Self-limiting Growth Behavior of Epitaxial NiSi₂ and its Impact on Controlled Silicidation of Metal Source/Drain in Silicon Nanowire MOSFETs

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1. Introduction

Metal source/drain (S/D) is indispensable for upcoming aggressively scaled metal-oxide-semiconductor field effect transistors (MOSFETs) [1-4]. It contributes to reduction of parasitic resistance without the need for abrupt junction profile.

When metal S/D is applied to silicon nanowire (SNW) MOSFETs, however, narrow width effect in silicidation [5] will emerge as a major issue as illustrated in Fig. 1. Because of the difficulty of controlling the silicidation reaction in a small-body silicon, silicide phase becomes disordered and excess silicidation invades the channel region.

In this report, we present a unique growth behavior of epitaxial NiSi₂ film and discuss its potential of controlling the silicidation process in small body silicon.

2. Experimental

Nickel films were deposited by sputtering in two typical conditions, one in Ar gas and another in Ar/N₂ mixture gas. The latter condition forms nitrogen (N)-doped Ni film, which was confirmed by physical analyses. Experimental flow is shown in Fig. 2. Si(100) substrates were mostly used, and poly-Si films on SiO₂ layer and SNW were used for some experiments.

Crystalline phases of silicides were determined by in-plane X-ray diffraction (IPXRD). The amount of metal atoms in the films was analyzed by X-ray fluorescence (XRF). Combining the XRF data with IPXRD results, thicknesses of silicide films were evaluated. Grazing incident X-ray reflectivity (GIXR), on the other hand, was used to analyze the thickness, density, and interfacial roughness of epitaxial NiSi₂ films accurately.

3. Results and Discussion

N-doping in Ni films is effective to formation of NiSi₂ crystalline phase by 500°C annealing. Comparative silicidation studies using Ni and N-doped Ni films are shown in Fig. 3. Poly-crystalline and epitaxial NiSi₂ films are obtained by depositing N-doped Ni films followed by annealing at 500°C, although the applied annealing temperature 500°C is the typical condition for NiSi phase formation and annealing temperature higher than 800°C is generally required for NiSi₂ formation. Epitaxial growth of CoSi₂ and NiSi₂ films by low temperature annealing is also attainable by inserting thin oxide layer [6] and depositing Ti/Ni bi-layer structure [7]. According to these results, it is concluded that the key factor in obtaining epitaxial disilicides is the control of metal atom diffusion rate into Si. The effect of the N-doping technique in this study is also considered as forming a SiN barrier layer on Si surface or preventing the fast diffusion of Ni atom by creating a weak Ni-N bonding.

A unique growth behavior is found in the epitaxial growth of NiSi₂ films. Dependence of silicide film thick-
tween grain boundary diffusion and lattice diffusion in Ni$_2$Si crystal, it is reported that they differ as large as 5 orders [8]. Thus the growth rate of epitaxial NiSi$_2$ film is governed by the lattice diffusion and is very slow when compared with that of poly-crystalline NiSi$_2$ film. The self-limiting growth manner observed in epitaxial NiSi$_2$ growth is an evidence that the growth thickness is controlled by the annealing temperature and time, not by the deposited Ni thickness.

The slow growth rate attained in epitaxial NiSi$_2$ has a great impact on fabrication of metal S/D in SNW MOSFETs. It is no more necessary to adjust the Ni deposition thickness precisely because the NiSi$_2$ single phase is naturally formed and its growth front is controllable by annealing temperature and time. Epitaxial NiSi$_2$ growth is also helpful to formation of atomic-scale flat junction [3].

Finally, epitaxial growth technique of NiSi$_2$ is actually applied to a SNW structure, as shown in Fig. 6. By the deposition of sufficient thickness of N-doped Ni film, the SNW structure is fully silicided without residual Si region. Judging from the clear and regular lattice image, the SNW is transformed into epitaxial NiSi$_2$ completely.

4. Conclusion
Self-limiting growth behavior observed in epitaxial NiSi$_2$ manifests that the film growth is driven by lattice diffusion mechanism and not by grain boundary diffusion. Formation of single NiSi$_2$ phase at a practically slow growth rate is a powerful tool for the silicidation of Metal S/D in SNW MOSFETs.

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References