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Oxygen Behavior Around Heavily Doped Ultra-Shallow Junction in Si

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The diffusion and gettering of oxygen are investigated after low-energy arsenic implantation and furnace annealing of SiO_2/Si structures. Secondary ion mass spectrometry was used for examination of arsenic and oxygen depth profiles. It is shown that arsenic-doped ultra-shallow junction in Si stimulates the background oxygen gettering by SiO_2/Si interface at the annealing temperatures higher than 850 °C.

Keywords: ion implantation, interface, arsenic, junction, diffusion, gettering, oxygen, SiO_2, sims.

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1. INTRODUCTION

The processes for forming source/drain extension regions of metal oxide semiconductor field effect transistors (MOSFET) become increasingly important as device dimensions are scaled down. The basic cause is short channel effect. To overcome it is required the creation of ultra-shallow junction (USJ) with the high dopant activation. It is predicted by International Technology Roadmap for Semiconductors (IRTS) that USJ less than 5 nm in depth will be necessary to produce the next generation of silicon transistors [1]. Low energy implantation of arsenic is widely used for creation of n-type extensions with fluencies from 10^{14} to 10^{16} cm^{-2}. However, the formation USJ is complicated by the dopant segregation at the interface, deactivation and transient enhanced diffusion (TED) as result of interaction with point defects. Directions of overcoming these problems are discussed in many papers [2-4].

Another factor affecting on the properties of the ultrashallow junction in the Czochralski Si may be an oxygen impurity with a concentration of usually around 10^{18} cm^{-3}. It is known that the diffusion – mediated oxygen precipitation in silicon leads to the formation of extended defects and metal gettering that are responsible for current leakage [5,6].

Near USJ the oxygen precipitation is strongly dependent on the presence of vacancies generated by ion implantation and the existing mechanical stresses at different thermal treatment. However, the oxygen precipitation is retarded in the heavily As-doped Si. That is connected with reduced oxygen diffusion at the increase of arsenic concentration [7].

Some authors are believed that interstitial oxygen diffusion is reduced by the formation of certain type of "As-O" complex [8]. But there is no direct experimental evidence of the existence of such complex. Using first-principles calculations, the authors have shown that the formation of "As-O" complex is energetically unfavorable. The reduced oxygen diffusion is connected with O-As-V complex where V surrounded by one atom of arsenic, one atom of oxygen and several silicon atoms [9]. We can assume that the formation of such complex is the result of transformation As_nV (n = 2, 3, 4) complex (where V - vacancy), responsible for the arsenic deactivation in silicon [10]. In this case, the capture of oxygen atom can change the electrical activation As_nV complexes and influence on the electrical characteristics of USJ.

In the presented work the oxygen distribution was studied close to the USJ for the different energy of arsenic implantation and annealing temperatures.

2. EXPERIMENT

All experiments were performed on 100-oriented silicon p - type wafer with electric resistance 10 ohms × cm. The cut samples from the wafer were implanted through the 2.5 nm screening oxide by As ions with a dose of 4 × 10^{14} cm^{-2} and energies of 5 keV and 10 keV. Furnace annealing was carried out at the temperature range of 750°C - 950°C in nitrogen ambient for 5 minutes. Analysis of the dopant depth profiles was performed by secondary ion mass spectrometry (SIMS) method on the Cameca IMS 4F instrument (France). Cs^+ primary ion beam with energy 1 keV was used for secondary ion generation. The sputter rate was determined by measuring the SIMS crater depth with a surface profiler Dektak 3030.

3. RESULTS AND DISCUSSION

Fig. 1 shows SIMS depth profiles of the arsenic and oxygen distributions before and after annealing in the temperature range 750 - 950°C for 5 minutes. The implantation energy of arsenic was 5 keV. It is seen that arsenic is redistributed in the surface and deep directions. The arsenic concentration at the SiO_2/Si interface and the tail of the profile are increased but reduced in the region of arsenic projected range (Rp). The "tail" is region at a depth of 60 nm. The redistribution of arsenic is increased at the higher annealing temperatures. At the same time there is change the oxygen concentration in the vicinity of the USJ.

Fig. 2a shows the concentration of accumulated oxygen in SiO_2 film, Rp and tail regions of implanted arsenic as a function of the annealing temperature. It is seen that the oxygen concentration are increased in all three regions. However, the increase of annealing temperature of the initial samples leads to the decrease of accumulated oxygen concentration. These dependencies

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are exponential shape in the Rp and tail regions of the arsenic depth profile. At the same time the dependence for SiO_2 film has a minimum value at the annealing temperature 850°C. Obviously, part of the oxygen is removed from the SiO_2 film at this temperature. In the absence of desorption, reduction of oxygen in the SiO_2 film must lead to the oxygen increase in another region of the sample. The structure with a larger distance between the arsenic maximum distribution and the interface SiO_2/Si were investigated to check it.

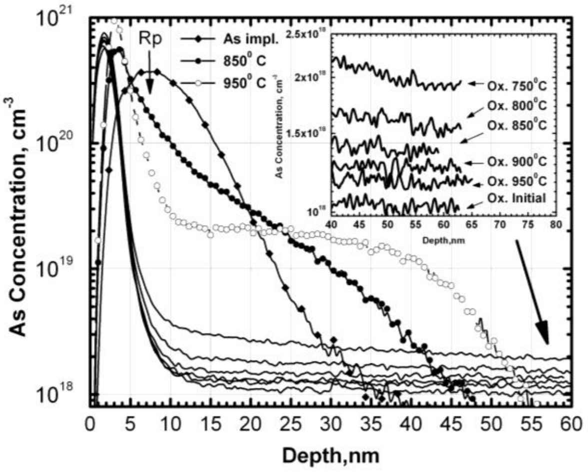

Fig. 1 – SIMS depth profiles comparing the temperature dependence of diffusion and segregation of background oxygen and As for 5 keV implantation through a 2.5 nm oxide.

Fig. 2b shows the concentration of accumulated oxygen in SiO_2 film, Rp and tail regions of 10 keV implanted arsenic as a function of the annealing temperature.

It is seen that annealing in the temperature range 750° - 800°C leads to a decrease of the oxygen content in the studied regions. At temperature 850°C the concentrations of accumulated oxygen in the Rp and tail regions are increased while in the SiO_2 film are decreased. At higher annealing temperature the oxygen concentrations in the Rp and tail regions are reduced but in the SiO_2 film are increased.

Obviously that the amount of accumulated oxygen is defined by distance between the arsenic projected range (Rp) and SiO_2/Si interface. In the first case, the amount of absorbed oxygen by arsenic at temperatures of 750° – 800°C is much larger and therefore no increase of concentration in the Rp region at 850°C.

As seen in figures 2a and 2b the concentrations of accumulated oxygen in the SiO_2 film are increased at the temperature greater 850°C.

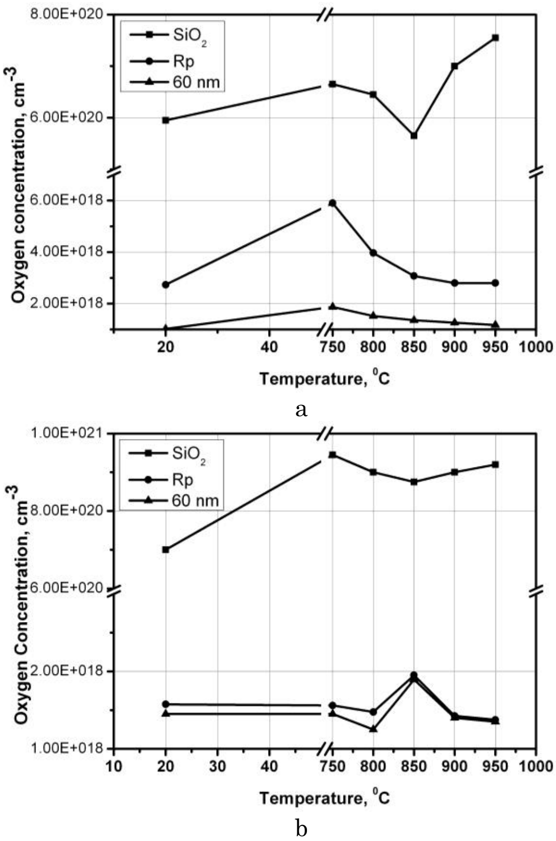

Fig. 2 – Oxygen concentrations at the screening SiO2, arsenic projected range (Rp) and arsenic tail (60 nm) regions of Si for As implantation energy 5 keV (a) and 10 keV (b) in dependence on temperature.

At the same time the decrease of oxygen concentration in the Rp and less noticeable in the tail of arsenic profile are observed. The obtained data indicate on the direct participation of the silicon background oxygen in the formation of nanometer oxide films on the silicon surface during the USJ creation.

4. CONCLUSION

Arsenic implanted region are gettering the background oxygen from the silicon wafer and SiO_2 screening layer up to an annealing temperature 850°C. Concentration of accumulated oxygen depends on the distance to the SiO_2/Si interface. The increase of annealing temperature of the initial samples stimulates the efficient arsenic redistribution towards the SiO_2/Si interface with the oxygen accumulation in SiO_2 layer.

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