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Boron doped Polycrystalline $Si_{1-X}Ge_X$ Resistors for High Precision Analog ICs

H. Watanabe, M. Tamura*, M. Dainin, M. Seto, T. Shohbu, Y. Ohsako, Y. Takimoto, Y. Ishimoto, H. Ino, E. Imanishi, M. Satoh, H. Satoh, K. Yamashita, and K. Taniguchi*

Electronic Devices Company, Ricoh Co. Ltd.
13-1, Himemurocho, Ikeda, Osaka, Japan hwata@nts.ricoh.co.jp
*Department of Electronics and Information Systems, Faculty of Engineering, Osaka University,
2-1, Yamadaoka, Suita, Osaka, Japan taniguti@eie.eng.osaka-u.ac.jp

1. Introduction

Polycrystalline silicon (poly Si) films have been used in integrated circuits as gate electrodes and resistors because of their compatibility to CMOS process. Recent studies show that the polycrystalline silicon germanium (poly $Si_{1-X}Ge_X$) is suitable alternative to poly Si for gate electrodes because it reduces boron penetration and gate depletion [1]-[2]. Poly $Si_{1-X}Ge_X$ is also used in thin film transistors because it has lower thermal budget for crystallization and higher dopant activation than poly Si [3]. The diffusion and electrical activation properties of boron and arsenic in poly Si and poly $Si_{1-X}Ge_X$ have been reported [4]-[6].

The aim of this paper is to investigate the electrical properties of boron doped poly $Si_{1-X}Ge_X$ films in more detail because high precision analog ICs require accurate resistor ladders with stable resistivity. In this work, we studied poly $Si_{1-X}Ge_X$ (X=0, 0.2, 0.4) whose Hall mobility, resistivity, fluctuation, and trapping density as a function of doping concentration were measured. Based on the measured results, the following two key features were obtained. (1) poly $Si_{0.6}Ge_{0.4}$ film has small fluctuation of resistivity even in low dopant concentration and (2) Ge included in poly Si reduces the number of Si dangling bonds which significantly affect the resistivity of poly Si film. These results indicate that the poly $Si_{1-X}Ge_X$ resistor is superior to poly Si for more accurate resistor elements in analog circuits.

2. Experimental

Poly Si and poly $Si_{1-X}Ge_X$ thin films with thickness of 500nm were deposited on thermally grown SiO_2 by using low-pressured CVD in the temperature rage from 550 to 620°C with SiH_4 and GeH_4 gas sources. Boron atoms were doped with ion implantation at 30KeV with dosages from 1×10^{13} to 7.5×10^{14} cm^{-2}. The activation temperature for all wafers was 920°C. In order to investigate the influence of hydrogen, silicon nitride film was deposited by using plasma-assisted CVD on the poly Si and poly $Si_{1-X}Ge_X$ thin films for the samples with/without the interlayer metal film between poly crystalline and silicon nitride films. The interlayer metal film prevents the diffusion of hydrogen.

Resistivities were measured with Van der Pauw patterned samples. Mobility, effective carrier concentrations were determined by Hall measurement. Barrier height was obtained from temperature dependence of resistivities. Trapping densities (spin densities) were also measured with ESR measurement.

3. Results and Discussion

Resistivity and Mobility

Figure 1(a) shows the measured resistivity as a function of Hall carrier concentration for poly Si, poly $Si_{0.8}Ge_{0.2}$ and poly $Si_{0.6}Ge_{0.4}$ films. In the low carrier concentration region, the significant reduction of resistivity with germanium concentration is observed. This is consistent with the increase of Hall mobility as shown in Figure 1(b). Seto reported that the mobility of poly Si becomes the minimum where carrier concentration equals trapping density and also the mobility increases in proportion to the carrier concentration in the carrier concentration region above trapping density [7]. The electrical properties of poly $Si_{0.8}Ge_{0.2}$ film are similar to that of poly Si. However, that of poly $Si_{0.6}Ge_{0.4}$ film obviously differs from those of others.

Fluctuation

Figure 2 shows the percent fluctuation of resistivity, standard deviation over mean value, across a wafer as a function of resistivity. Uniformity of resistivity in poly $Si_{0.6}Ge_{0.4}$ film is superior to those of poly Si and poly $Si_{0.8}Ge_{0.2}$ films especially in higher resistivity region. The stable electrical characteristics of poly $Si_{0.6}Ge_{0.4}$ film ensure the accurate resistors in higher resistance region especially for low-power analog circuit applications. The reason why poly $Si_{0.6}Ge_{0.4}$ film has different characteristics from the others can be explained with both carrier mobility shown in Figure 1(b) and barrier height of grain boundary shown in Figure 3. The decrease of grain boundary resistance due to barrier height lowering may reduce the resistivity fluctuation.

Influence of Hydrogen

It is well known that hydrogen atoms significantly affect the resistivity of poly Si film. Figure 4 shows the measured resistivity for the samples with/without interlayer metals which absorb generated hydrogen atoms from silicon nitride films. Figure 4 clearly shows that hydrogen atoms affect the electrical characteristics of poly Si but not those of poly $Si_{0.8}Ge_{0.2}$ and poly $Si_{0.6}Ge_{0.4}$.

Figure 5(a)-(c) show measured ESR spectra as a

function of doping concentration, from which we can derive the density of traps originating from either Si or Ge dangling bonds. It should be noted that the amount of Si dangling bonds drastically decreases with germanium concentration.

These facts indicate that germanium may change the chemical properties of grain boundary at which Ge would terminate Si dangling bonds. The negligible influence of hydrogen atoms onto poly $Si_{1-X}Ge_X$ film suggests that Ge dangling bonds may be inactive to hydrogen.

4. Conclusion

We presented the superior electrical characteristics of poly $Si_{1-X}Ge_X$ for accurate resistor elements in low power analog circuits. (1) Poly $Si_{0.6}Ge_{0.4}$ film has small fluctuation of resistivity even in low dopant concentration and (2) Ge included in poly Si reduces the number of Si dangling bonds which significantly affect the resistivity of poly Si film. Germanium atoms incorporated in grain boundary have two roles; the barrier height lowering and the property modification of dangling bonds.

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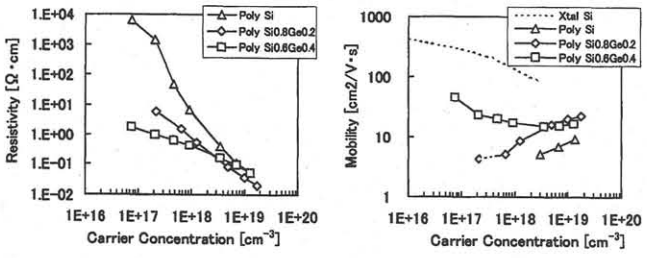


(a) (b)

Fig. 1 (a) Resistivity as a function of Hall carrier concentration for poly Si, poly $Si_{0.8}Ge_{0.2}$ and poly $Si_{0.6}Ge_{0.4}$ films. (b) Hall mobility as a function of carrier concentration. Electrical properties of poly $Si_{0.6}Ge_{0.4}$ differ from those of poly Si and poly $Si_{0.8}Ge_{0.2}$ films.

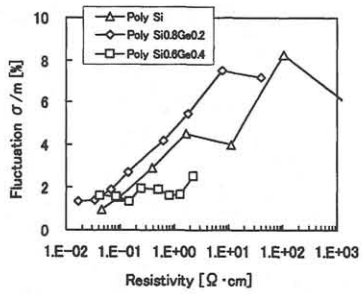


Fig. 2 Fluctuation as a function of resistivity. Poly $Si_{0.6}Ge_{0.4}$ is superior to poly Si and poly $Si_{0.8}Ge_{0.2}$ films in higher resistivity region.

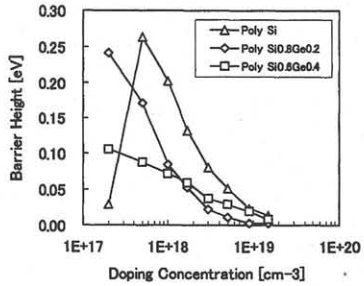
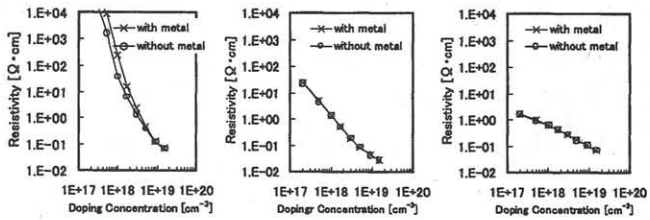
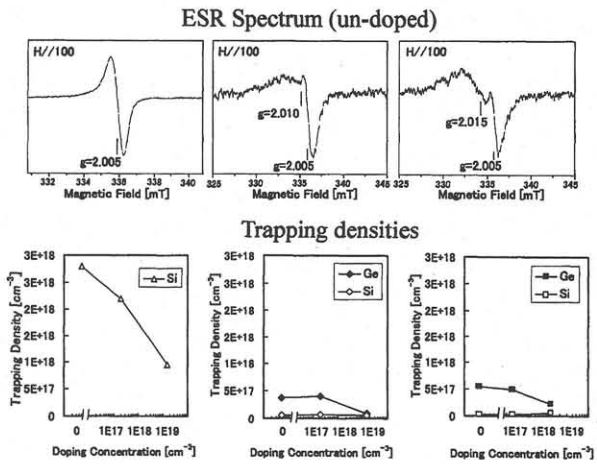


Fig. 3 Measured barrier height of grain boundary as a function of doping concentration.



(a) Poly Si (b) Poly $Si_{0.8}Ge_{0.2}$ (c) Poly $Si_{0.6}Ge_{0.4}$

Fig. 4 Influence of hydrogen on resistivity. Only poly Si film is affected by hydrogen, which was verified with the samples with/without interlayer metal between poly crystalline and silicon nitride films.



(a) Poly Si (b) Poly $Si_{0.8}Ge_{0.2}$ (c) Poly $Si_{0.6}Ge_{0.4}$

Fig. 5 (Top) ESR spectra of un-doped films and (Bottom) trapping densities obtained from the spectra as a function of doping concentration. Note that trapping densities of Si and Ge of poly $Si_{1-X}Ge_X$ are separated.