A Comparison of Tungsten Films Grown by CVD and Hot-wire Assisted ALD

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ABSTRACT

Plasma-enhanced atomic layer deposition has been proposed as a suitable technique to grow metals [1]. In this work, we develop hot-wire assisted ALD (HWALD) where plasma is replaced by a tungsten filament heated up to 1700-2000 ^{o}C. Molecular H_2 can efficiently dissociate on a heated filament, generating *atomic* hydrogen (at-H) [2]. In the current approach we utilize HWALD of tungsten (W) by alternating pulses of WF_6 and at-H. A 100-nm SiO_2 thermally grown on Si wafer was used as a substrate to enable electrical characterization of W films. Due to slow nucleation of W on SiO_2, a 2-5 nm thin seed layer of W was pre-formed prior to ALD by (i) depositing a 5 nm amorphous Si (a-Si) layer using Si_2H_6 and (ii) introducing WF_6 to convert the a-Si into a W layer. The growth behaviour was monitored in real time by an in-situ spectroscopic ellipsometer (SE). The detailed ALD process is discussed in our publication [3].

In this work, we compare HWALD and chemical vapour deposition (CVD) samples in terms of growth kinetics and properties. For CVD, the samples were made in a mixture of WF_6 and molecular (H_2) or *atomic* hydrogen. and by HWALD with pulses of WF_6 and a. Resistivity of the WF_6-H_2 CVD layers was 20 μΩ·cm, whereas for the WF_6-at-H CVD layers it was 28 μΩ·cm. Interestingly, the resistivity increased to 100 μΩ·cm for the HWALD films. To note, the WF_6-H_2 CVD was performed at a substrate temperature of 325 ^{o}C, whereas WF_6-at-H CVD and HWALD at 315 ^{o}C. From SE, both refractive index and extinction coefficient of the HWALD W were much different with respect to the CVD W. X-ray diffraction (XRD) reveals that the HWALD W was crystallized as β-W, whereas both CVD W films were in α-W phase, see Fig. 1 (a). In Fig. 1 (b) a transmission electron microscopy (TEM) image of the HWALD W is shown. There is no interface visible between the W seed layer and the HWALD W. Fast fourier transform of the TEM image also indicated d-spacing of β-W. Importantly, β-W is commonly formed by a reduction of tungsten oxide and exhibits a higher resistivity and a lower density compared to α-W [4]. In our case the results of X-ray photoelectron spectroscopy of HWALD W revealed 98 at.% of W and the concentration of oxygen lower than 2 at.%. Obtaining near-pure β-W probably means intermediate oxidation of HWALD W followed by a reduction by *atomic* H. In our presentation, we will further compare nucleation, growth kinetics and properties of W films grown in CVD and ALD modes.

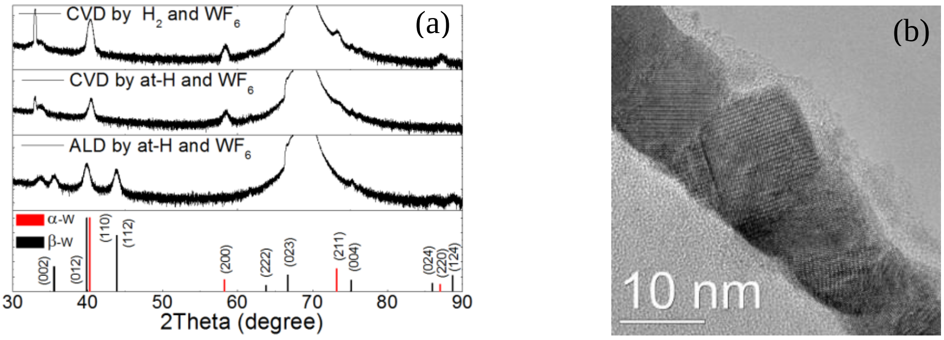

Fig. 1 (a) XRD results of films grown by ALD/CVD. (b) TEM image of cross-section of an ALD W layer.

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