ELECTRICAL CHARACTERISTICS OF Au SCHOTTKY CONTACTS EVAPORATED ON PULSED ELECTRON BEAM ANNEALED N-TYPE (100) SILICON

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RESUME

Des diodes Schottky ont été réalisées sur du silicium de type N dont la surface a subi un recuit par bombardement électronique pulsé (P.E.B.A.) Au-delà d'un seuil situé aux environs de 1.0 J/cm^2 , le recuit P.E.B.A. provoque une forte détérioration des caractéristiques électriques des diodes, une diminution de la barrière de potentiel au contact Au-Si(N) et une augmentation rapide du facteur d'idéalité. Des mesures de capacités montrent qu'une forte concentration de donneurs est introduite par le recuit P.E.B.A. Leur concentration superficielle, pouvant dépasser 10^{16} cm^{-3} , et leur profil ont été déterminés par des oxydations anodiques successives. En outre, une amélioration sensible des caractéristiques des diodes est obtenue lorsque le traitement P.E.B.A. est suivi d'un recuit thermique isochrone sous hydrogène durant 30 minutes jusqu'à 600°C .

ABSTRACT

Gold Schottky contacts were deposited on Pulsed Electron Beam Annealed (P.E.B.A.) virgin N-type (100) silicon. Above a 1 J/cm^2 fluence threshold a strong degradation of the Schottky diodes I(V) characteristics has been observed with a drop of the barrier height and a fast increase of the ideality factor. Moreover, capacitance measurements combined with oxide stripping have shown that donor centers in excess of 10^{16} cm^{-3} are generated in the P.E.B.A. induced regrowth layer. Isochronal thermal annealing under H_2 atmosphere was performed on P.E.B.A. processed samples before depositing the Gold contacts. Improvement of the diode characteristics have been obtained when increasing the annealing temperature up to 600°C .

I. INTRODUCTION

Among other fast liquid phase epitaxy processes Pulsed Electron Beam Annealing (P.E.B.A.) has been successfully used to activate implanted dopants in silicon /1,2/. However, pulsed laser or electron beam annealing is generally accompanied by electrically active defects generation in the regrowth layer /3/. In a previous work DLTS measurements have shown that various majority carrier traps are induced by P.E.B.A. depending on the electron beam parameters /4/.

In this work, the degradation of Au/Si Schottky diodes made on P.E.B.A. processed (100) N-type silicon has been studied as a function of the electron beam parameters (Energy deposition profile-fluence). The effect of a post-P.E.B.A. isochronal thermal treatment under H_2 atmosphere was also investigated in order to study the induced defects annealing behaviour.

II. EXPERIMENT

Czochralski grown (100) N-type silicon wafers 3 to $10 \Omega \cdot \text{cm}$ in resistivity were first HF rinsed and then annealed with 50 ns duration electron beam pulses under cryogenic vacuum using a SPIRE 300 pulsed electron beam processor. This machine is described in ref.2. It allows for polykinetic electron beam parameters adjustment by mean of the field emission diode perveance which is controlled by the r/d_0 ratio, r being the cathode radius and d_0 the cathode-anode distance. In this work, two values of the r/d_0 ratio were selected resulting in a rather penetrating electron depth-dose profile for pulse n°1 ($r/d_0 = 7.3$, mean electron energy =

15 keV) and in a sharper electron depth-dose profile for pulse n°2 ($r/d_0 = 6.5$, mean electron energy = 12 keV). For each electron pulses the beam fluence has been varied from 0.8 to 1.5 J/cm^2 . After P.E.B.A. Al back contacts were evaporated and annealed for 15 mn at 150°C . Finally, the Au contact was evaporated on the P.E.B.A. processed area. Reference diodes made on non-P.E.B.A. processed silicon exhibit good and reproducible rectifier characteristics.

III. RESULTS

The $I(V)$ characteristics of Schottky diodes made on pulse n°1 processed silicon are plotted on Fig.1 as a function of the beam fluence. The rectifier effect disappears at 1.1 J/cm^2 and the ideality factor n which was 1.16 for the reference diode reaches values as high as 2.7 at only 1.2 J/cm^2 as shown on Fig.2. On the same figure is also plotted the values of n versus fluence for diodes made on pulse n°2 processed silicon. We notice the same threshold around 1 J/cm^2 whatever the type of electron beam pulse but the ideality factor remains slightly lower for pulse n°2 compared to pulse n°1.

Fig.1 - $I(V)$ characteristics of Au/Si-N Schottky diodes made on silicon processed with electron beam pulse n°1 at variable fluence.

Fig.2 - Evolution of the diode ideality factor n versus fluence

Fig.3 shows the evolution versus fluence of the barrier height V_{bn} as deduced from the saturation current I_s . Higher values are obtained for pulse n°2 compared to pulse n°1 indicating the same trend as for the ideality factor evolution. $C(V)$ measurements have been carried out at 1 MHz and Fig.4 shows the fast increase of the measured capacity at -0.5 V above 1 J/cm^2 . This result is coherent with the degradation threshold deduced from $I(V)$ curves of Fig.1.

Fig.3 - Evolution of the barrier height V_{bn} versus fluence

Fig.4 - Evolution of the diode capacity at -0.5 V as a function of the beam fluence.

Oxide stripping of the P.E.B.A. processed silicon layer was performed in order to investigate the diode characteristics evolution as a function of depth. Au contacts were deposited at each step after removal of a 15 nm thick oxide layer. At only 90 nm beneath the initial surface the $I(V)$ curve of a Schottky diode made on silicon which has been processed with pulse n°1 at 1.2 J/cm^2 is very close to the one measured with a reference diode. The ideality

factor recovers a value of 1.25 and the barrier height rises from 0.57 V to 0.7 V. Fig.5 shows the decrease of the capacitance measured at -1 V after each 15 nm silicon removal. One can observe that the reference diode capacitance is recovered at about 90 nm. A good-fit of the depth-capacitance curve of Fig.5 has been carried out using an exponential defect concentration profile /5/. This leads to donor centers surface concentration in excess of 10^{16} cm^{-3} . In addition capacitance measurements after oxide stripping of silicon samples processed with pulse n°2 at 1.2 J/cm^2 indicates that the donor profile extends deeper than 90 nm. This result can be related to the differences in the P.E.B.A. induced thermal effects between the two types of electron beam pulse as will be discussed in the next section.

Moreover, table I shows the evolution of the diode characteristics when P.E.B.A. is followed by a 30 mn thermal treatment under H_2 atmosphere. Al and Au contacts were deposited after thermal annealing. Considerable improvement of the diode characteristics is observed when the annealing temperature is increased from 300°C to 600°C. But even at this temperature the typical parameters of a reference diode are not completely recovered.

Fig.5 - Diode capacitance at -1 V as a function of the removed silicon layer thickness.

Annealing Temperature °C	Ideality Factor	I_s (A/cm ²)	Capacity (pF) -1 V ; 1 MHz	V_{bn} (V)
20	2.92	$3.35 \cdot 10^{-3}$	165.2	0.570
300	2.85	$2.21 \cdot 10^{-3}$	153.2	0.580
400	1.96	$1.03 \cdot 10^{-3}$	124.2	0.600
500	1.73	$9.76 \cdot 10^{-4}$	119.9	0.601
550	1.64	$7.76 \cdot 10^{-4}$	106.8	0.612
600	1.52	$1.08 \cdot 10^{-4}$	97.8	0.660
Reference diode	1.16	$6.60 \cdot 10^{-7}$	89.7	0.791

Table 1 - Evolution of the diode parameters after a 30 mn thermal treatment under H_2 atmosphere at variable temperature.

IV. DISCUSSION

For a beam fluence lower than 1 J/cm^2 P.E.B.A. produces only a small change in the Au/Si-N Schottky diode electrical parameters. However, above this threshold a fast degradation occurs with the two types of electron beam pulses used in this work. The sharp increase of the capacitance measured at -1 V indicates that donor centers are induced by P.E.B.A. in high concentration in the silicon regrowth layer. They exhibit a steep profile which is more penetrating in the case of pulse n°2 processed samples. Computer simulation have shown that for fluences higher than 1 J/cm^2 the silicon surface layer turns into melt either for pulse n°1 or for pulse n°2 /6/. However, at 1.2 J/cm^2 , the P.E.B.A. induced fully molten depth is $0.6 \mu\text{m}$ for pulse n°2 while it is only $0.1 \mu\text{m}$ for pulse n°1. So we think that the most damaging defects are generated in the P.E.B.A. induced molten layer. Because of the improvement obtained with the post-P.E.B.A. thermal treatment up to 600°C we suggest that quenched-in point defects are mostly responsible for the diodes degradation.

Moreover, Patel et al. have shown that dislocations could be annealed only at temperatures higher than 700°C /7/. So, the residual diode degradation after P.E.B.A. plus 600°C thermal treatment under H_2 atmosphere could be related either to residual point defects not annealed below 600°C or more probably to dislocations. These have been recently observed by mean of electron microscopy in the P.E.B.A. induced melting layer /8/.

V. CONCLUSION

Gold Schottky diodes made on P.E.B.A. processed N-type silicon exhibit fast degradation above a 1 J/cm^2 fluence threshold. The highly damage layer coincides with the P.E.B.A. induced molten layer where donor centers are likely to be generated during the freezing process. However, a post-P.E.B.A. thermal treatment at 600°C during 30 mn in the presence of molecular hydrogen is not sufficient to recover the typical parameters of a Au/Si-N reference diode.

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