigations of the implanted layer in silicon samples

Experimental results

Experimental characteristics obtained for silicon samples: nonimplanted and O^{+6} implanted are shown in Fig.2.
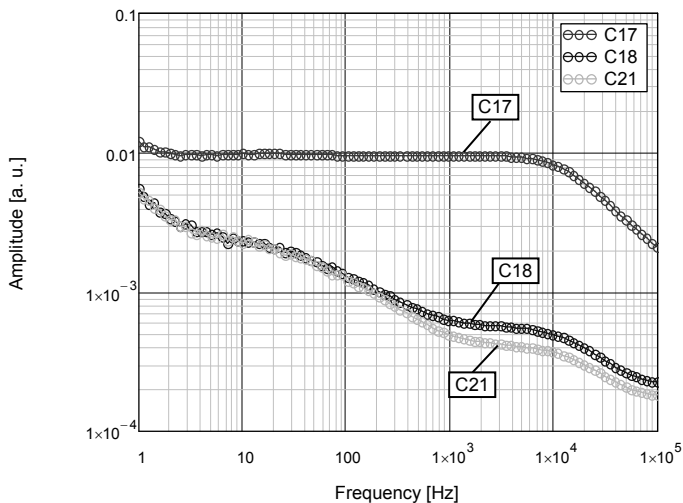

Fig. 2. Experimental MFCA characteristics for n-type silicon samples implanted with O^{+6} ions. C17 - n-type silicon sample nonimplanted, C18 – n-type silicon sample implanted with O^{+6} ions of the energy 90 keV and the dose $5·10^{13}$ ions/cm^2, C21 – n-type silicon sample implanted with O^{+6} ions of the energy 90 keV and the dose $5·10^{14}$ ions/cm^2.

Experimental characteristics obtained for silicon samples: nonimplanted and Ar[+8] implanted silicon are shown in Fig.3.
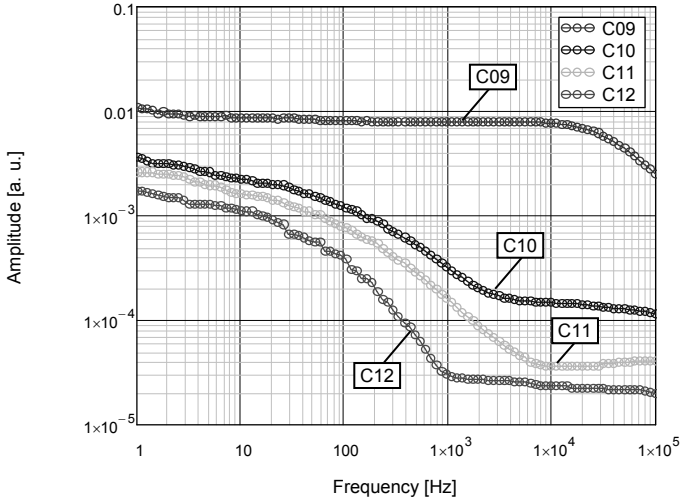

Fig. 3.   Experimental MFCA characteristics for p-type silicon samples implanted with Ar[+8] ions. C09 - p-type silicon sample nonimplanted, C10 – p-type silicon sample implanted with Ar[+8] ions of the energy 120 keV and the dose $5 \cdot 10^{13}$ ions/cm^2, C11 – p-type silicon sample implanted with Ar[+8] ions of the energy 120 keV and the dose $5 \cdot 10^{14}$ ions/cm^2 and C12 – p-type silicon sample implanted with Ar[+8] ions of the energy 120 keV and the dose $5 \cdot 10^{15}$ ions/cm^2

Discussion

For the pumping beam of light of the wavelength 660 nm the optical absorption coefficient for silicon is β=2630 cm^{-1}. The lifetimes of carriers for n-type sample nonimplanted sample was τ=18 μs. The lifetime of carriers for p-type nonimplanted sample was τ=15 μs.

When we assume that the lifetime of carriers in the damaged layer is much shorter than in the substrate then the decrease of the amplitude of the MFCA signal is expected according to the formula given below:

$$S = \int_{d}^{l} \beta \cdot \exp(-\beta \cdot x) \cdot \partial x \tag{1}$$

When the parameter k is the ratio of the amplitude of the MFCA signal of implanted silicon for the frequency in the range 10^3 Hz – 10^4 Hz to that of the nonimplanted signal when the thickness of the damaged layer can be computed as:

$$d = \frac{\ln(k)}{\beta} \qquad (2)$$

For n type silicon samples the following parameters k and d were obtained: $k_1=0.059 - d_1=10$ μm, $k_2=0.04 - d_2=12$ μm (see Fig.2).

For p-type silicon samples the following parameters k and d were obtained: $k_1=0.017 - d_1=15$ μm, $k_2=0.005 - d_2=20$ μm and $k_2=0.003 - d_2=22$ μm (see Fig.3).

Such thicknesses of damaged layers were also measured with an argon laser of the wavelength 514 nm where the optical absorption coefficient was 6300 cm^{-1}. Obtained thicknesses for this wavelength of the pumping light was almost identical with these presented in this paper what confirmed the theoretical model taken for computations of the thicknesses of damaged layers being the result of the high energy ion implantation.

The decrease of the amplitude of the MFCA signal in the frequency range from 1 Hz to 10^3 Hz is caused by the diffusion of carriers from the damaged layer to the substrate. With the increase of the frequency of modulation the diffusion length of carriers decreases and fewer carriers diffuse to the region of the substrate. For high frequencies of modulation the MFCA signal comes only from the substrate not from the implantation damaged layer.

Conclusions

The preliminary experimental results of the MFCA measurements of nonimplanted and implanted silicon samples, presented in the paper, indicate that the implantation process considerably modifies the frequency MFCA characteristics. The observed strong decrease of the amplitude of the MFCA signal was interpreted in a model of a damaged layer created in the result of a high energy implantation. Estimated thickness of damaged layers was in the range from 10 μm to 22 μm.

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Abstract

This paper presents experimental amplitude MFCA characteristics of the implanted silicon samples. Influence of the silicon implantation process for frequency MFCA characteristics has been analyzed. The idea and the experimental set-up of the proposed method have been presented and discussed. This paper proves that is possible to estimate depth of the implanted layer from MFCA experimental data.

Streszczenie

W artykule przedstawiono eksperymentalne charakterystyki MFCA dla próbek implantowanego krzemu. Przeanalizowano wpływ procesu implantacji krzemu na charakterystyki MFCA. Przedstawiono i poddano dyskusji ideę zaproponowanej metody oraz stanowisko eksperymentalne. Praca udowadnia, że możliwa jest estymacja głębokości warstwy implantowanej na podstawie eksperymentalnych charakterystyk MFCA.