A study of leakage characteristics in silicided p+/n shallow junctions using transmission electron microscopy (TEM) coupled with selective chemical etching

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I. INTRODUCTION

A cobalt self-aligned-silicide (Co-salicide) process has become an essential technology for high performance ultra-large-scale integrated (ULSI) circuits.[1] However, as the design rule continues to scale down, a junction leakage problem caused by a Co-silicidation process can be a key issue for next generation integrated circuits. Efforts to find out leakage mechanisms in ULSI devices made with silicide processes have become a critical challenge for a decade.[2]-[4] However, the precise leakage model remains still unclear due to the complex characteristics of the junction leakage. In this work, two dimensional (2D) dopant profiling using transmission electron microscopy (TEM) combined with selective chemical etching is employed to investigate the leakage mechanism in p+/n shallow junctions that are fabricated using Co silicidation and STI processes.

II. EXPERIMENTAL PROCEDURE

The 0.15 mm technology was applied for the fabrication of the test chips. Only key processes are summarized below. After the STI process, phosphorous implantation was performed to form n-well. To fabricate source/drain, co-implantations of BF2 and boron (B) were carried out with energies of 20 and 20 keV to doses of 4×1015 and 2×1013 cm-2, respectively. These samples were then annealed at 1050 °C for 10 s in a N2 ambient. After removing native oxide, 15 nm-thick Co films were deposited, on which 15 nm-thick

Ti films were grown. For the Co silicidation process, rapid thermal annealing (RTA) was performed at 600 °C for 30 s in a N2 ambient. After removing the unreacted metal, an RTA process was performed again at 750 °C for 30 s in a N2 ambient to form Co disilicide. For comparison, non-silicided junctions were also fabricated.

III. RESULTS AND DISCUSSION

Fig. 1 shows the cumulative probability of reverse leakage current of the silicided and non-silicided p+/n junction samples with different junction structures, which were measured at reverse bias of -2 V. [Peripheral intensive 270′0.6 mm2 (′310) and flat intensive 270′186 mm2 diode patterns were defined by STI with a depth of 350 nm.] It is shown that the Co silicidation has a larger influence on the peripheral intensive diodes than the flat intensive diodes. In other words, the increase of the reverse leakage current due to the salicidation is far higher in the peripheral samples than in the flat samples. Such current increase was previously attributed to the occurrence of shallow junctions caused by the penetration of Co-disilicide into the junction area.[5]

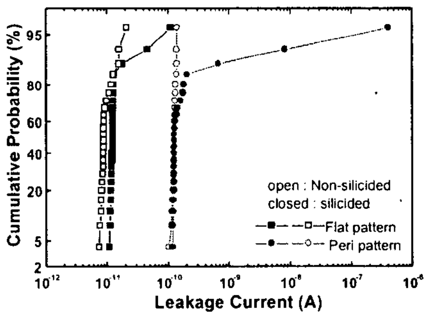

Fig. 1. The cumulative probability plots of reverse leakage current of the silicided and non-silicided p+/n junction samples with different junction structures

To characterize the profiles of 2D Si interstitials (generated by source/drain ion implantation damage) and junction after the silicidation process were simulated by TSUPREM-4 using the transient enhanced diffusion (TED) model (using default values).[6] The profiles after the silicidation process are shown in Fig. 2. The concentrations of the interstitials are very low near the edge of the active region, compared to those in the middle of the active region.[7] It is noteworthy that the junction profile (the bold line) bends upward near the edge of the active region, showing that the shallower junction is formed in this region.

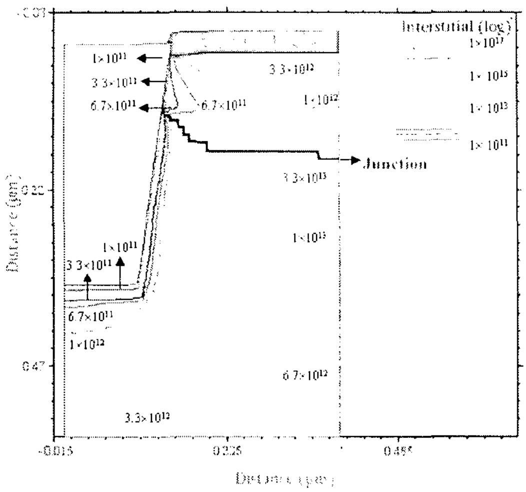

Fig. 2. Profiles of 2D Si interstitials (generated by source/drain implantation) and junction simulated by TSUPREM-4 using transient enhanced diffusion model after the silicidation process

In order to directly reveal 2D junction profiles in the p+/n junction, TEM coupled with selective chemical etching was performed. For TEM examination, ion-milled cross-section thin foil specimens were chemically etched using a mixture of HF:HNO3:CH3COOH (1:100:10) for 5 sec under +0.8V DC bias. Since the contrast of TEM images and the number of depth data points depend sensitively on diffraction conditions used, we employed multi-beam imaging at <110> zone axis in order to obtain good spatial resolution required for fully understanding both structural information and the accurate mapping of junction profiles, as proposed by Maher and Zhang [8]. Fig. 3 represents TEM image obtained from suitably selective chemical etched sample with Co-salicidation and STI process. The image clearly illustrates the presence of dark thickness fringes that are formed as a result of concentration dependent etch rate in the B doped regions. Since individual dark fringes are composed of points with identical concentration, they can be taken to convert into iso-concentration contours [9]. The iso-concentration contours are approximately parallel to the surface of Si substrate in the middle region of active. The distance from the top surface of silicide to the last visible iso-concentration contour was measured to be 173 (± 5) nm in middle region of active. It is noteworthy that the contours appear to be abnormally bent upward near interface between active and filed oxide as indicated by the arrow. This leads to shorter distance between the bottom of silicide and junction edge at STI interface than active center, i.e. shallower junction. Such abnormal behavior of junction profile results from the depletion of boron atoms near active edge caused by TED. Interstitial Si atoms generated from S/D ion implantation damage flow into STI interface which plays a role of recombination sites, resulting in less concentration of interstitial Si atoms near STI interface than that in the middle of active region [7]. Thus, TED causes boron atoms pile-up at active center, while boron atoms are reduced near active edge. This leads to bent-up junction profile near active edge. Therefore, the higher leakage current in the silicided samples, especially for perimeter samples (consisting of a number of leakage sources), could be attributed to the formation of the shallower junction at the active edge due to the bending-up junction profile.

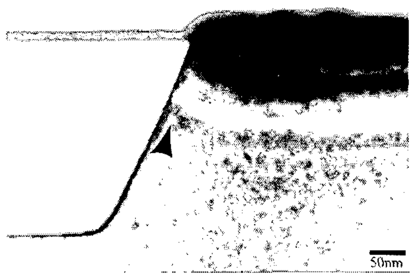

Fig. 3. A TEM image obtained from selective-chemical-etched silicided sample, showing 2D dopant profiles. It is worth noting that the junction profile bends upward, as indicated by the arrow.

IV. SUMMARY

TEM combined with selective chemical etching technique was successfully employed to characterize the leakage mechanism in p+/n shallow junctions fabricated using the Co-silicidation and STI processes. The TEM and TSUPREM-4 simulation results showed that the junction profiles abnormally bend upward near the edge of the active region due to TED, resulting in the formation of the shallower junctions. It was proposed that the shallower junctions are responsible for the leakage current in the shallow silicided p+/n junctions.

Reference

[1] D. K. Sohn, J.-S. Park, B. H. Lee, J.-U. Bae, K. S. Oh, S. K. Lee, J. S. Byun, and J. J. Kim, IEDM Tech. Dig., pp. 1005-1008, 1998.

[2] K. Goto, A. Fushida, J. Watanabe, T. Sukegawa, K. Kawamura, T. Yamazaki, and T. Sugii, IEDM Tech. Dig., pp. 449-452, 1995.

[3] H. C. Cheng, M. H. Juang, C. T. Lin, and L. M. Huang, IEEE Trans. Electron Devices Lett., vol. 15, pp. 342-344, 1994.

[4] A. Steegen, A. Lauwers, M. de Potter, G. Badenes, R. Rooyackers, and K. Maex, Symp. on VLSI Technol. Digest of Technol. Paper, pp.180-181, 2000.

[5] H.-D. Lee, IEEE Trans. Electron Devices, vol. 47, pp. 762-767, 2000.

[6] Technology Modeling Associate, Inc., TSUPREM-4, Version 98.4, April 1998.

[7] C. S. Rafferty, H.-H. Vuong, S. A. Eshraghi, M. D. Giles, M. R. Pinto, and S. J. Hillenius, IEDM Tech. Dig., pp. 311-314, 1993.

[8] D. M. Maher and B. Zhang, J. Vac. Sci. Technol. B, vol. 12, pp. 347-352, 1994.

[9] C.-J. Choi and T.-Y. Seong, J. Electrochem. Soc., vol. 147, pp. 1525-1529, 2000.