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A—4—3 Interfacial Doping by Recoil Implantation for Nonvolatile Memories

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Electrically reprogramable nonvolatile semiconductor memories have gained a vast market in recent years for the demands of computer microprograming. Recently, with interfacial doping, significant improvements in switching speed and memory retention has been achieved over plain MNOS or MAOS structures by Kahng et al.[1] This structure, however, would suffer from the lack of controllability of memory characteristics, since the very small amounts of interfacial dopants are deposited by a vacuum evaporation method. We propose, here, a novel technique to introduce interfacial dopants between two dielectrics utilizing recoil implantation.[2,3]

A thin metal film is deposited on a thermally oxidized silicon wafer. When ions are implanted into the metal film, some amounts of the metal atoms migrate into the quite thin layer of the SiO_2 film (I_I) due to knock-on effect (recoil implantation). A dielectric film (I_{II}) is deposited on the SiO_2 surface after the metal film is chemically removed. Then a gate electrode is followed to construct a dual dielectric MIS structure.

The range of the maximum recoil, relative to the incident Si range, was calculated for various metals, and is shown in Fig.1. This figure shows that a target with the heavier atomic mass has the shallower recoil range, and is superior for an interfacial dopant. Besides of this reason, tungsten was chosen because of its other properties appropiate for the interfacial dopant; little thermal diffusivity, low vapor pressure and thermal stability. Figure 2 shows fractional tungsten atoms transmitted through SiO_2 film into Si substrate measured by backscattering analysis. It was confirmed that more than about 90% of recoil tungsten atoms were restricted within 50 Å of the SiO_2 film. The number of recoil-implanted tungsten atoms is found to increase in proportion to the incident Si dose, and to be easily controlled over a wide range as is shown in Fig.3.

A nonvolatile semiconductor memory was constructed incorporating the recoil implantation with a MNOS structure. Figure 4 shows shifts of the threshold voltage versus the number of recoil-implanted atoms after a positive pulse was applied for each gate electrode. Recoil-implanted tungsten atoms more than 10^{14} cm^{-2} are found effective to make the threshold voltage shift. Charge injection and trapping into the memory sites are substantially enhanced by intentionally employed interfacial doping. The shift of threshold voltage is controlled by the number of recoil tungsten (i.e. dose of Si ions). Figure 5 shows an inverter operation of the memory transistor. Write (17 V, 200 μsec) and erase (-30 V, 300 μsec) pulses were applied to the gate repeatedly. Switching speed and pulse voltage of write-erase operation has been improved over conventional MNOS structures even with thinner SiO_2 films.

Consequently, recoil implantation has been found quite useful to introduce interfacial dopants at a very narrow region between two dielectrics and characteristics of the memory can be controlled accurately utilizing this technique.

REFERENCES

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2) H. Ishiwara and S. Furukawa, Proc. 5th Int. Conf. Ion Impla. Boulder (1976).

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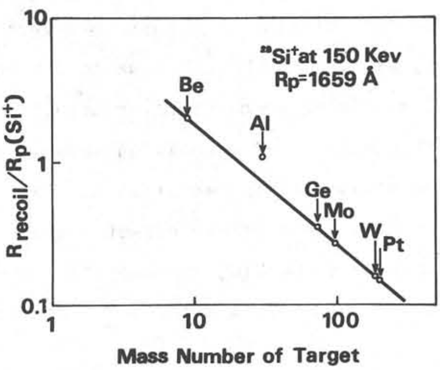

Fig.1 Range of maximum recoil.

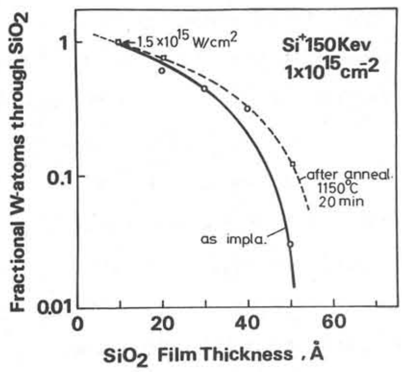

Fig.2 Transmission of W atoms.

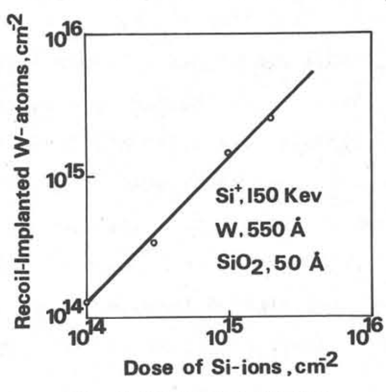

Fig.3 Controllability.

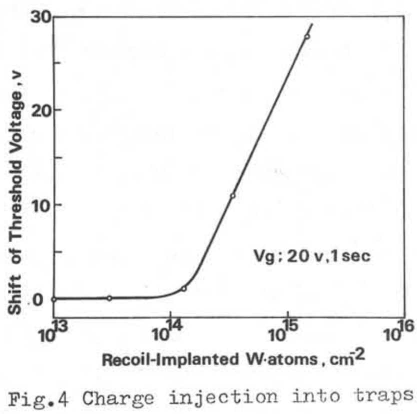

Fig.4 Charge injection into traps

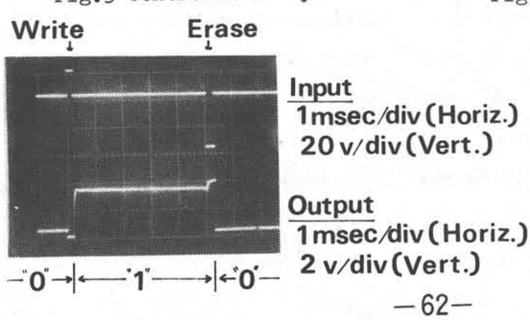

Fig.5 Write and erase operation of the memory FET.