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Formation of Highly Pure Nickel Films by Hot-wire-assisted ALD

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Abstract

We successfully formed highly pure Ni films by atomic layer deposition (ALD) coupled with hot-wire-assistance (HW) system at low substrate temperature of 250°C using nickelocene ($NiCp_2$) and NH_3 as a precursor and reductant, respectively. Thanks to efficient decomposition of NH_3 by HW system, carbon content could be decreased to 1% and nitrogen was under detection limit of XPS.

1. Introduction

Nickel and its silicide are promising materials for contact electrode and metal gates of MOSFETs. In recent years, it was introduced for the metal electrode in metal-insulator-metal (MIM) capacitor such as unipolar resistive random access memory (unipolar ReRAM) due to its high work function (5.15 eV) and compatibility with CMP process. Atomic layer deposition (ALD) is a most strong candidate for future-generation technology due to its excellent step coverage, atomic scale thickness controllability, and film uniformity.

Ni deposition by conventional thermal ALD, however, cannot prevent the residual contamination in the film (C, O, and N), and plasma-ALD induces the damage to underlying materials. Here, we propose a novel method of hot-wire-assisted ALD (HW-ALD) overcoming the issues possessed by above-mentioned conventional ALD processes.

Based on our quantum chemical calculations, we found that NH_2 radical is more reactive than other radicals such as H radical, and hot-wire assisted cracking of NH_3 may be the best way to supply NH_2 radical.

2. Experimental

An in-house ALD system installing tungsten hot wire (1cm above the substrate) was employed, which promotes decomposition reaction of NH_3 into NH_2 radical. The base pressure was about 1×10^{-5} Pa. To avoid oxygen contamination, oxygen-free precursor ($NiCp_2$) was selected, which was supplied to the reactor via bubbler using He carrier gas. Procedure adopted in this study was as follows: (1) supplying the precursor to adsorb on the substrate, (2) purging the remaining precursor by He, (3) supplying NH_3 and simultaneously turning on the tungsten filament (HW became 1350℃), (4) turning off the filament, and purging the remaining reductant and by-products by He. The deposition temperatures were changed from 250℃ to 350℃.

3. Results and Discussion

Growth per cycle (GPC) was increased with increase of NH_3 feeding time, and saturated at long feeding time (Fig.1). Underlying materials did not influence the GPC largely (0.61 Å on SiO_2, 0.69 Å on Si). This may be caused by different incubation time on different underlayers. Meanwhile, carbon content decreased with increase of NH_3 feeding time and became almost constant for different temperature of 250°C and 350°C (Fig.2). The lowest carbon content achieved in this study was about 1% at 250℃, and the Ni film resistivity at this condition was 27 μΩ-cm without a post-anneal. Nitrogen contamination was not detected by XPS despite using NH_3.

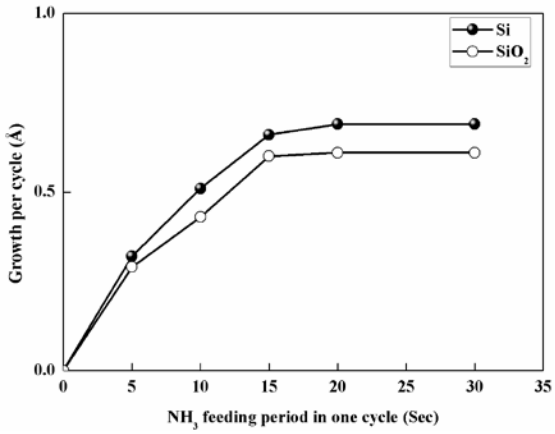

Fig. 1 Growth per cycle on different substrates with different NH_3 feeding periods at 250℃

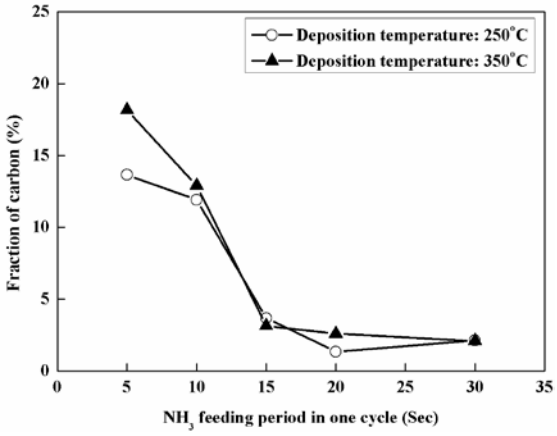

Fig. 2 Carbon content in Ni films at 250℃ and 350℃ with different NH_3 feeding periods