Evaluation of Laser Doping of Si from MCLT Measurement

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ABSTRACT

The measurement of minority carrier lifetime (MCLT) of p-n Si fabricated with aid of laser doping technique was reported. The measurement is achieved by using open circuit voltage decay (OCVD) technique. The experiment data confirms that the value of MCLT and profile of V_{OC} decay were very sensitive to the doping laser energy.

Introduction

In the fabrication of semiconductor devices, the conventional solid state diffusion (furnace diffusion) is accomplished by heating the entire substrate at about 1000 ºC. In contrast, liquid state diffusion can be achieved by laser-induced melting of the near surface while the bulk of the wafer remains at abou room temperature, i.e no deterioration in minority carrier lifetime of ubstrate is expected [1-3]. The lifetime of photogenerated excess minority carriers is an important parameter in photovoltaic device. Indeed, the conversion efficiency of photovoltaic device is strongly dependent upon the base region minority carrier lifetime of the device. In series of experimental works, we have fabricated p-n Si diode by laser doping technique, and we have reported the electrical and photovoltaic characteristics of near-ideal device [4-6].No experimental data has been reported on MCLT of Si junction devices manufactured by laser–induced diffusion technique.The aim of the present work is to measure and analyze the MCLT of homo-junction Si fabricated with aid of Nd:YAG laser pulses.

Experiment

The Si substrates were CZ grown, boron doped having electrical resistively of (3-5) Ω.cm, the crystal-

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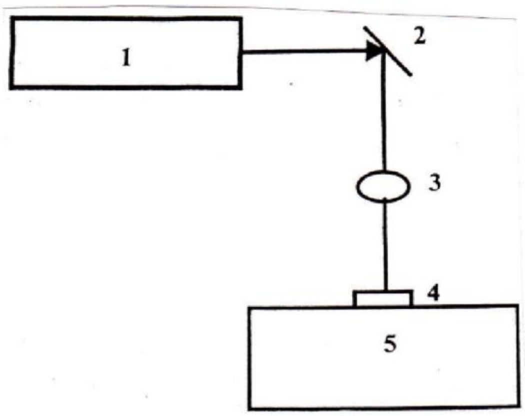
line orientation of Si crystal is (111). These wafers were chemically etched with CP-4 solution and then rinsed in ultrapure deionized H_2O. Five nines purity of antimony thin film was deposited on p-Si substrate with10nm thick using thermal resistive technique. After deposition process, The samples have been irradiated with Nd:YAG laser pulses with different energies. The laser doping parameters are summarized in Table (1).

Table (1). Laser Doping Parameters.

Wavelength μm	1.064
Pulse duration	300 μs
Mode distraction	TEM_{00}
Energy (mJ)	100-500
Diameter (mm)	1.2

The schematic diagram of experiment set-up of laser doping is presented in Fig. (1).



1) Nd:YAG Laser (2) 45°Mirror (3) Lens (f=20cm) (4) p-Type Si Substrate with Sb-Layer (5) X-Y Table Fig. (1). Experimental Set-up of Laser Doping Apparatus.

Residual atoms where removed by rinsing the diodes in NaOH solution. Four point probe measurement have been carried out to investigate the conductivity type of laser doped layers [3]. Ohmic contacts were made on both n-type and p-type silicon surfaces by deposition of Al and Au respectively [7]. These samples are packaged in TO-5 style headers. Conducting silver paste was used to make wiring process. The MCLT measurement of the fabricated junction was achieved by using photo-induced open-circuit voltage decay (OCVD) method. Investigations of Mahan [8] show that a reliable lifetime (□ estimate can be obtained from OCVD. The MCTL can be computed from the following expression:

$$\tau = \frac{k_B T}{q} \frac{1}{dV_{OC}/dt} \quad ....(1)$$

where k_B is Boltzmann's constant, T is absolute temperature, q is electron charge. V_{OC} is open-circuit voltage, and t is time. The schematic diagram of OCVD circuit is shown in Fig. (2). The circuit is comprised of stroboscope as flash light source type 1214B and Philips type PM 3302 storage oscilloscope to monitor V_{OC} decay.

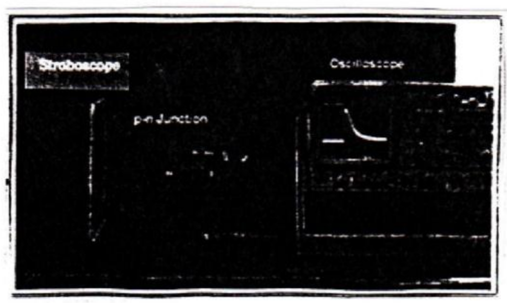


Fig. (2). Photo-Induced OCVD Measuring System.

Results and Discussion

Four point probe measurements reveled that all doped laser layers were n-type. Fig.3(a-h) as show the V_{OC} decay curves for p-n junction made with different laser pulse energies. It is obvious from the figure that the profile of decaying is function of laser doping energy .All decay profiles having three distinct regions. The first region corresponds to condition of high level injection, which the excess minority carrier concentration exceeds the equilibrium majority carrier concentration in the base region of the cell. When this condition is met, the decay curve is nearly linear. The region Π of the decay curve corresponds to a condition of intermediate injection, where the excess minority carrier concentration in the base is greater than the thermal equilibrium minority carrier concentration but less than the thermal equilibrium majority carrier concentration. In region III of decay curve, a low – injection condition exists, where the excess minority carrier concentration is less than the equilibrium minority carrier concentration. The decay profile of fabrication junctions is very similar to those for silicon solar cells. On the other hand, these junction give different values of MCLT as shown in Table (2). The p-n junction formed with 0-3 J having longest MCLT. This result can be attributed to the fact that the laser energy used was very closed to laser melting threshold (LMT), i.e minimum structural defects induced in the laser processed region. Deterioration in MCLT of junction formed with laser energy > 0.3 J has been observed, i.e high rate of recombination, this effect can be ascribed to the defects e.g ripples, dislocation, cracks, and interface recombination velocity accompanied laser doping process [9, 10]. In addition the low internal shunt resistance of junction fabricated with higher laser energy affect the MCLT and observed V_{OC} decay behavior (see Fig (3-h). To obtain high accurate measurement electrical shielding of p-n junction is accomplished to reduce the electrical noise arises from stroboscope.

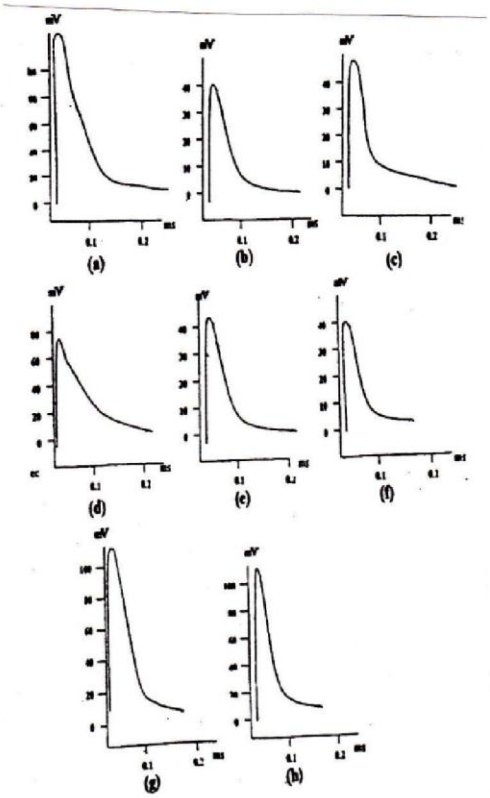


Fig. (3). Stroboscope Pulse Waveform of p-n Junctions Made with Different Laser Energies. (a) 0.2J, (b) 0.22J, (c) 0.24J, (d) 0.27J, (e) 0.3J, (f) 0.32J, (g) 0.34J, (h) 0.36J.

No significant variation of MCLT after measuring of fabricated junction over a period of many months are shown in Fig. (4).

Table (2). MCLT as a Function of Laser Doping Energy.

Laser doping energy (J)	MCLT (μs)	MCLT (μs) for conventional silicon solar cells [8]
0.2	29	10-30
0.22	43	
0.24	55	
0.27	57	
0.3	80	
0.32	51	
0.34	26	
0.36	22	

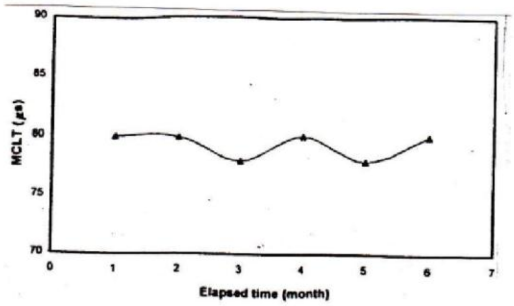


Fig. (4). Aging factor plot.

Concluding Remarks:

Simple and reliable OCVD method for determining MCLT of Si diodes fabricated by laser has been used to evaluate laser-doping process. The V_{OC} decay curve of devices is similar to that for diffused p-n junction Si-solar cell. The p-n junction formed with 0.3 J (optimum laser energy) gave longer lifetime, however the MCLT of these junction were higher than diffused p-n junction solar cell which reflect the advantage of laser doping over conventional doping.

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تقييم عملية اشابة السليكون بالليزر من خلال قياسات فترة حياة حاملات الشحن الأقلية

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الخلاصة

في هذا البحث تم قياس فترة حيات حاملات الشحن الأقلية للسليكون المشاب بالليزر. تم استخدام تقنية انحلال فولتية الدائرة المفتوحة في هذا القياس.إن النتائج العملية أوضحت بأن مقدار وشكل الانحلال للفولتية كانت تعتمد بشكل كبير على معلمات شعاع الليزر والمتمثلة بطاقة نبضة الليزر.