Electrical properties and thermal stability of Al/WN$_x$/Ti submicron contact structure

YONG TAE KIM, HYUNSANG SIM, AND SEONG-IL KIM

Div. System Engineering, Semiconductor Devices Laboratory, Korea Institute of Science and Technology, Seoul 135, Korea
phone: +82-02-958-5733, fax: +82-02-958-5739
e-mail: ytkim@kiste.re.kr

A submicron contact scheme using WN$_x$ diffusion barrier has been suggested for multilevel interconnect structure. The contact resistance of 0.4 x 0.48 μm^2 size Al/WN/Ti/n$^+$-Si is 120-140 Ω and the leakage current density is below than 10^{-16}-10^{-15} A/μm^2. The effect of F atoms on the submicron contact has been investigated with the nuclear resonance analysis method.

1. Introduction

The evolution of very large scale integrated (VLSI) circuits provokes considerable concern over the multilevel interconnect technology since the limitations of device performance becomes to more depend on the characterisitcs of interconnect than the scaled active device. Especially, thin film multilevel interconnects are subject to increasingly high current densities due to the scaled down width. In this work, we have suggested a new contact scheme of Al/WN$_x$/Ti for the 0.4 x 0.48 μm^2 contact size. For the practical application, it is very important to obtain the good thermal stability in this submicron contact and interconnect structures[1]. Typically, since the WN$_x$ diffusion barrier is produced by atomic layer deposition process using WF$_6$ gas, which may influence harmful effects on the electrical properties of Al/WN$_x$/Ti contact structure. Therefore, we have investigated the thermal stability and effects of fluorine atoms in the Al/WN$_x$/Ti submicron contact.

2. Experiments

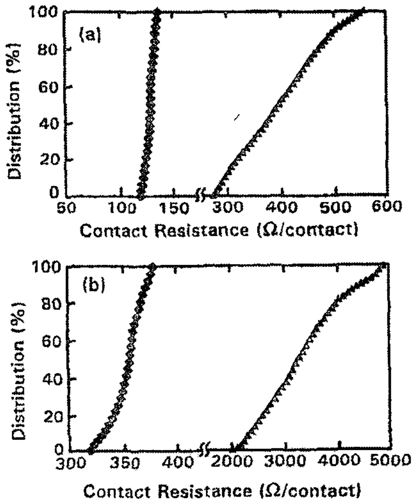
6 inch wafers were cleaned and oxidized. n$^+$ and p$^+$ regions were formed on the contact openings by the implantation of phosphorus and boron ions. Multilevel interconnect metallization on the contact pening was prepared by sputtering 20 nm thickness Ti as a first metal and depoisting 50 nm WN$_x$ diffusion barrier layer with the atomic layer deposition method. The deposition temperature of WN$_x$ was 350 °C and the deposition processes were followed by atomic layer deposition (ALD) procedures[2]. For the some samples, NH$_3$ plasma pre-treatment were carried ourt at the initial stage of the ALD process to prevent the F atoms to be adsorbed on Ti surface. Finally 500 nm Al film was evaporated on the WN$_x$ diffusion barrier layer by the electron beam evaporation method. More than 100 of Kelvin contact structures were patterned for the electrical measurements. The contact size was 0.4 x 0.48 μm^2. Especially, for the comparison of Al/WN$_x$/Ti contact scheme, Al/TiN/Ti contact structures were also fabricated and compared.

3. Results and Discussions

Figure 1 (a) and (b) show the distribution of contact resistances of Al/WN$_x$/Ti/n$^+$ and p$^+$-Si. Fig. 1(a) reveals that the contact resistances of Al/WN$_x$/Ti/n$^+$-Si prepared without the NH$_3$ plasma pre-treatment are widely dispersed from 290 to 550 Ω (the closed triangle line in Fig. 1(a)). In contrast, the closed diamond line in Fig. 1(b) shows that the contact resistances of same structure with the NH$_3$ plasma pre-treatment are nearly constant at 120 Ω. Fig. 1 (b) also shows that the contact resistances of Al/WN$_x$/Ti/p$^+$-Si with the NH$_3$ plasma pre-treatment stay in the relatively narrow range of 320-375 Ω compared with the extremely high values (2000-5000 Ω) of Al/WN$_x$/Ti/p$^+$-Si without the NH$_3$ plasma pre-treatment. Why the contact resistance is so greatly influenced by the plasma treatment. We measured the nuclear resonance reaction spectrum (Fig. 2) for fluorine atoms on the WN_x/Ti interface where the NH_3 plasma pre-treatment was not carried out. The gamma ray at 6.13 MeV, single and double escape peaks at 5.62 and 5.11 MeV indicate that F atoms are remained on the WN_x/Ti interface where the WN_x diffusion barrier was deposited without the NH_3 plasma pre-treatment. From these experimental results, we could concluded that the contact resistances of submiron structure is extremely sensitive to the fluorine atoms because the F atoms produce the titanuim fluoride layer at the WN_x/Ti interface, which results in the high contact resistance. The leakage current characteristics of submicron contact structures shows the thermal stability of contact systems after annealing at 450°C for 48 hr. The leakage current density of Al/WN_x/Ti/n^+ and p^+-Si with the NH_3 plasma pre-treatment shows that the distribution is stable and the current density does not exceed 10^{-15} A/μm^2.

4. Conclusions

Contact resistances and leakage current distribution of Al/WN_x/Ti/n^+ and p^+-Si with the NH_3 plasma pre-treatment seems to be more promising than the same multilevel interconnect structure without with the NH_3 plasma pre-treatment because the NH_3 plasma pre-treatment is very effective for preventing the adsortion of F atoms on the WN_x/Ti interface. And thermal stability and electrical properties of Al/WN_x/Ti/n^+ and p^+-Si with the NH_3 plasma pre-treatment is superior to that of Al/TiN/Ti/ n^+ and p^+-Si.



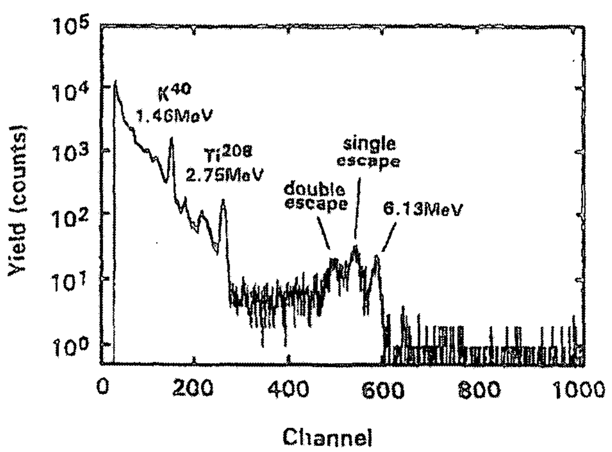


Fig. 1. The distribution of contact resistances of (a) Al/WN_x/Ti/n^+-Si and (b) Al/WN_x/Ti/p^+-Si.

Fig. 2. The nuclear resonance reaction spectrum for the F atoms on the WN_x/Ti interface.

Acknowledgments

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