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Lateral Diffusion Distance Measurement for 40-80 nm Junctions by Etching/TEM-EELS Method

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1. Abstract

Lateral diffusion distance measurement technique has been developed by wet-etching combined with TEM-EELS method. The lateral diffusion distance is about 0.6 times of the vertical diffusion distance for 40-80nm junctions. The detection limit and spatial resolution are about 5E18cm^{-3} and 5nm, respectively. These results suggest that this technique is promising for analyzing devices under 0.1μm.

2. Introduction

It is very important to know the exact two-dimensional dopant profiles to simulate electrical characteristics of MOSFET correctly. Many methods have been reported for 2D dopant profiling, by SCM [1], by etching-AFM [2], by etching-STM [3] and by etching-TEM [4]. The techniques by wet-etching are based on the characteristic that the etching rate depends on carrier concentration. 2D carrier distribution can be obtained by measuring the surface shape after the etching. But the method to determine the correct equi-concentration line is obscure [5] and spatial resolutions of these imaging techniques are poor for delineations of ultra shallow junctions. In this work, these problems are solved by etching time optimization and by using energy filtered transmission electron microscopy, respectively. The lateral distances of boron diffusion are evaluated by this method together with electrical C-V measurement.

3. Thickness Mapping by TEM-EELS

Thickness mapping technique using electron energy loss spectroscopy (EELS) was applied to 2D carrier profiling for the first time. The thickness of the sample t at a certain spot can be expressed by mean free path of inelastic scattering λ, total transmitted intensity I_t and zero loss intensity I_0 as follows [6]

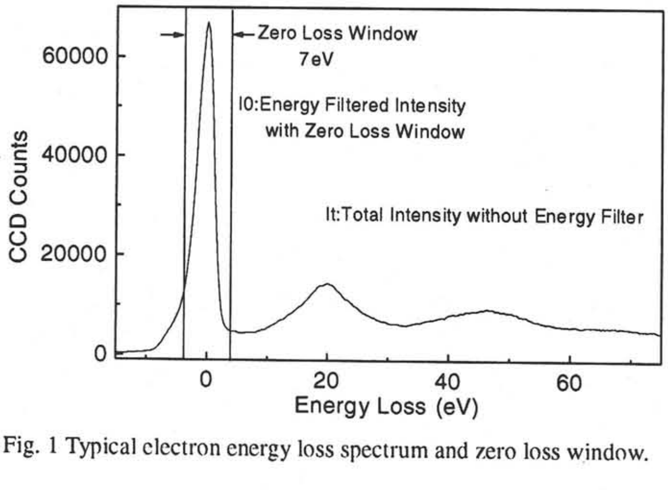

Fig. 1 Typical electron energy loss spectrum and zero loss window.

$$t=\lambda \ln(I_t/I_0). \qquad (1)$$

2D thickness distributions can be obtained by taking normal TEM images (corresponding to I_t) and energy filtered TEM images (I_0) with the energy window shown in Fig.1, and by calculating eq.(1) at every pixel of CCD detector. Owing to a better spatial resolution of about 5nm than AFM, it becomes possible to measure 2D carrier distribution with ultra shallow junctions.

4. Dopant Selective Etching

The chemical etching was performed with the conventional etching solution HF:HNO$_3$:CH$_3$COOH=1:3:8 at 5℃ under room light after cross sectional TEM sample preparation by ion milling.

Highly B-doped epitaxial Si layers with various thicknesses were sandwiched by lightly B-doped epitaxial Si layers as Fig.2 to investigate effects of carrier distribution on the etching rate. Two of these samples were etched for 20 and 30 seconds, respectively. The etched thickness profiles by TEM-EELS are shown in Fig.2. In case of the 30nm thick highly B-doped layer, the profile is flat at 20 seconds, while a hollow appears at 30 seconds. It means that an incubation time exists before the high rate etching starts, depending on the area of highly B-doped layer. This tendency clearly indicates that equi-thickness lines don't correspond to equi-concentration lines.

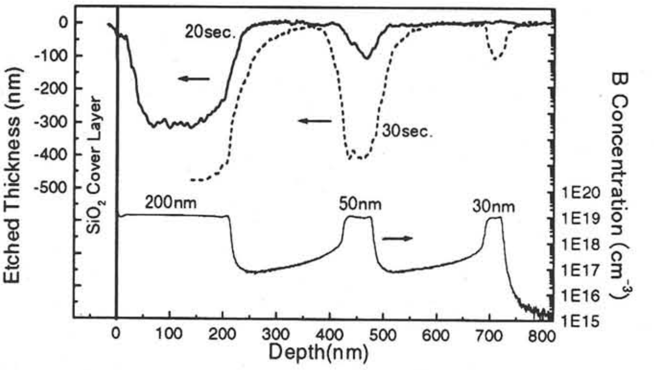

Fig. 2 Boron concentration depth profile of epitaxial Si sample by SIMS and etched thickness profiles after the chemical etching by TEM-EELS.

5. Interpretation of Etched Surface

Cross sectional TEM samples of boron implanted n-type silicon with a SiO$_2$ cover layer were etched for 10, 20, 30 and 40 seconds. Boron depth profile by SIMS and etched thickness profiles by TEM-EELS are given in Fig.3.

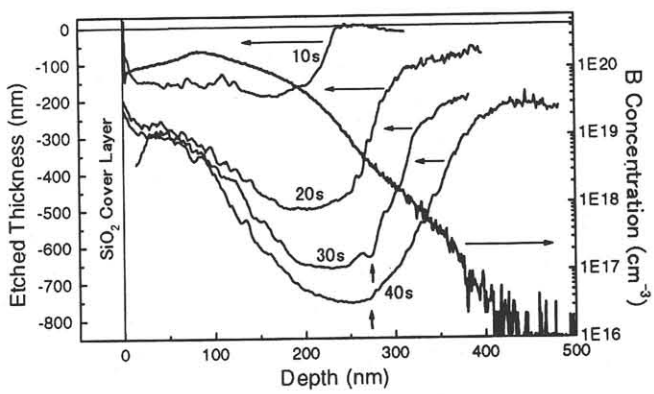

Fig. 3 Boron depth profile by SIMS and etched thickness depth profiles after the etching of 10, 20, 30 and 40 seconds by TEM-EELS.

There is a point where gradient of the profile changes discontinuously (indicated by upward arrows in Fig.3). This point is fixed at about 5E18cm^{-3} when the etching time is more than 30 seconds. By assuming the etching rate dependence on carrier concentration with bulk silicon etching rate, and boron depth profile as Fig.3, the expected thickness depth profiles are simulated in Fig.4. Though effects of the incubation time aren't considered in this simulation, the results suggest that a drastic variation of the etching rate at a certain concentration generates a discontinuous point and it exists at the same place at any etching time more than a certain threshold time. So, the discontinuous point reflects only carrier concentration and doesn't reflect carrier distribution.

In short the essential thing to get accurate 2D carrier profiles is to set the etching time enough so that the effect of the incubation time can be ignored.

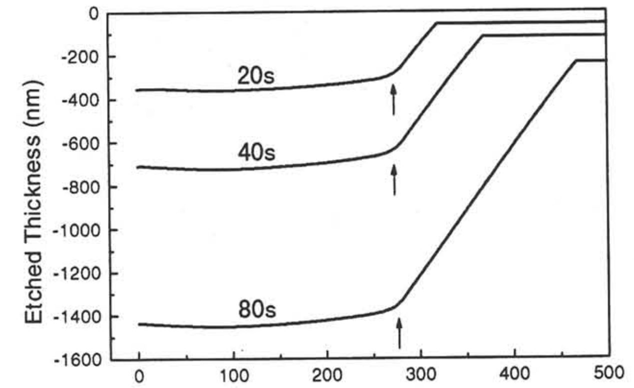

Fig. 4 A simulation of etched thickness profiles of the sample used in Fig.3.

6. Measurement of Lateral Diffusion Distance

This technique was applied to measure lateral diffusion distance of pMOSFET source/drains. Boron was implanted at 1keV with 1E15cm^{-2}, followed by RTA at 950 and 1050℃ for 10 seconds. The chemical etching was performed for 60 seconds.

The lateral and vertical distances at 5E18cm^{-3} measured by the etching/TEM-EELS technique and corresponding distances at 1E18cm^{-3} (at pn junction) converted by a simulation are shown in Fig.5. The distances at pn junction measured by SIMS (vertical) and electrical C-V measurement (lateral) are also shown in Fig.5. The C-V characteristic between gate and source/drain was measured, and the lateral diffusion distance was calculated by comparing the capacitance at the strong inversion region with that at the accumulation region.

The results by the etching/TEM-EELS method were consistent with those of SIMS/electrical method for both lateral and vertical distances. The lateral diffusion distance at pn junction was about 0.6 times of the vertical distance for 40-80nm junctions.

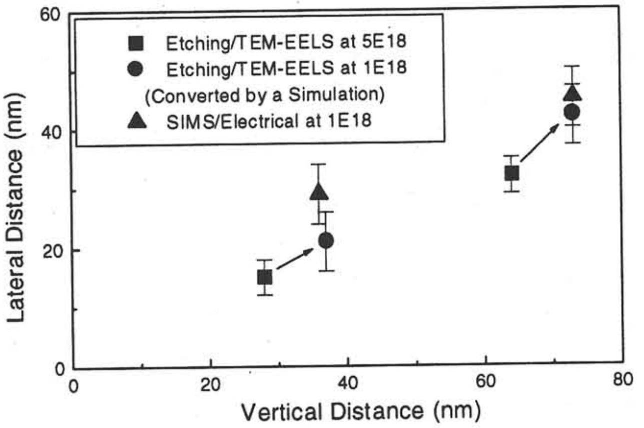

Fig.5. Lateral and Vertical diffusion distances at 5E18cm^{-3} measured by etching/TEM-EELS and the distances at pn junction (1E18cm^{-3}) converted by a simulation. The distances at pn junction measured by SIMS (vertical) and by electrical C-V measurement (lateral) are also shown.

7. Conclusions

A new technique combining wet-etching and TEM-EELS was developed to measure the lateral diffusion distance for 40-80nm junctions. The ratio of lateral to vertical distance at pn junction was about 0.6 by this technique, which was consistent with that measured by SIMS/electrical C-V measurement.

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References

1) J. J. Kopanski, J. F. Marchiando, D. W. Berning, R. Alvis and H. E. Smith: Proc. 4th Int. Workshop on the Meas., Charact. and Modeling of Ultra-Shallow Doping Profiles, 53.1 (1997).

2) V. Raineri, V. Privitera, W. Vandervorst, L. Hellemans and J. Snauwaert: Appl. Phys. Lett. **64** (1994) 354.

3) T. Takigami and M. Tanimoto: Appl. Phys. Lett. **58** (1991) 2288.

4) C. Spinella, V. Raineri, F. La Via and S. U. Campisano: Proc. 3rd Int. Workshop on the Meas. and Charact. of Ultra-Shallow Doping Profiles, 42.1 (1995).

5) V. A. Ukraintsev, R. McGlothlin, M. A. Gribelyuk and Hal Edwards: Proc. 4th Int. Workshop on the Meas., Charact. and Modeling of Ultra-Shallow Doping Profiles, 68.1 (1997).

6) R. F. Egerton: Electron Energy-Loss Spectroscopy in the Electron Microscope, 2nd ed. (Plenum, New York, 1996).