Extended Abstracts of the 1999 International Conference on Solid State Devices and Materials, Tokyo, 1999, pp. 510-511

Two-Dimensional Dopant Profiling of nMOSFETs with Shallow-Extensions Using Electrochemical Etching Technique

Yorinobu Kunimune, Naoharu Nishio, Akira Mineji, Kensuke Yamaguchi and Hiroaki Kikuchi

ULSI Device Development Laboratory, NEC Corporation,
Shimokuzawa 1120, Sagamihara, Kanagawa 229-1198, Japan
Phone: +81-42-771-0747 Fax: +81-42-771-0938 e-mail: kunimune@lsi.nec.co.jp

1. Abstract

High resolution (<5nm) two-dimensional dopant profiles at the concentration of $1.5\times10^{18}cm^{-3}$ for nMOSFETs with shallow-extensions and deep-source/drains were successfully obtained by using the electrochemical etching technique for the first time. The result by this technique was consistent with that measured by the electrical measurement. Now the range to which the etching technique is applicable becomes wider.

2. Introduction

On manufacturing sub-0.1μm devices, the controlling of the dopant lateral diffusion becomes extremely crucial not only for pMOSFETs but also for nMOSFETs.

Recently, the two-dimensional profiling techniques using the scanning probe microscopes are widely reported [1-3]. Among those, scanning capacitance microscopy (SCM) has been one of the most promising techniques [1]. But the spatial resolution of this technique is limited by the tip radius and only about 20nm has ever been achieved [1]. This resolution is insufficient for the state-of-the-art devices.

On the other hand, methods using wet-etching combined with transmission electron microscopy (TEM) have been developed as high spatial resolution techniques [4,5]. However, this technique isn't applicable for the analysis of MOSFETs with shallow-extensions and deep-source/drains (deep-S/Ds), because the etching rate is dependent not only on the carrier concentration but also on the concentration at the surrounding regions [4,5].

Here, we demonstrate the electrochemical etching, which is the anodic oxidation in HF solution under potentiostatic control, is hardly dependent on the surrounding doping levels. Owing to this merit, the two-dimensional dopant profiling of nMOSFETs with shallow-extensions was successfully demonstrated, which had been difficult by using the conventional etching technique. Additionally, this has several merits such as a high controllability and the smooth surface compared with the conventional etching [6].

3. Experiments

3-1 Sample preparation

A silicon substrate with doped regions is glued with three silicon substrates as shown in Fig.1 and its thickness to the cross-sectional direction is reduced to 200μm by the mechanical polishing. The gold layer is deposited onto backside of the sample to decrease the resistivity. The sample is glued to the working electrode by the silver paste. The working electrode is wholly covered with teflon tape and teflon grease except the sample surface.(Fig.1) A schematic view of the three electrodes system is shown in Fig.2. The voltage between the sample surface and the reference electrode is controlled by a potentiostat. The etching solution is HF(49%):H_2O=1:20. The voltage between the sample and the reference electrode is kept 2V. The silicon is oxidized by injected holes caused by the electric field, and continuously the oxides are etched away by HF solution. The etched depth depends on the dopant concentration. At this voltage, the etched surface becomes very smooth [7].

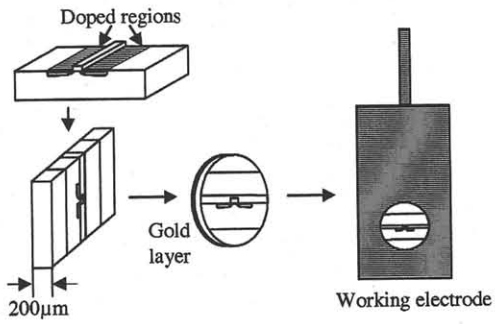

Fig.1 A sample preparation flow. The sample is glued to the working electrode by the silver paste.

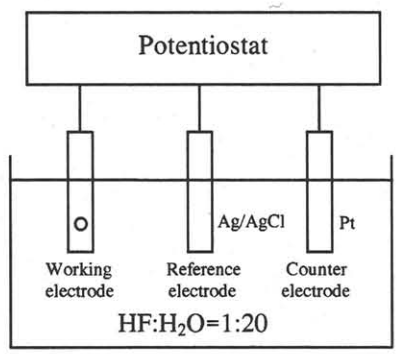

Fig.2 A schematic view of the three electrodes system.

3-2 Dependence of etching time

The electrochemical etching is adapted to phosphorous implanted silicon wafers with various etching time. The etching time is taken 2.5s, 4.5s and 6.5s. The SIMS profile and the etched depths are shown in Fig.3. The etched depths are measured by electron energy loss spectroscopy (EELS)

which can obtain two-dimensional thickness distribution of the sample [5].

The edge of the hollow appeared at $1.5\times10^{18}cm^{-3}$ for the etching time between 2.5s and 6.5s. This may be because the etching rate at the substrate (Boron:$1\times10^{15}cm^{-3}$) is negligible compared with that at the phosphorous heavily doped regions.

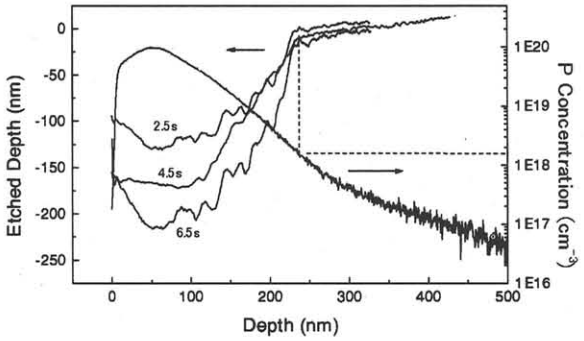

Fig.3 The electrochemical etching is performed for 2.5s, 4.5s and 6.5s. The etched depths and phosphorous concentration are shown.

3-3 Dependence of doping profiles

The electrochemical etching was performed for three different doping profiles. The etching time was set 2.5s for every sample.

The depths at $1.5\times10^{18}cm^{-3}$ and those at the edge of hollows are shown in Fig.4. The differences were within 5nm for every profile. The depth of the hollow for each sample was nearly equal. This indicates that the etching rate at a certain point is hardly affected by the surrounding doping level.

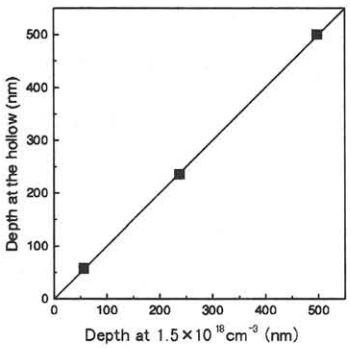

Fig.4 The depth at $1.5\times10^{18}cm^{-3}$ is compared with the depth at the edge of the hollow.

4. Device Characterization

We applied the electrochemical etching technique to measure the two-dimensional dopant distribution of the nMOSFET with shallow-extensions and deep-S/Ds. The sample is etched for 2.5s with a bias voltage of 2V in $HF:H_2O$=1:20 solution. A XTEM is shown in Fig.5. The vertical dopants profiles and the etched depth at the deep-SD region are shown in Fig.6. Certainly, the concentration at the edge of the hollow is about $1.5\times10^{18}cm^{-3}$. The dotted white line in Fig.5 indicates the position at $1.5\times10^{18}cm^{-3}$. To the lateral direction, this almost corresponds to the metallurgical pn junction.

The lateral diffusion distance (i.e. ΔL) is about 16nm from the electrochemical etching, while it is about 18nm from the electrical measurement. The result ensures the accuracy of the electrochemical etching technique.

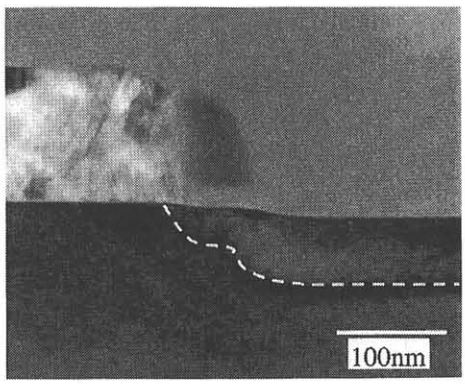

Fig.5 A XTEM of the nMOSFET after the electrochemical etching.

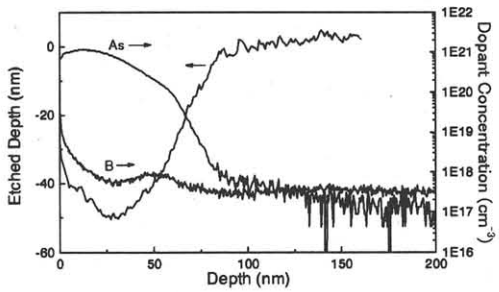

Fig.6 The etched depth and dopants (B,As) concentration profiles at the deep-S/D region.

5. Conclusions

In conclusion, we have demonstrated that the etching rate at a certain point was hardly affected by the surrounding doping concentration in case of the electrochemical etching. This technique is practical for characterization of sub-0.1μm devices with various doping profiles like shallow-extensions.

Acknowledgements

The authors thank O. Kudo, N. Endo and K. Ikeda for useful advice, R. Adaniya for sample preparation.

References

1) W. Timp et al.: IEDM Tech. Dig., 555 (1998).
2) P. De Wolf et al.: IEDM Tech. Dig., 559 (1998).
3) Kuo-Jen Chao et al.: J. Vac. Sci. Technol. B 16, 453 (1998).
4) V. A. Ukraintsev et al.: J. Vac. Sci. Technol. B 16, 476 (1998).
5) Y. Kunimune et al.: Ext. Abs. SSDM, 10 (1998).
6) T. Trenkler et al.: J. Vac. Sci. Technol. B 16, 349 (1998).
7) R. L. Smith et al.:J. Appl. Phys., 71, R5 (1992).