I-V and C-V Measurements of Fabricated P^+/N junction Diode in Antimony doped (111) Silicon

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In this paper, the electrical characteristics of fabricated p+-n junction diode are demonstrated and interpreted with different theoretical calculations. Dopants distribution by boron ion implantation on silicon wafer were simulated with TRIM-code and ICECREM simulator. In order to make electrical activation of implanted carriers, thermal annealing treatments are carried out by RTP method for 1min. at 1000 °c under inert N_2 gas condition. In this case, profiles of dopants distribution before and after heat treatments in the substrate are observed from computer simulations. In the I-V characteristics of fabricated diodes, an analytical description method of a new triangular junction model is demonstrated and the results with calculated triangular junction are compared with measured data and theoretical calculated results of abrupt junction. Forward voltage drop with new triangular junction model is lower than the case of abrupt junction model. In the C-V characteristics of diode, the calculated data are compared with the measured data. Another I-V characteristics of diodes are measured after proton implantation in electrical isolation method instead of conventional etching method. From the measured data, the turn-on characteristics after proton implantation is more improved than before proton implantation. Also the C-V characteristics of diode are compared with the measured data before proton implantation. From the results of measured data, reasonable deviations are showed. But the C-V characteristics of diode after proton implantation are deviated greatly from the calculated data because of leakage currents in defect regions and layer shift of depletion by proton implantation.

Keywords: I-V, C-V, Proton Implantation, Triangular and Abrupt Junction Model

1. INTRODUCTION

P^+-N junction diode[1-7]are fabricated by boron mplantation in n type (111) silicon wafer. Boron ion profiles are simulated by the using of TRIM[8] and CECREM[9-11] programs and the depth of p-n unctions from the distribution of dopants are also letermined before and after thermal treatments of RTP n N_2 gas for electrical activation. Measured I-V characteristics of fabricated diodes are compared with he results of calculations using abrupt junction[1-5] and new triangular junction models. In this case, the alculated results of a new triangular junction models howed good agreements with the experimental data under forward and reverse bias conditions. The characteristics of fabricated diodes are measured compared with the calculated results of abrupt junc model[6]. The results of calculated and measured data showed similar curves. I-V and C-V characteri are also measured after proton implantation for elect isolations instead of conventional dry and wet etc methods. Forward voltage drop after proton implanta was found to be lower than the case of planar type di From current-voltage measurements, turn-on voltag forward bias is remarkably decreased for high s switching diode operation. After proton irradiation electrical isolation, it was observed that experiment V characteristics are deviated greatly from the calcul ılts because of the shift of depletion layer and the ;age current of surrounding defect regions.

2. CALCULATION AND MODEL ANALYSIS

Current equation for p-n junction diode can be cribed as [5]:

$$I = I_0[\exp(V_a/V_T)-1] \quad (1)$$

$$I_0 = qAD_p p_{n0} / W_n \quad (2)$$

ere I_0 is reverse bias saturation current, A is area of ction, p_{n0} is equilibrium hole concentration, W_n is letion layer thickness of n region, D_p is hole diffusion fficients, V_a is applied voltage, V_T is thermal voltage, ectively. Under reverse bias conditions, the junction acitance C_j can be expressed as a followed equation

$$C_j = \frac{A}{2}[\frac{2q\varepsilon}{V_0 - V_a} \times N_d]^{\frac{1}{2}} \quad \text{for } p^+\text{-n type} \quad (3)$$

ere A is area of junction, q is electron charge, ε is mittivity($\varepsilon = \varepsilon_r\varepsilon_0$), V_0 is contact potential, V_a is applied tage, N_d is donor concentration, respectively. Under ward bias conditions, the junction capacitance C_d can expressed as followed equation (4):

$$C_D = \frac{1}{3}\frac{q^2}{kT}A(L - x_{n0})p_{n0}\exp[\frac{q(V_0 - V_a)}{kT}] \quad (4)$$

ere L is diode length, x_{n0} is depletion of n side region. cially this diffusion capacitance C_D can be a limiting factor because of the delay time of RC in high frequenc circuits. For the calculation of I-V characteristics, th values of used parameters are shown in table 1.

For the calculation of incremental conductance i fabricated p^+-n junction diode, the conductance i expressed as equation (5):

$$g_d = \frac{dI_D}{dV_a} = (\frac{e}{kT})I_0 \exp(\frac{eV_a}{kT}) \quad (5)$$

where V_a is the diode applied voltage and I_0 is the diod reverse saturation current.

ıle 1. Values of parameters for the calculation of I-V racteristics in fabricated p^+-n junction.

Symbol	values of parameters	Units
Q	1.6×10^{-19}	[C]
A	9.025×10^{-3}	[㎠]
W_n	0.36×10^{-4}	[cm]
D_p	6.13	[㎠/s]
V_T	0.0259	[V]
ε	1.0448×10^{-12}	[F/cm]

3. EXPERIMENTAL

P^+-N junction diodes are fabricated through boro implantation into (111) silicon wafer. The resistivity c used silicon wafer is 0.002 Ω·cm and size of wafer is inch diameter. The antimony concentration of n typ silicon substrate is 1×10^{20} cm^{-3}. For p^+-n junction boron implantation with 1×10^{16} cm^{-2} dose is carried ou at accelerated energy of 60 keV into antimony dope (111) silicon wafer. Tilt angle in this case is 7°. The flo chart of fabrication steps for p-n junction diode presented in Fig. 1 Diode 1 is a planar type structure an diode 2 is a structure with proton bombardments for th side isolation of diode instead of conventional etchin methods. Proton implantation with 5×10^{16} cm^{-2} dose an tilt angle 0° is carried out at accelerated energy of 10 keV into antimony doped silicon wafer with proper mas The cross section as depicted in Fig. 2 illustrates simple planar diode and another diode structure fc electrical isolation by proton implantation.

Image of cross sectional view of fabricated diode b

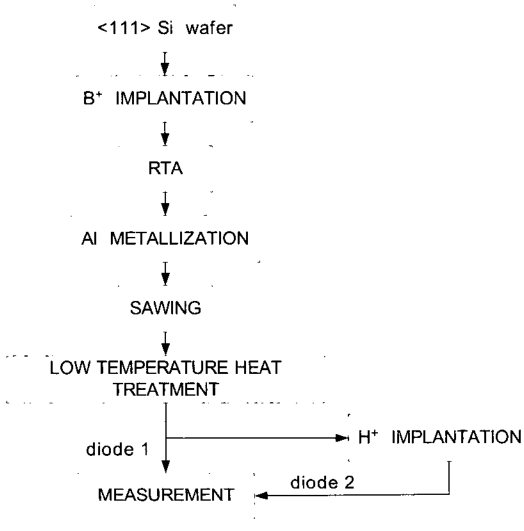
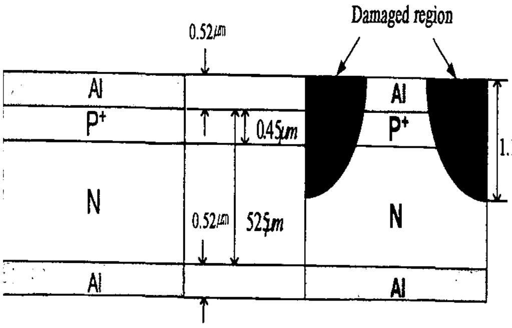
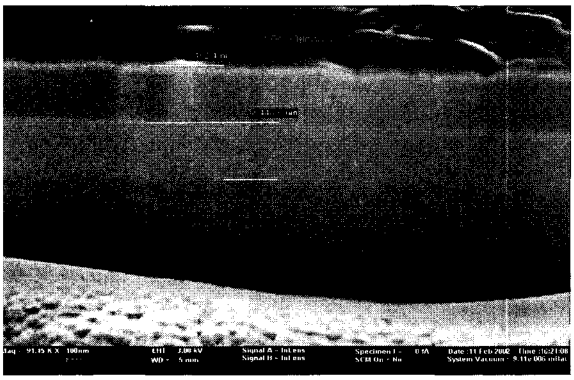


Fig. 1. Flow chart of fabrication steps for two differe p^+-n junction diode.

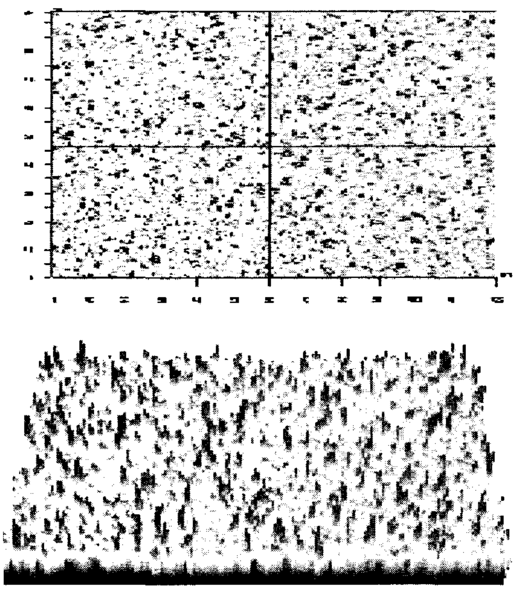
-ESEM (Field Emission Scanning Microscope) is shown n Fig. 3. The picture of Fig. 3 was taken without tilt compensation. Therefore, The thickness of aluminum ayer has to multiply the value of 0.454 by 1/cos30°.



-ig. 2. Cross sectional view of fabricated diodes.



-ig. 3. Measurement of cross sectional image by FESEM n fabricated diode.



-ig. 4. Measurement of Al surface image by optical profiler in Al/Si structure.

Consequently, the results in a size is a 0.52μm.The sample is cutted by FIB (Focus Ion Be using 30 kV accelerating voltage , 500 PA Ga ion b current and the image is measured by FES using 3keV accelerating voltage and 200pA elec beam current conditions. The white underpart of the 3 is debris from the cutting process. It has no relev to measure the cross sectional FESEM image.

The depth of p^+ -n junction of fabricated diode estimated through ICECREM process simulation resu The metallization of front and back side of wafe carried out by aluminum sputtering technology. aluminum thickness for front and back side is 0.5 For good adhension and ohmic contacts between Al silicon, the sample of diode is annealed in a atmosphere for 20 minutes at 450 °c. For the elect isolation of diode sides, proton implantations are car out and shown in Fig. 2. The conditions of implanta are 100 keV energy and 5×10^{16} cm^{-2} dose in antin doped (111) silicon wafer. The roughness of alumi surface is measured by Wyko optical profiler as depi in Fig.4. Average and RMS(root mean square) rough of Al layer are 4.95 nm and 7.53nm, respectively.

4. MEASUREMENTS AND DISCUSSION

The distributions of boron implantation are expre as triangular junction model for the first time instea conventional abrupt and linear models. Current vol characteristics are measured using HP 4155A parameter analyzer. Boron distributions before and thermal annealing under N_2 atmosphere atmosphere presented from ICECREM simulation results in Fig.

The range parameters of boron profile from T simulations are shown in Table 2. The redistributio boron profiles after thermal annealing of RTP u tungsten halogen lamp can be presented from ICECF simulations as Fig. 5.

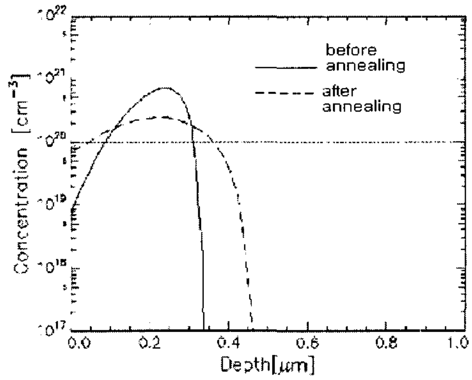
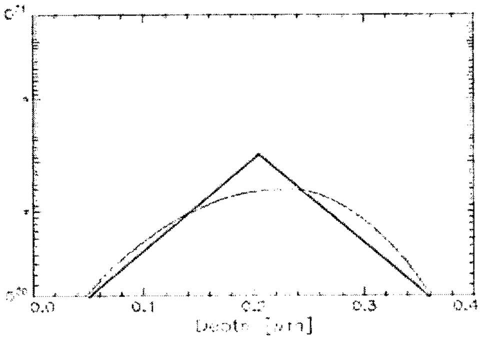


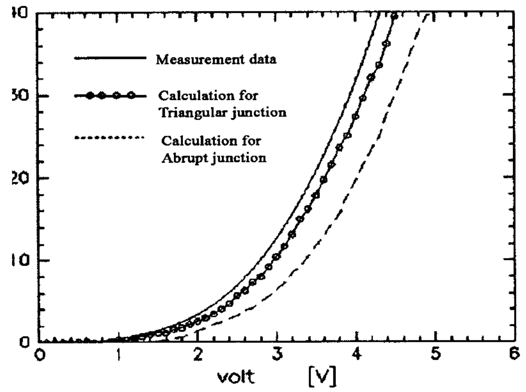
Fig. 5. Boron distribution from simulation results. (E keV, Dose=1×10^{16} cm^{-2}, T=1000 °c,1 min.)

ɜ 2. The range parameters of moments in boron les.

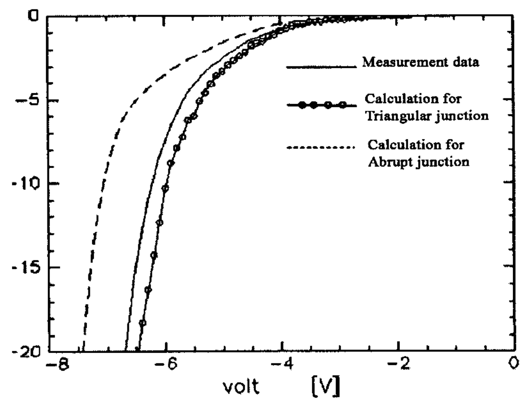
p (μm)	ΔR_p (μm)	γ	β
ı.2093	0.0588	-0.7066	3.3089



6. Triangular junction model of implanted boron ile.



7. I-V characteristics of fabricated planar diode ɜr forward bias.



8. I-V characteristics of fabricated planar diode ɜr reverse bias.

The depth of p-n junction after thermal annealing can be described as triangular model from Fig. 6.
Triangular model is suggested from configuration of cap-profile above background substrate concentration from Fig. 6 (substrate background concentration=1×10^{20} cm^{-3}, p-n junction depth X_j=0.36μm.).

The I-V characteristics of fabricated planar diode are measured under forward and reverse bias as depicted in Fig. 7 and 8 respectively.

Proton profile is presented as depicted in Fig. 9 by simulations of TRIM and ICECREM and maximum penetration depth of proton ions in planar diode showed about 1.15 μm. The range parameters of proton profile in Al/Si bilayer structure are calculated from TRIM simulations, and shown in Table 3.

For the electrical side isolation, proton implantations are carried out into masked silicon substrate instead of conventional etching methods for mesa structure. The penetration depth of proton is 1.15 μm and this depth is enough for the electrical isolation of side parts in Al(0.5 μm) /P$^+$ (0.45 μm) bilayer structure as depicted Fig. 5 and 9.

From Fig. 10 and 11, the calculated data with triangular junction model are compared with the measured data. Before proton implantation, the data by suggested triangular calculation are presented good fitting results with experimental data and showed also better results than the data of abrupt junction model. It can be observed from Fig. 10 and 11 that the measured data after proton implantation deviate greatly

Table 3. The range parameters of moments in proton profiles.

R_p (μm)	ΔR_p (μm)	γ	β
0.9099	0.1078	-1.6396	9.0528

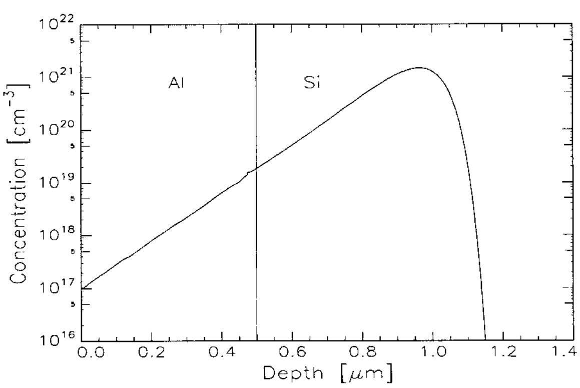


Fig. 9. Proton ions distribution for electrical isolation from Fig. 2 (E=100 keV, Dose=5×10^{16} cm^{-2}).

from calculated data because of the shift of p-n junction positions and leakage currents from side walls due to proton implantation.

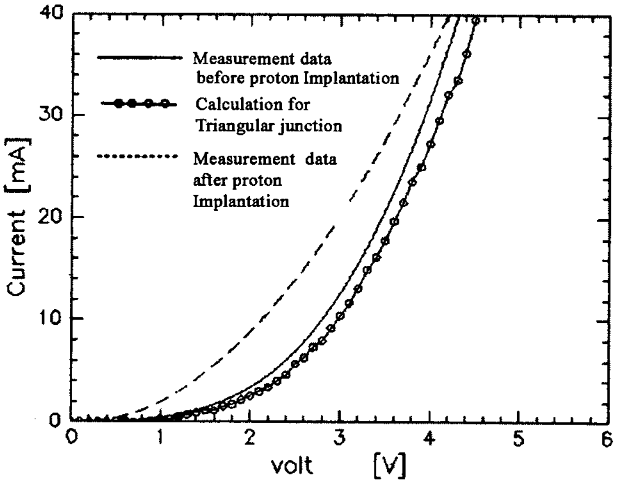


Fig. 10. I-V characteristics under forward bias after proton implantation.

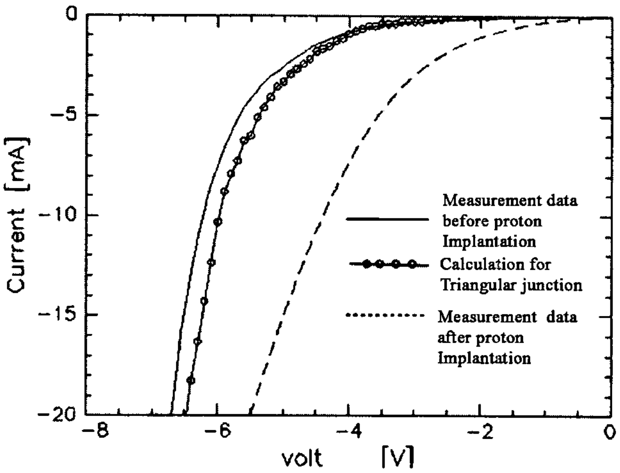


Fig. 11. I-V characteristics under reverse bias after proton implantation.

Table 4. Comparision of measured I-V and calculated results.

Data / Bias	Measured data		Calculated data	
	Before proton Implan-tation	After Proton Implan-Tation	Abrupt junction Model	Triangular junction Model
Forward Bias	0.82 [V]	0.26 [V]	1.2 [V]	0.82 [V]
Reverse Bias	-3 [V]	-0.48[V]	-4 [V]	-3 [V]

The results of measured I-V are compared v calculated data in Table 4. From table 4, it is clear turn-on characteristics of diodes are remarka developed after proton implantation. (0.82 → 0.26 V forward bias, the voltage drop of diode after p implantation is lower than the case of planar type d The current of diode is also reduced to some de accordingly to the limited area by proton implant for electrical isolation.

After proton bombardments, the C-V characteristi diodes are measured under forward and reverse bia measured data are also compared with calculated da shown in Fig. 12.

The measured data of conductance by HP analyzer are compared with calculated results. It ca observed from Fig. 13 that the calculated results u equation (5) show good agreements with measured d

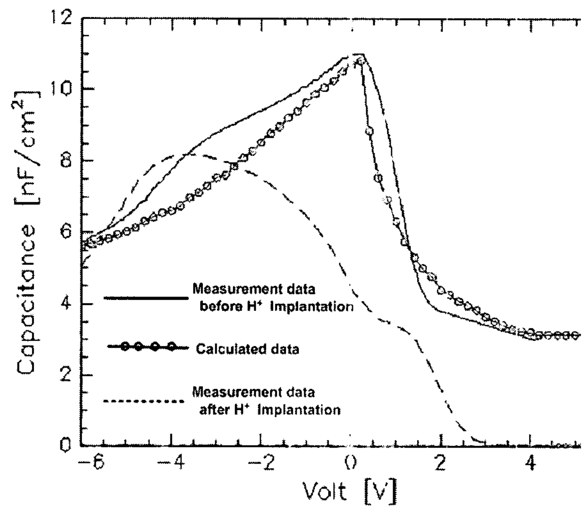


Fig. 12. C-V characteristics in fabricated diode.

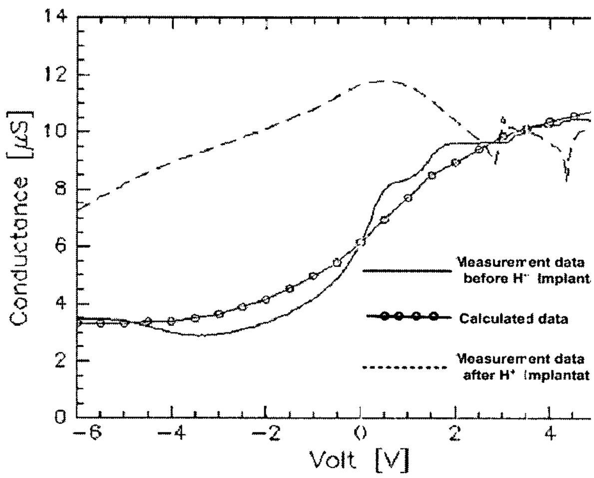


Fig. 13. Conductance measurements under applied vol in fabricated diodes.

deviation of theoretical conductance from the rimental values is more pronounced for the case of ɔn implanted condition than that of the pre-proton antation condition. The reason for this deviation is ıge currents from side walls and the shift of etion layer of p-n junction in diode. After the proton antation, electrical active region of diode is reduced ıme degree.

5. CONCLUSION

ʌo types of diodes such as planar and isolated ɔture by proton implantation are fabricated and sured the characteristics of I-V and C-V relations. ılculations of I-V characteristics, the data of a new ;ested triangular junction model shows good ements with measured data and shows also better lts than the data of theoretical abrupt junction el. The observed forward voltage drop using a triangular junction model is lower than abrupt tion model. The turn-on characteristics after on implantation is more improved than the case re proton implantation.

:-V characteristics of diode, the calculated results abrupt junction model are compared with sured data and the results of calculation showed onably good agreements with experimental data. ı C-V characteristics of diode are compared with measured data before and after proton lantation. From the results of measured data after on implantation, relatively big deviations are vn from the calculation results of abrupt junction el because of leakage currents in defect regions of aged side-walls and the shifts of depletion layer of junctions by proton implantation.

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