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Axial Local Lifetime Control in High-Voltage Diodes Based on Proximity Gettering of Platinum by Proton-Implantation Damages*

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Abstract: A new lifetime control technique-localized platinum lifetime control (LPLC) is introduced. Silicon samples are implanted with 550keV protons at dosages from 1×10^{13} to $5\times10^{14}cm^{-2}$. Subsequently, platinum diffusion in silicon is performed at 700 or 750 ℃ for 15 or 30min, respectively. Then the in-diffused platinum into damaged regions of the proton-implanted silicon is investigated by use of deep-level transient spectroscopy (DLTS). Finally, for all of the LPLC samples, the distribution of the in-diffused substitutional platinum agrees well with the damage distribution resulting from the low-dosage proton implantation. Also, the diodes show a very low leakage current even at elevated temperatures while keeping the major advantages of ion irradiation devices, including low turn-off loss and soft recovery.

Key words: platinum; DLTS; hydrogen implantation; interstitial
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1 Introduction

Ion irradiation has been widely used in semiconductor device technologies. One of the main fields of interest is local lifetime control, which can introduce recombination centers with a controllable defect distribution and represent the modern techniques for optimization of electrical parameters in power devices. The major advantages of ion irradiation devices are the reduction of the reverse recovery parameter, i. e., t_{rr}, with a large recovery soft factor S and without increasing the forward voltage drop. However, these improvements of electrical parameters are usually at the expense of an increase in the reverse leakage current and result in a strong influence of the temperature on the device performance[1,2].

Another way of introducing recombination centers is by the in-diffusion of transition metals, such as Pt and Au. In particular, using Pt diffusion to fabricate power diodes, we can optimize the reverse in-diffusion recovery parameter t_{rr} without a remarkable increase in reverse leakage current. Unfortunately, this diffusion of Pt atoms will produce evenly distributed defect profiles, finally resulting in a snappy recovery, i. e., a small recovery soft factor S[3].

Ion irradiation is also widely used in the production processing of the modern semiconductor devices to remove undesirable contaminants, such as Au and Pt from the active regions of the devices. These contaminants may lead to high leakage currents and soft reverse current-voltage characteristics. The removal is accomplished by trapping the contaminants at gettering sites, which have been produced by ion irradiation and are located away from the active regions[4].

Making use of this gettering phenomenon, this paper for the first time demonstrates the possibility of fabricating high-power silicon diodes with localized Pt doping by the use of low-dose proton implantation. Thus, this technique, which is called localized platinum lifetime control

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(LPLC), possesses both the advantages of the ion irradiation technique and the conventional platinum diffusion technique, and therefore simultaneously has a very low leakage current, very small reverse recovery parameter t_{rr}, and very large recovery soft factor S.

2 Experiment

All our samples are p^+-n-n^+ silicon planar diodes. The starting material is n-type FZ〈111〉Si. The B concentration of the p^+ region, of 4.5μm thickness as measured by spreading resistance methods, varies from 4.43×10^{17} to $1 \times 10^{14} cm^{-3}$. For LPLC samples, a 150nm-thick PtSi layer is produced by sputtering and sintering (300 ℃, 60min) on the p^+ side. Then, LPLC samples are implanted at room temperature with 550keV protons at doses ranging from 1×10^{13} to $5 \times 10^{14} cm^{-2}$. By use of SRIM (stopping and range of ion in matter) simulation software, we find that the projection range of the proton particles is 6.85μm, which forms the maximum region of the vacancy defects as gettering sites in the n-base region close to the anode junction. The region is most favorable to elevate electrical parameter characteristics. The doping profile of the LPLC samples and the simulated distribution of primary damage-vacancies resulting from 550keV proton implantation are shown in Fig. 1. Annealing is performed at 700 or 750 ℃ for 15 or 30min respectively, allowing Pt to diffuse into the Si from the PtSi layer.

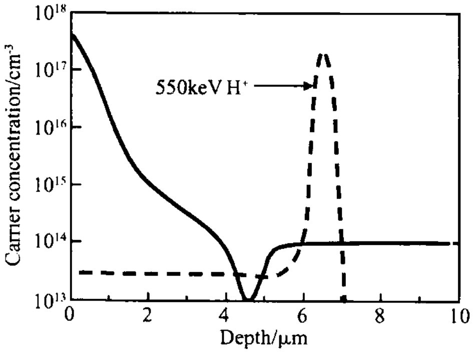

Fig. 1 Doping profile of the p-i-n diode with the carrier concentration versus depth and simulated distribution of primary radiation damage-vacancies (dashed line) generated by 500keV proton implantation

The reference sample of ion irradiation is fabricated by proton implantation at the same energy and dose as the LPLC sample, which is called the HI sample. For the reference sample for conventional Pt diffusion, which is called the PL sample, a PtSi layer is also formed on the p + side first, and then Pt in-diffusion is carried out at 700 or 750 ℃ for 6h.

DLTS measurements are made in a PC-controlled setup, which basically consists of a 1MHz capacitance bridge, a 50MHz pulse generator, and a liquid nitrogen bath into which a sample holder is placed, operating in the temperature range of 77～350K. DLTS signals are acquired with nine rate windows simultaneously (between 20 and $5.12 ms^{-1}$). A pulse length of 10ms is chosen so that the traps can be completely filled with charge carriers[5].

3 Results and discussion

Figure 2 shows the DLTS measurements of all of the LPLC samples, and only the emission signal peak of substitutional platinum (Pts) appears. From a detailed analysis of the emission rate $e_n(T) \times T^{-2}$, we derived the value of the deep-level for the introduced defect, $E_T = E_C - 0.23eV$ (E_C, E_T denote the energy positions of the conduction band edge, and any deep level, respectively). This value is in good agreement with that obtained by Evwaraye[6]. Of course, a reference sample was fabricated with an aluminum Schottky contact, which had no proton implantation. As shown in Fig. 2, no emission peak on the same scale as the LPLC samples is observed for this sample. Clearly, the emission signal peak of Pts appearing in the LPLC samples is due to the proximity gettering of in-diffusion Pt resulting from proton implantation.

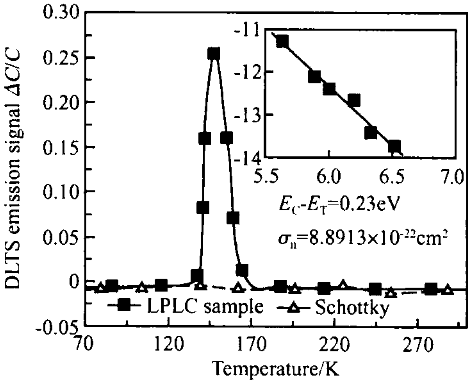

Fig. 2 DLTS spectra showing the measurement with 100ms rate window to compare our novel samples and Al Schottky diodes The novel sample is implanted with 550keV protons at a dosage of $8 \times 10^{13} cm^{-2}$ and annealed at 700 ℃ for 15min.

Figure 3 shows the depth profile of the in-diffusion Pt of the LPLC sample. From the figure, we can see the in-diffused Pt depth distribution is approximately congruous with that of vacancies created by hydrogen implantation. Thus we can be sure that the vacancies have served as gettering sites to result in the formation of localized Pts.

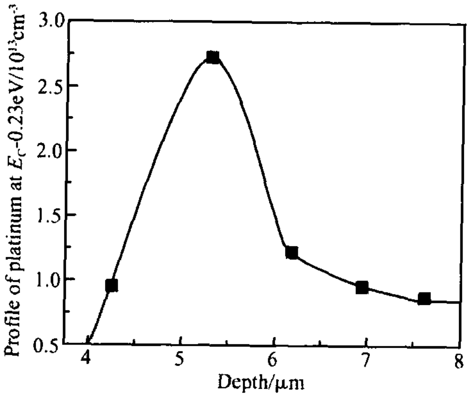

Fig. 3 Concentration versus depth profiles of the platinum acceptor trap at $E_T = E_C - 0.23$eV after 550keV/8 $\times 10^{13}$cm^{-2} proton irradiation followed by in-diffusion of Pt at 700 °C for 15min

After the DLTS measurements, we tested the electrical parameters of all of our samples, including the reverse recovery parameter t_{rr}, reverse leakage current at 125 °C I_R, and reverse recovery soft factor S.

Figures 4 and 5 give the trade-off of t_{rr}-I_R and t_{rr}-S for the LPLC samples and reference samples (i.e. HI and PL samples), respectively.

Figure 4 clearly shows that the LPLC sample realizes a better trade-off of t_{rr}-I_R than the reference samples. This is in good agreement with simulation results obtained by Wu[7], who compared electrical parameters of localized platinum devices with ion irradiation, convention platinum diffusion devices.

Figure 5 clearly shows that the LPLC sample realizes a better trade-off of t_{rr}-S than the PL sample, and the same t_{rr}-S trade-off as the HI sample. This is also in good agreement with simulation results obtained by Wu[7].

4 Conclusion

The local distribution of Pt was realized in the standard process of a high-power p-i-n diode with benefits of significantly lower leakage and a larger recovery soft factor, while conserving the smaller reverse recovery time. Also, this is the first time that Pt doping has been introduced by use of the gettering phenomena of H^+ irradiation defects in a p-i-n Si diode. Additional tests of better optimizing parameters and reliability are currently being developed to open a new way toward an ideal high-power Si diode.

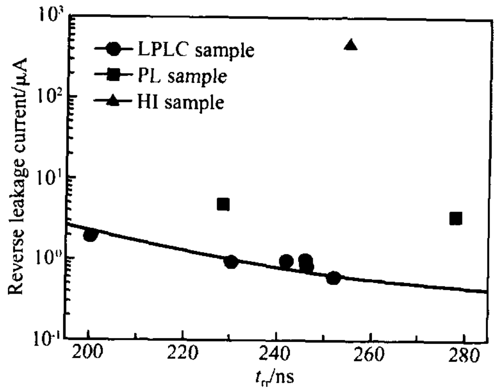

Fig. 4 Trade-off curve of I_R versus t_{rr} for our novel, PL, and HI samples t_{rr} I_F = 1A, V_R = 30V, di/dt = -20A/μs, RT

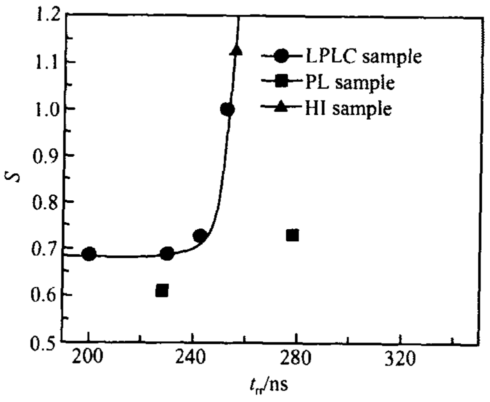

Fig. 5 Trade-off curve of t_{rr} versus S factor for our novel, PL and HI samples t_{rr} and S I_F = 1A, V_R = 30V, di/dt = -20A/μs, RT

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高压二极管中局域铂掺杂的寿命控制新技术[*]

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摘要: 提出一种寿命控制新技术——氢离子辐照缺陷汲取铂局域寿命控制技术. 所有样管首先进行能量为 550keV,剂量为 $1\times10^{13}\sim5\times10^{14}\mathrm{cm}^{-2}$ 的氢离子辐照;接着分别进行 700～750 ℃,15～30min 的退火,以完成铂在硅中的扩散和氢离子辐照缺陷对铂原子的汲取. 随后,所有样管进行了深能级瞬态谱仪测试(DLTS),以得到缺陷汲取后样管中的铂浓度分布. 最终,所有样品都得到了与氢离子辐照缺陷具有相似分布的局域铂浓度分布. 同时,与现有的整体寿命控制技术和氢、氦离子辐照局域寿命控制技术相比,局域铂掺杂样管具有反向恢复时间小、反向恢复软度因子大和漏电流极小的优点.

关键词: 铂汲取; DLTS; 氢离子辐照; 间隙原子
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