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Microstructural investigation of nickel silicide thin films and the silicide–silicon interface using transmission electron microscopy

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Abstract

This article discusses the results of transmission electron microscopy (TEM)-based investigation of nickel silicide (NiSi) thin films grown on silicon. Nickel silicide is currently used as the CMOS technology standard for local interconnects and in electrical contacts. Films were characterized with a range of TEM-based techniques along with glancing angle X-ray diffraction. The nickel silicide thin films were formed by vacuum annealing thin films of nickel (50 nm) deposited on (1 0 0) silicon. The cross-sectional samples indicated a final silicide thickness of about 110 nm. This investigation studied and reports on three aspects of the thermally formed thin films: the uniformity in composition of the film using jump ratio maps; the nature of the interface using high resolution imaging; and the crystalline orientation of the thin films using selected-area electron diffraction (SAED). The analysis highlighted uniform composition in the thin films, which was also substantiated by spectroscopy techniques; an interface exhibiting the desired abrupt transition from silicide to silicon; and desired and preferential crystalline orientation corresponding to stoichiometric NiSi, supported by glancing angle X-ray diffraction results.

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1. Introduction

Nickel monosilicide (NiSi) thin films are the current CMOS industry standard for ohmic contacts and local interconnects. These films have many advantages over the other silicides which have been used in the past (mainly titanium disilicide $TiSi_2$ and cobalt disilicide $CoSi_2$). These advantages include: (i) less silicon consumption—this is important for shallow junctions, (ii) low temperature of formation, and (iii) low Schottky barrier heights to both n-type and p-type silicon for comparable performance to both nMOS and pMOS devices (Iwai et al., 2002; Chen et al., 1997). In addition, nickel silicide (NiSi) thin films are highly suitable for microsystem applications, as they exhibit low stress and are resistant to most silicon bulk micromachining etchants (such as potassium hydroxide) (Qin et al., 2000; Bhaskaran et al., 2007). These properties are unique to the monosilicide phase (NiSi) of the thin films.

For achieving the desired low levels of contact resistance for CMOS ohmic contacts, so as to conform to the International Technology Roadmap for Semiconductors (ITRS),[1] accurate characterisation of the resistance of each interface of the ohmic contact structure is required. This electrical characterisation has to be preceded by materials characterisation to understand the nature of the interface, so as to understand interface properties influencing electrical results. Materials characterisation of the silicide to silicon interface is important as the presence of an abrupt interface is vital for the characterisation of the resistance of the interface region and for accurate quantitative estimation of the resistance of ohmic contacts.

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[1] International Technology Roadmap for Semiconductors (ITRS), 2006, Update (Available online at: http://www.itrs.net/links/2006Update/FinalToPost/09_Interconnect2006Update.pdf).

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This article discusses the transmission electron microscopy (TEM)-based investigation of nickel silicide thin films: energy filtered imaging to study the thin film cross-sections, jump ratio maps to confirm the composition uniformity of the thin film, high resolution imaging to characterise the interface, and selected-area electron diffraction (SAED) to determine the orientation of the thin films. Glancing angle X-ray diffraction (GA-XRD) analysis was also used to complement the SAED analysis. The results from this combination of techniques have shed light on the grain structure, surface roughness, interface roughness, and orientation of the thin films.

2. Experimental details

2.1. Formation of nickel silicide

Nickel silicide thin films have been formed by annealing nickel thin films on (1 0 0) n-type silicon substrates (resistivity of 1–10 Ω cm). The nickel thin films were deposited by electron beam evaporation with no substrate heating to a thickness of 50 nm; the native oxide on the silicon substrates was removed by a buffered hydrofluoric acid dip prior to deposition of nickel. The nickel-coated silicon samples were placed on a substrate heater and ramped up at 10 °C/min to 350 °C in vacuum (1×10^{-5} Torr). The samples were held at temperature for 30 min before being cooled in vacuum at 10 °C/min. A resulting nickel silicide thin film of approximately 114 ± 4 nm (as verified by selective etching and profilometry) was obtained as a result of vacuum annealing.

2.2. TEM analysis

Cross-sectional TEM (XTEM) specimens were prepared by mechanically polishing using a tripod to create wedge-shaped specimens, with final stages of polishing performed on a 1 μm diamond-lapping sheet. The specimens were then ion milled to electron transparency at room temperature using 4.5 kV argon ions incident at 5° (using double beam modulation). Plan view specimens were prepared by mechanically grinding away the backing silicon from the film, and ion milling (as above, but with continuous milling during sample rotation) to electron transparency. The analysis was carried out at an accelerating

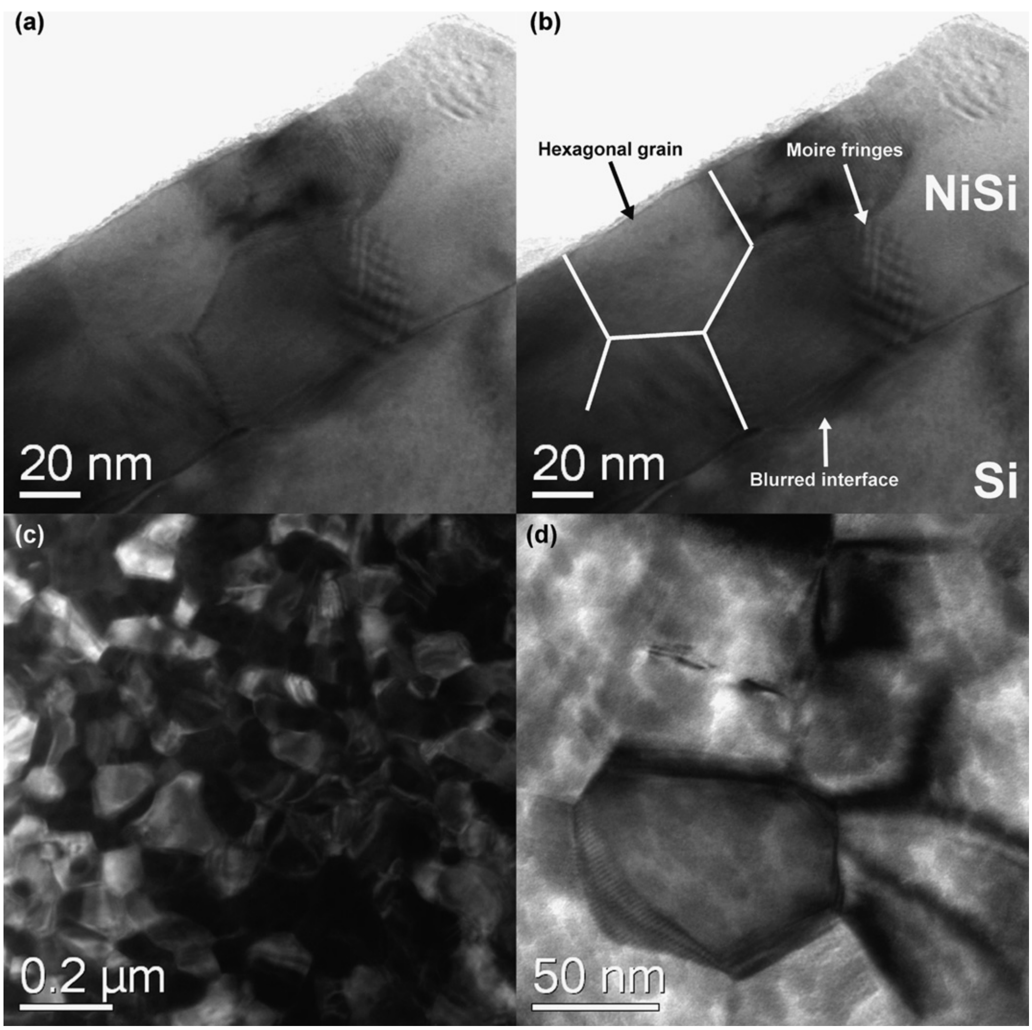

Fig. 1. Results from TEM analysis of NiSi thin films: (a) XTEM highlighting equiaxed grains in the NiSi thin film in which Moiré (interference) fringes due to orientation differences between grains can be observed; (b) notable features in the as-obtained image (a) are indicated; (c) plan view, elastic hollow cone dark field image of the film, highlighting individual grains with diameters of 60–200 nm; and (d) plan view TEM image showing polygonal NiSi grains.