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Thermal stability enhancement of silicides by using N_2 and Ar implantation

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Abstract

Thermal stability of titanium and cobalt silicides were enhanced by implementing nitrogen or argon implantation prior to silicide formation. Silicide formed on N_2 or Ar implanted blanket wafers, P-type, or N-type poly-silicon had better thermal stability as compared with non-implant ones. Furthermore, Ar implanted approach demonstrated superior thermal stability characteristics even in a RTP test of 1000 °C/180 s. With the aid of N_2 or Ar implantation, the grain growth of the silicide under high temperature was suppressed and thus it prohibited further diffusion and redistribution of the metal.

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Keywords: Cobalt silicide; Thermal stability; Nitrogen implantation; Argon implantation; Grain growth; Resistance

1. Introduction

Silicide is widely used as low-resistance gate electrodes and local interconnection in ULSI technology. In order to reduce parasitic resistance, salicide (self-aligned silicide) on gate and source/drain regions is implemented for reducing sheet resistance. In addition to low resistance, good process compatibility with Si, e.g. ability to withstand high temperature, oxidizing ambient, various chemical cleans used during processing, little electro-migration, easy to be dry etched and good contacts to other materials make silicide process be implemented into many silicon integrated circuits. However, a serious limitation to the

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application of silicide in the actual device is the thermal stability of silicide on long and narrow poly-silicon lines or in narrow contacts on Si substrate [1,2].

Cobalt silicide can be an attractive alternative to titanium silicide for CMOS process of 0.25 μm and beyond, because of its superior characteristics with low resistance, excellent chemical stability (up to 700–900 °C), and little or no resistance degradation on narrow lines/gates [2]. However, it is well known that the degradation of $CoSi_x$ after high temperature annealing is strongly affected by the salicide thickness [3]. Lateral silicide formation, non-planar silicide formation or silicide grain growth during high temperature annealing can result in silicide protrusions into junctions and thus junction leakage. For salicide on poly-silicon gates, grain growth problems can also lead to threshold voltage shifts or gate oxide leakage [4]. Ravesi et al. [5,6] found that Ar ion beam with beam energy of 1 keV made $CoSi_x$ no increase in resistance up to 1000 °C.

The purpose of this paper is to investigate the titanium and cobalt silicide thermal stability by using N_2 and Ar implantation on bare Si substrate, P-type and N-type poly-silicon for low-resistance interconnect application.

2. Experimental

Thermal stability of titanium and cobalt silicide on blanket wafer, P-type, and N-type poly-silicon was investigated. Nitrogen or argon implantation prior to silicide formation was employed for thermal stability. Four-point probe sheet resistance, Rs, measurement was employed for pre- and post-RTP thermal annealing. The thermal stability was identified as the Rs deviation. The process flow is shown in Fig. 1 and described briefly as follows.

Bare wafers, P^+Poly-Si, or N^+Poly-Si → Sacrificial oxide growth → N_2 or Ar implantation → Remove sacrificial oxide → Ti or Co deposition (150–250 Å, 80–140 Å) → TiN deposition (50–250 Å) → RTA1 → Selective etch → RTA2 → Rs measurement → RTP thermal annealing at 950 °C or 1000 °C → Rs measurement.

- Wafer starting (p-type Si, 8-12 Ω-cm)
- SAC oxide growth
- With/without N_2 or Ar implantation
- SAC oxide removed
- Pre Ti / Co-DEP clean
- Ti or Co/TiN deposition → Rs measurement
- 1st RTA (RTA1) → Rs measurement
- Selective etch
- 2nd RTA (RTA2) → Rs measurement/SIMS/TEM
- Post-RTP process → Rs measurement/TEM

Fig. 1. Process flow of $CoSi_x$, $TiSi_x$ formation with N_2 or Ar implantation.

3. Results and discussion

3.1. Thermal stability improvement on $TiSi_x$ formation by nitrogen and argon implantation

N_2 and Ar implanted Si substrate were implemented prior to $TiSi_x$ formation for thermal stability improvement. In Ti salicide formation, two-step annealing is used to get lower resistance and stable phase. It will form C49 phase and block lateral diffusion of Si in first step. In the second step, the higher annealing temperature transforms C49 phase to nucleation-limited C54 phase with low resistance. After silicidation, the N_2 and Ar implantation indeed improve the thermal stability of $TiSi_x$ formation, as shown in Figs. 2(a) and (b). As compared with directly $TiSi_x$ formation, N_2 and Ar implanted $TiSi_x$ shows more stable Rs after enhanced 950 °C RTP test. For the TEM cross-sectional images of N_2 and Ar implanted $TiSi_x$, Ar implanted $TiSi_x$ has smoother surface than N_2 implanted one, as shown in Fig. 3.

3.2. Thermal stability improvement on $CoSi_x$ formation by nitrogen and argon implantation

$CoSi_x$ formation is similar to TiSix process. It needs two-step annealing to achieve low-resistance silicide phase. After the second annealing step, non-implant-based $CoSi_x$ demonstrates the lowest resistance among the $CoSi_x$ with various N_2 and Ar implantation conditions on blanket wafer. However, the thermal stability of non-implant-