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Investigation of aluminum film properties and microstructure for replacement metal gate application

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ABSTRACT

The fundamental film properties and micro-structures of the different aluminum (Al) metal layers are evaluated to fabricate a replacement metal gate (RMG) device for the high-k metal gate (HKMG) application at 28 nm node. A PVD Al fill-in metal deposition process, called one step hot Al (HAL), was found the resistivity increases with increasing the thickness of the Ti wetting layer. The higher pinhole density with the preferred (1 1 1) crystal orientation in the HAL layers indicate the film properties with lower reflectivity, higher resistivity and lower removal rate of the Al chemical mechanical polishing (AlCMP). In contrast, the other PVD Al deposition approach, called two steps cold hot Al (CHAL), was identified to possess lower resistivity and higher reflectivity without pinhole structures than the HAL. The smaller grain sizes with the preferred (2 2 0) orientation in the CHAL could effectively prevent the formation of pinhole and enhance the removal rate of the AlCMP. The non-uniform with crystallized $TiAl_3$ phase detected in the bottom of the as-deposited HAL and CHAL films could obviously impact the removal rate of the AlCMP. An optimized CHAL fill-in metal deposition process with a larger than 40 Å Ti wetting layer are needed to simultaneously meet the process requirements of the Al gapfill and AlCMP planarization for achieving a reliable RMG structures.

1. Introduction

High-k metal gate (HKMG) integration using a replacement metal gate (RMG) approach was led by Intel, who had the first 45 nm HKMG processor in volume production in 2007 [1]. The RMG is mainly constructed by the work function (WF) metals of the N/P metal–oxide-semiconductor field- effect transistor (MOSFET), the barrier metal and the top fill-in metal layers [1–5]. In fact, the aluminum (Al) and tungsten (W) metal films have ever been the candidates to be the top fill-in metal layer for forming the structures of RMG [6–10]. Nevertheless, the Al has recently become the mainstream due to the lower resistance property than W for fabricating the HKMG devices and products [1,3]. In order to improve the capability of the top Al metal gapfill and planarization, a Ti wetting layer is required [4,11]. Moreover, the Al chemical mechanical polishing (AlCMP) implementing after WF and low resistance Al top fill-in metal depositions has shown to be a key integral process of the RMG approach for final defining the uniformity and defectivity performances of the metal gate structures [8–10]. In this paper, the fundamental Al metal film properties and microstructures with different thicknesses of the Ti wetting layers and Al deposition approaches have been investigated. The impacts of the Al film properties and microstructures on the AlCMP and RMG gapfill process window are also addressed to meet the requirement of 28 nm HKMG technology node.

2. Experimental

300 mm blanket and pattern wafers were major constructed with physical vapor deposition (PVD) Al film/chemical vapor deposition (CVD) Al seed layer/PVD Ti wetting layer/N/P MOSFET WF metals/TaN etch stop layer/CVD oxide film/Si-substrate were prepared to obtain the Al film properties, microstructure and the removal rates of the AlCMP process. Two PVD Al deposition processes, called one step hot Al (HAL) and two steps cold–hot Al (CHAL), were used to deposit on different thickness of Ti wetting layers with 40, 80 and 120 Å thickness. The one step HAL films were continuously processed at one unique high temperature condition. In contrast, the two steps CHAL films were firstly deposited at a lower temperature step and then processed at this unique high temperature condition. The AlCMP process was carried out on a rotary type polisher with three polishing platens. A real time process control (RTPC) endpoint detection was utilized to control the bulk Al film removal and planarization on the platen one. The remaining Al and WF metal layers were removed and stop on oxide layer on the platen two. A low down force polishing process on a soft pad were developed for wafer chemical buffing on the platen three

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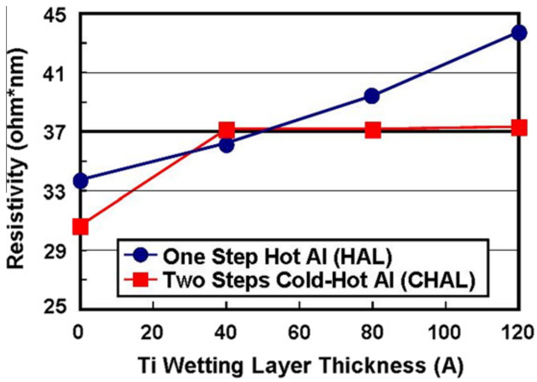

Fig. 1. Effects of Ti wetting layer thickness for different Al film deposition approaches on resistivity.

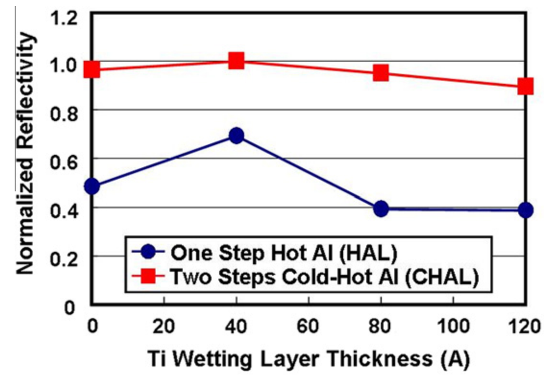

Fig. 2. Effects of Ti wetting layer thickness for different Al film deposition approaches on reflectivity.

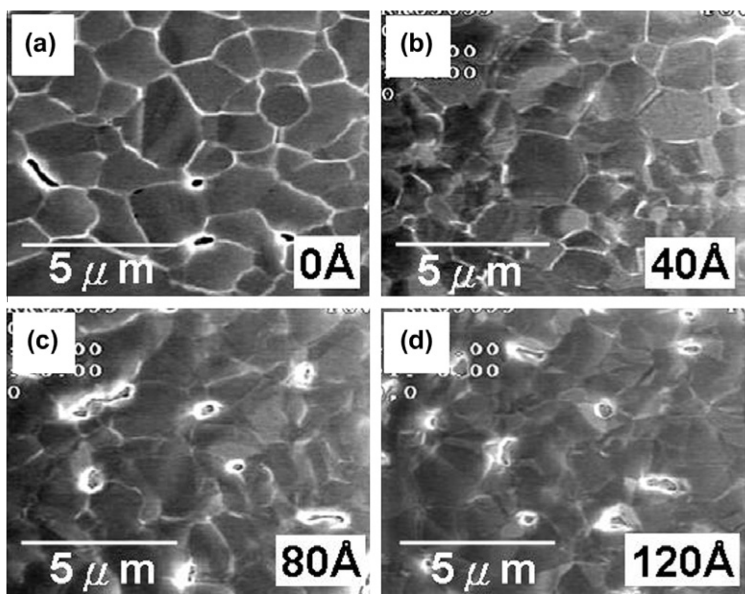

Fig. 3. Top-viewed SEM images show the effects of Ti wetting layer thickness for as-deposited HAL on pinholes and grain structures.

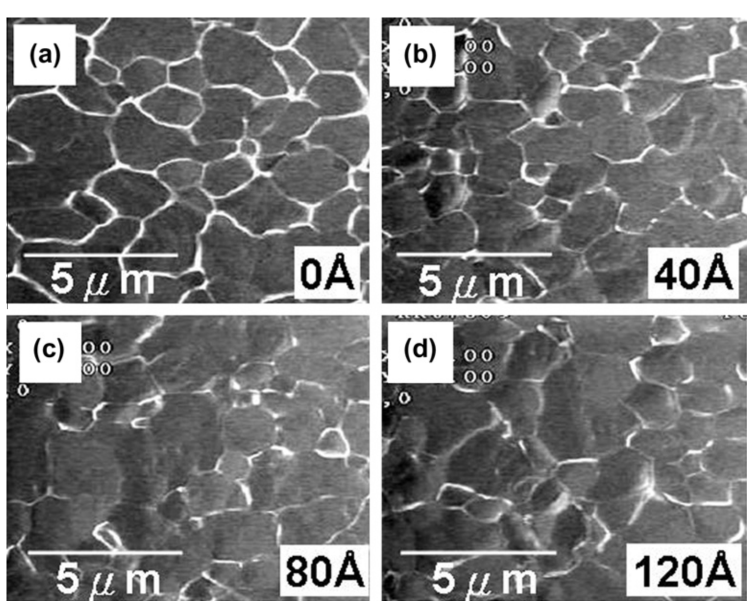

Fig. 4. Top-viewed SEM images show the effects of Ti wetting layer thickness for as-deposited CHAL on pinholes and grain structures.