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Characterization of the Co-Silicide Penetration Depth into the Junction Area

Hi-Deok Lee, Keun-Koo Kang[1], Myoung-Jun Jang[2], Joo-Hyoung Lee[2], Seong-Hyun Park[2], Key-Min Lee[2], Ki-Seok Yoon[2], Jung-Hoon Choi[2], Geun-Suk Park[2], and Young-Jin Park[2]

Dept. of Electronics Engineering, Chungnam National University, Gung-dong, Yusong-Gu, Taejon, 305-764, Korea
Phone : 82-42-821-6868, Fax : 82-42-823-5436, E-mail : hdlee@cnu.ac.kr
[1] Dept. of Physics, Chungbuk Nataional University, Hungduk-Gu, Chongju, Choongbuk, 361-725, Korea
[2] Memory R&D Division, Hynix Semiconductor Co., Hungduk-Gu, Chongju, Choongbuk, 361-480, Korea

1. Introduction

Self-aligned silicide (Salicide) of the source/drain and gate is one of the challenges in current ULSI technology because silicidation of shallow junctions may induce undesirably large leakage current [1]-[4]. However, the junction depth becomes shallower and shallower along with the scale-down of MOSFET to reduce device punchthrough and short channel effects. The shallow silicided junctions, up to now, have been characterized using current-voltage behavior at reverse bias region the increase of reverse leakage current of silicided junctions has been considered to be inherent to silicidation as if it should be.

In this paper, we found that the penetration depth of silicide layer into junction area can be assessed using the current-voltage behavior of silicided junction both in reverse and forward bias regions. The penetration depth of silicide layer can not be obtained using the I-V curve in reverse bias region because the reverse current of both the silicided and non-silicided junction is dominated by Poole-Frenkel barrier lowering masking thereby the effect of Schottky contact.

2. Experiment

A 0.15 μm CMOSFET technology is applied for fabrication of the n^+/p and p^+/n junctions on p-type (100) silicon substrate, and key processes can be found elsewhere [5]. The n^+/p and p^+/n junctions are formed by As and BF_2 implantation, respectively, in retrograde well, and a novel two step Co-salicide process is applied [6]. Areal and peripheral intensive junction diodes (Area and peri diodes in short), a rectangle of 270 × 186 μm^2 and 310 rectangles of 270 × 0.61 μm^2, respectively, were used for experiments. The doping density of n-well and p-well at the junction is about 3.0×10^{17} cm^{-3} and 4.0×10^{17} cm^{-3}, respectively.

3. Results and Discussion

In the case of n+/p junction, silicidation greatly affected the junction properties, as evidenced by increase of reverse leakage current, I_R by 2 orders of magnitude in silicided junction as shown in Fig. 1. The open and solid plot in all Figures is for non-silicide and silicide junction, respectively. However, in the case of p+/n junction, there is no increase of I_R. Fig. 2 shows current-voltage (I-V) behavior of n^+/p junctions at reverse bias region, and that of non-silicided junction is shown for comparison. The reverse leakage current of both silicided and non-silicided n^+/p junctions exhibits same exponential dependence on applied voltage although the I_R of silicided junction is much larger than that of non-silicided junction. The leakage mechanism was analyzed using the slope of I_R/E versus $E^{1/2}$ plot and I_R/T^2 versus $E^{1/2}$ plot and only I_R/E versus $E^{1/2}$ plot is shown in Fig. 3 because the reverse leakage current is dominated by Poole-Frenkel effect, that is, the obtained slopes are much larger than the ideal slope 0.089 $(V/cm)^{-1/2}$. p+/n junction was also dominated by Poole-Frenkel effect like n+/p junction.

Although the silicide junction showed drastic increase of reverse leakage current, whether the penetration of silicide layer into the junction area can not be determined in reverse bias region because both of the slicided and non-silicided junction are dominated by Poole-Frenkel barrier lowering masking thereby the effect of Schottky contact.

The cumulative probability of the forward current, I_F shows different characteristics for the n+/p junctions, i. e., there is little difference between silicided and non-silicided area diode while I_F of silicided junction is much larger than that of non-silicided junction for peri diode like I_R. Fig. 5 shows The forward I-V characteristics of the diodes. For the case of p^+-n junction I-V behavior of silicided diodes is essentially same as that of non-silicided diodes. However, the ideality factor, n of non-silicided area and perimeter n^+/p junction diodes is about 1.46 and 1.53, while that of the silicided diodes are about 1.54 and 1.24, respectively. The larger I_F with smaller ideality factor means that the I_F is not dominated by recombination current but by other mechanism like Schottky current.

The interesting point of Fig. 4 and 5 is the only increase of n+/p perimeter diode although reverse leakage current was increased for both of the area and perimeter diodes. In contrast to this phenomenon, in the previous study with Ti-silicided junction, the increase of I_R meant the increase of I_F with smaller ideality factor as shown in Figs. 6 and 7, which means the formation of Schottky contact area by penetration of silicide layer into the junction area [4]. Therefore, it can be concluded that first, the silicide layer of n+/p area diode penetrated into near the space-charge region, because only reverse leakage current was increased and second, in the case of perimeter diode the silicide layer penetrated into the space charge region because both of the reverse and forward current increased. The extracted Schottky contact area of perimeter diode is obtained about 3.02 μm^2 using the I_R/T^3 versus 1000/T curve as shown in Fig. 8.

4. Conclusion

The penetration depth of silicide layer is obtained using the I-V curve both in reverse and forward current regions. Although reverse leakage current of both the area and perimeter diode increased by silicidation, only forward current of perimeter diode was increased in the case of n+/p junction. Therefore, the penetrated depth of silicide layer is almost near to the space charge region for area diode and into the space charge region for perimeter diode. The Schottky contact area formed by silicide penetration is extracted as 3.02 μm^2. In the case of p+/n diode, there is no increase of forward and reverse current, hence no penetration of silicide layer.

References

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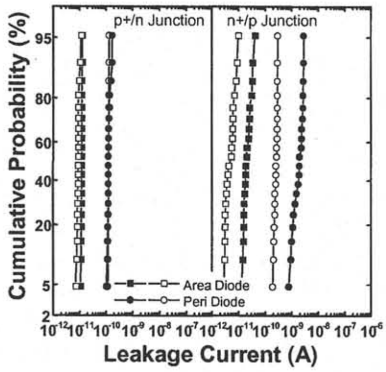


Fig. 1. Cumulative probability of n+/p and p+/n junction leakage current measured at reverse voltage of 2 V and at 20 ℃.

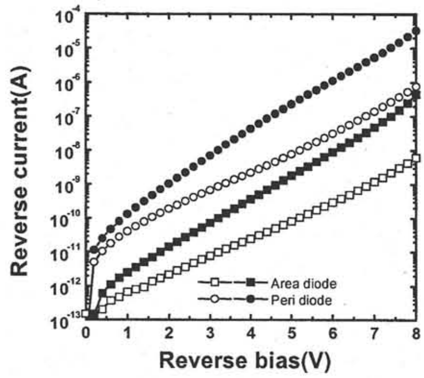


Fig. 2. The I-V characteristics of n+/p junction diodes in the reverse bias region at the temperature of 20℃. Open for non-silicide and solid for silicide junction.

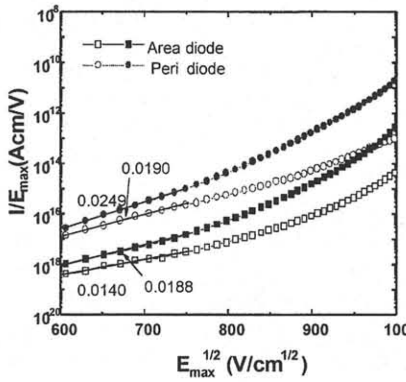


Fig. 3. I_R/E versus $E^{1/2}$plot for the Poole-Frenkel barrier lowing of n+-p junction in the reverse bias region at the temperature of 20℃.

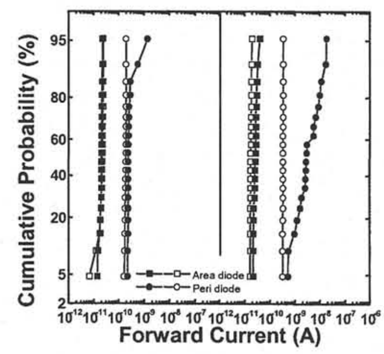
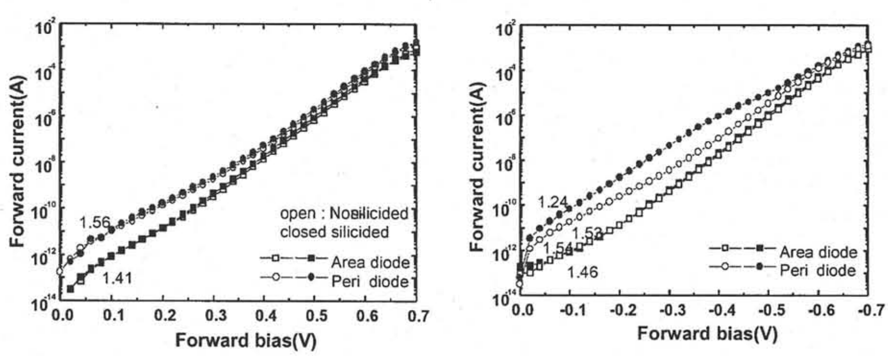


Fig. 4. Cumulative probabilities of the forward current of p+/n and n+/p diodes measured at the forward voltage of 0.2 V and 20 ℃.



(a) p+/n junction. (b) n+/p junction

Fig. 5. The current-voltage Plot of (a) p+/n and (b) n+/p junction diodes in the forward bias region at temperature 20℃. The numbers in the figure denote the ideality factor.

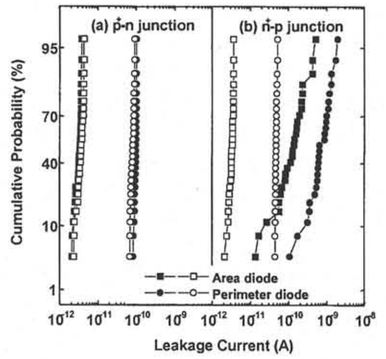


Fig. 6. Cumulative probabilities of the leakage current of p^+/n and n^+/p junction diodes with Ti-Silicide, measured at reverse voltage of 3 V and at 27 °C [4].

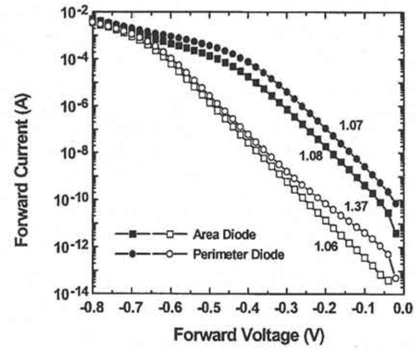


Fig. 7. The current-voltage plot of n^+/p junction diodes with Ti-Silicide in the forward bias region at temperature of 20 ℃ [4].

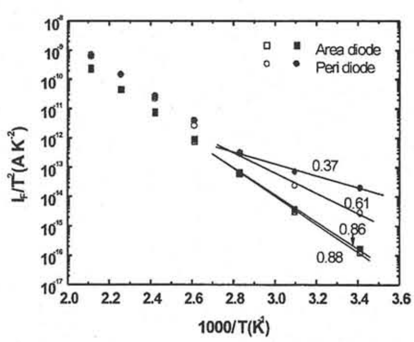


Fig. 8. I_R/T^3 versus 1000/T curve of silicided n+p junction for extracting Schottky contact area at 0.2V. The extracted Schottky contact area of peri diode is about 3.02 μm^2.