УДК 53.091;53.082.4;534.66.084;534.8;534:29;620.19

Sensitivity of dislocation engineered Si *p-n* junctions to influence of illumination and ultrasound

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Abstract

In this work it is shown that the dislocation engineered Si *p-n* junctions are sensitive to variations of illumination intensity. It is found that with the aim of ultrasound processing it is possible to purposefully modulate properties of the device structure.

Introduction

Due to unique light emitting properties dislocations have attracted much interest more than 50 years ago [1]. Especially this topic became important after discovery of the dislocation engineering [2]. According to the concept dislocation loops are introduced into the crystal by boron implantation. It is found that the thus obtained Si *p-n* junction can emit the light even at room temperature in the wavelength range, corresponding to dislocations (the so-called D1-D4 lines). Dislocation-related luminescence has been observed also upon implantation of H and He [3], O [4], Si in single crystalline Si [5] and multicrystalline Si [6]. It is interesting to note that light emission from Si at room temperature has been reported [7] in dislocation free Si also due to self-compression of electron-hole gas. Novel dislocation related features of Si has also been found such as the Stark effect [8], high electrical conductivity along dislocations compared to the bulk [8], manipulations of biomolecules at the surface of Si [9, 10], etc. In the present work it is shown that the dislocation-engineered Si *p-n* junctions are sensitive to variations of intensities of band-to-band illumination and to ultrasound treatment (UST).

Methods

The research has been performed using the samples of authors of Ref. [2].To reveal the role of low temperature annealing by UST two group of samples have been considered. The samples of the first group are not annealed and do not contain S impurities. The samples of the second group are doped by S of concentration 10^{13} cm^{-3} and are annealed at

T=1100 ^{0}C. The dislocation engineered Si *p-n* junctions have been prepared by B implantation into n-type Si [2, 11, 12] grown by Czochralski method with contact area 1.76 mm^2 and thickness 1.00 mm.

Current-voltage (*J-V*) characteristics before and after UST have been measured at room temperature. For UST the samples have been loaded into a bottle. The UST has been performed from the contact side by ceramic piezoconvertor. Frequency of the UST was 2.4 MHz. The UST has been done in alcohol. Samples have been treated by ultrasound of powers 0.5 and 1.0 W/cm^2 within 15 and 30 min (Table I).

The results and discussions

Figure 1 presents the light *J-V* curve before UST. Analysis shows that the short-circuit current I_{sc} and open-circuit voltage V_{oc} are considerable smaller than those of commonly used Si based solar cells. This result was expected because the device structures understudied are light emitting diodes and the structure is not optimized, contacts are not suitable for solar cells. In this particular case the most important point is not the magnitude of I_{sc} and V_{oc}, but the sensitivity of the dislocation engineered Si *p-n* junctions to illuminations of weak intensities in the photon wavelength range corresponding to edge of fundamental absorption.

Sensitity of the device structure is clearly seen on the dependence of I_{sc} and V_{oc} on Φ (Fig. 2). It is seen that I_{sc} and V_{oc} sharply increase with increasing Φ at smaller Φ and more slowly increase at larger Φ. The coefficient of light sensitivity has been estimated for current $C_I = dI_{sc}/\Phi$ and photovoltage $C_V = dV_{oc}/\Phi$, which at small illumination intensities are equal to $C_I = 1.9$ A/W and $C_V = 30.3$ V/ (W/cm^2), respectively. Comparison of these results with those available from literature for Si solar cells shows that the C_I and C_V, estimated in this work are considerable larger than $C_I = 0.002$ A/W and $C_V = 30.3$ V/ (W/cm^2) [13] for Si as well as $C_I = 0.0008$ A/W and $C_V = 7.0 \times 10^{-6}$ V/ (W/cm^2) [14] for GaAs solar cells. Consequently, the dislocation engineered Si *p-n* junctions can be used as sensors of weak illumination intensities.

The reason of photosensitivity of the device structures can, probably, be related to smaller value ~1.8 micros of carrier lifetime in the dislocation engineered Si at room temperature [2, 15, 16] than that in dislocation-free Si. As it is well known [2, 17, 18], dislocations create he necessary conditions for radiative recombination of carrier lifetime. However, in close vicinity of dislocations there is deformation field, which can attract different defects and impurities decorating the dislocations and play important role in the charge carrier recombination through dislocations [19]. In this point of view there is the need in purposeful annealing of these defects. However, the annealing at high temperatures can result in structural modifications of the dislocations. Here the low temperature annealing becomes extremely important. UST at T = 300 K has been used in this work for solution of the above problem. Figure 3 shows *J-V* dependence after UST within 15 min. Analysis shows that UST has lead to enhancement of both I_{sc} and V_{oc}. This result indicates that UST-induced annealing is possible. After UST sensitive of the device structure has become as $C_I = 4.4$ A/W and $C_V = 36.2$ V/(W/cm^2), which considerable exceeds photosensitivy of the samples not subjected to UST.

However, according to experiments, annealing by UST can be useful not all the time. UST of one of the samples has lead to worsening of properties of the dislocation engineered Si *p-n* junction (Fig. 4). After UST within 30 min the short circuit value I_{sc} and open circuit voltage V_{oc} as well as sensitivity coefficients C_I and C_V considerable reduced.

Conclusion

In this work dislocation engineered Si *p-n* junctions have been studied. It is shown that the device structures are sensitive to variations of intensities of band-to-band illumination. It is established that by UST is possible purposefully modulate properties of the device structures.

Acknowledgements

We wish to thank Dr. M. Lourenco and Professor K. Homewood (Advanced Technology Institute, School of Electronics and Physical Sciences, University of Surrey, Guildford, Surrey GU2 7XH, UK) for providing the samples of the dislocation engineered silicon. This work has received financial support from the Academy of Sciences of Uzbekistan. The authors are thankful to Dr. B. Aytbaev and Kh. Ismailov for assistance in measurements.

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Figure captions

Fig.1. Light J-V dependence before UST for different intensities of illumination intensities Φ (mW/cm^2): (o) 0.04; (Δ) 0.158; (∇) 1.096; (□) 3.02; (◊) 6.3 mW/cm^2.

Fig.2. Dependence of the short-circuit current J_{sc} and open-circuit voltage V_{oc} on illumination intensity Φ before (open symbols) and after UST (closed symbols) within 15 min UST of frequency 2.4 MHz and power 1 W/cm^2.

Fig. 3. Light J-V dependence of the sample after 15min UST of frequency 2.4 MHz and power 1 W/cm^2 at different illumination intensities Φ (mW/cm^2): (o) 0.04; (Δ) 0.158; (∇) 1.096; (□) 3.02; (◊) 6.3 mW/cm^2.

Рис. 4. Light J-V dependence before (open symbols) and after (closed symbols) UST of frequency 2.4 MHz and power 1 W/cm^2 during 30 min at different illumination intensities Φ (mW/cm^2): (o) 0.04; (Δ) 0.158; (∇) 1.096; (□) 3.02; (◊) 6.3 mW/cm^2.