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THE INFLUENCE OF BARRIER LAYER ON TEXTURE AND MORPHOLOGY OF CU FILM ON SILICON WAFER SUBSTRATES.

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ABSTRACT
This paper describes the influence of the barrier material on texture, surface roughness and surface morphology of the Cu films, electroplated on silicon wafer substrates using a copper sulfate solution at a current density of 60 mA/cm^2. The silicon substrate had a diffusion barrier layer of IMP Ta, IMP TaN, CVD TiN or PVD TiN and a Cu seed layer over the underlying barriers. The Cu seed layer on TiN had strong <111> orientation but for those on Ta and TaN this orientation was in <220> direction. The preferred orientation of the electroplated Cu film on silicon wafer is found to be in <111> direction followed by growth in <200> and <220> directions. The degree of growth in <111> orientation is higher on both CVD TiN and PVD TiN barrier layers compared to those on IMP Ta and IMP TiN. The texture of the plated film is independent of the underlying substrate texture. The surface roughness and morphology are seen to be dependent strongly on the texture of the electroplated Cu film; the surface is smoother in a stronger textured film.

Keywords: Copper electroplating, silicon wafer, barrier layer, texture, surface morphology

1. INTRODUCTION
Copper has attracted considerable attention as a potential ULSI metallization material because of its low bulk electrical resistivity and superior resistance to electromigration in comparison to aluminium and its alloys. Cu deposition can be achieved by many techniques, such as PVD, CVD, sputtering, electroplating and electro-less plating. Because of low capital cost, high quality film, low processing temperature and good via/trench filling capability electroplating process has gained popularity over other deposition techniques. Successful electrodeposition of copper, producing a film resistivity of <2.0μΩ cm, has been demonstrated and shown to have good via-filling capabilities [1-5]. However, Cu reacts rapidly with silicon to form silicide at a temperature as low as 200C and drifts through the oxide under field acceleration. Any trace of Cu in silicon will create traps that are deleterious to device operation [6], therefore a barrier layer between Cu and its underlying layers is a prerequisite for Cu to be used in silicon IC applications.

Texture is the preferred distribution of grains (individual crystalline) having a particular crystallographic orientation with respect to a fixed reference frame. It is an important structural parameter for bulk materials and coatings. Texture and surface morphology of metal deposits are strongly affected by crystal properties of the depositing metal as well as by mass and charge transfer across the interface boundary. The growth process of a crystal depends on the crystallographic character of the growing surface and is mainly affected by the surface structure itself. Electrodeposition on a randomly oriented polycrystalline substrate can result in the development of preferred orientation or texture in deposits.

In this paper the texture and morphology of the electroplated Cu films, together with the performance of TiN, Ta and TaN diffusion barriers deposited by CVD, PVD and IMP processes, are investigated.

2. EXPERIMENTAL
Copper electroplating was performed in a H_2SO_4 electrolyte prepared using copper sulphate crystals ($CuSO_4 \cdot 5H_2O$) 200 g/l; sulphuric acid (H_2SO_4) 50 ml/l; deionised water and no additive was added. The electroplating was carried out at a 60 mA/cm^2 current density for 20 minutes.

Blanket wafer samples with different diffusion barrier layers were used in this study. The barrier layers were IMP Ta, IMP TaN, CVD TiN, and PVD TiN. On top of the barrier layer, a layer of IMP Cu was deposited to act as a conducting seed layer for electroplating.

The surface roughness of the plated film was measured using Tencor/Alpha Step 500 surface profilometry. Shimadzu^{TM} XRD 6000 diffractometer was used to get XRD patterns of the electroplated Cu films. Textures of the films were determined from the peak intensities of the XRD patterns. Field Emission Scanning Electron Microscope (FESEM) was used to examine the surface morphology.

3. RESULTS AND DISCUSSIONS

3.1 Texture of the Cu Film

XRD patterns of the Cu seed layer and plated Cu film presented in Figure 1 show that the Cu seed layer has strong <111> texture followed by <200> and <220> when deposited on CVD and PVD TiN. While depositing seed layer on underlying IMP TaN and IMP Ta barriers, the Cu seed became strongly oriented in <220> direction followed by <111> and <200>. Upon plating, the Cu films rapidly increased the <111> orientation compared to <200> and <220> orientations.

Electroplated Cu films on IMP Ta and IMP TaN also showed a higher degree of <111> orientation regardless of the high <220> texture of the underlying seed layer. Seah et al. [7] also reported strong <111> oriented Cu films on W seeded substrates while both <111> and <220> were preferred orientations on Cu seed surfaces. Present observation suggests that the texture of the electroplated Cu film is independent of the underlying copper seed orientation.

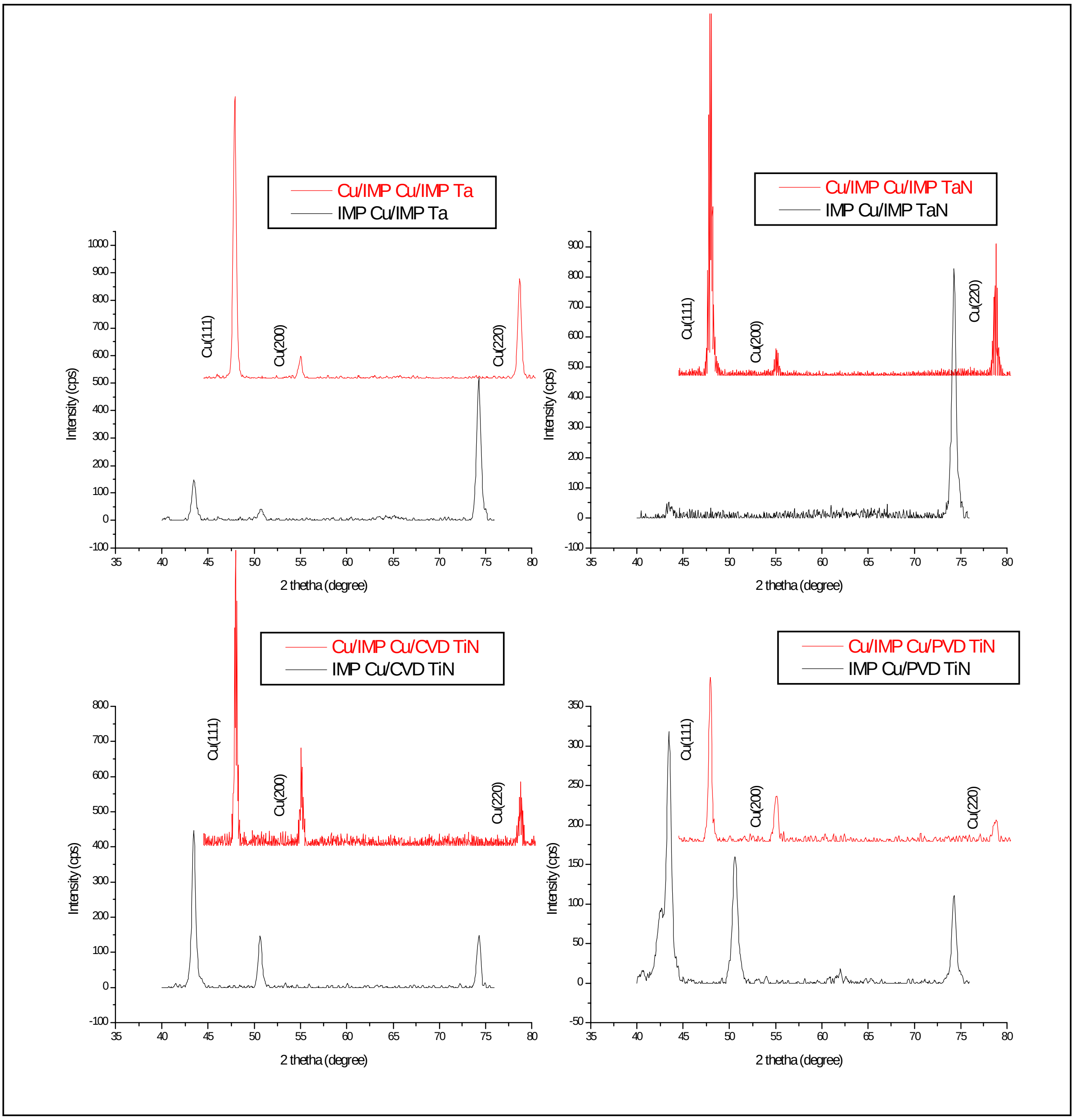


Figure 1: XRD spectra of plated copper film and copper seed on silicon wafer containing different barrier layers

The competitive growth model of the development of texture during deposition is based on the idea that different crystal faces have different rates of growth. Thus, there is a growth rate competition between crystalline of various orientations. Crystallites of various orientations could be generated either during preferential nucleation process or during the competitive growth mechanism subsequent to the stage of coalescence.

For a metal deposition, it is commonly observed that only the first monolayer acquires the lattice parameters of the substrate that is if pseudomorphic growth occurs at all. Upon electroplating, copper film grows epitaxially by developing the same texture of its underlying copper seed [8, 9].

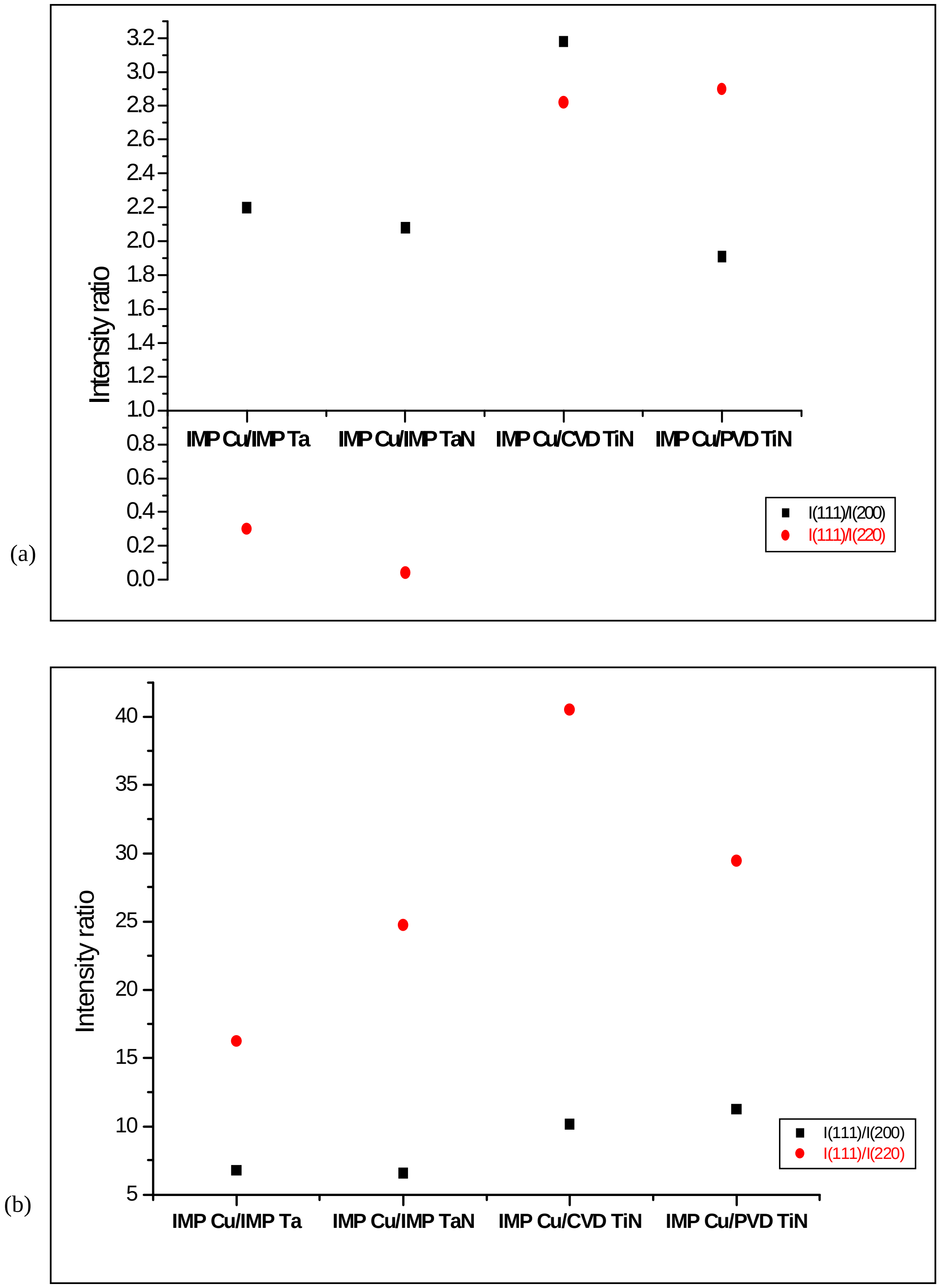


Figure 2: The intensity ratios of $I_{(111)}/I_{(200)}$ and $I_{(111)}/I_{(220)}$ for (a) copper seed, and (b) electroplated copper film

Because of the increasing strain from the formation of pseudomorphic multilayer, the deposit then continues to grow in its own habit beyond the first monolayer [10]. For a thick deposit, texture is completely independent of the substrate orientation [11]. The own habit direction of copper is <111>. The copper films plated in this study were all greater than a few μm and they are considered as thick films. Thus, the copper films were all <111> textured.

The growths of the Cu film in <111>, <200> and <220> directions were on different substrates arbitrarily assessed from the XRD spectrum intensities. The intensity ratios, $I_{(111)}/I_{(200)}$ and $I_{(111)}/I_{(220)}$, of the IMP Cu seed layer and of those of the electroplated Cu film are shown in Figures 2a and 2b respectively. Results in Figure 2a show that the intensity ratio of $I_{(111)}/I_{(200)}$ is highest for the seed layer on CVD TiN and then on PVD TiN. But for Ta and TaN barrier layers the intensity ratio of $I_{(111)}/I_{(220)}$ is less than unity indicating that the seed is oriented more in <220> direction than in <111> direction.

The electroplated Cu films on CVD TiN and PVD TiN exhibited higher $I_{(111)}/I_{(200)}$ and $I_{(111)}/I_{(220)}$ ratios than those on IMP Ta and IMP TaN. The growths of <111> texture on CVD TiN and PVD TiN are seen to be faster than those on IMP Ta and IMP TaN (Figure 2b). It is presumed that because of the high degree of <220> orientation of the copper seed on IMP Ta and IMP TaN in Figure 2a, the $I_{(111)}/I_{(220)}$ intensity ratio of the copper film overlay on those substrates are lower.

3.2 Surface Roughness

The surface roughness was measured by surface profiler and the results for both seed layers and electroplated copper films are presented in Figure 3. The RMS values of Cu seed on different barrier layers are found to be in the range of 27 ~ 29 Å. For electroplated Cu films the RMS values vary from 250 to 450 Å. The electroplated copper film on CVD TiN and PVD TiN produced smoother surface compared to those on IMP Ta and IMP TaN. The RMS values of electrodeposited copper film on IMP Ta and IMP TaN are about 1.6 times of those on CVD TiN and PVD TiN.

Present observations suggest that the texture of thick copper film is independent of the substrate texture. Similarly the surface roughness is independent of the roughness of seed layer.

The correlation between the surface roughness and texture of copper film electroplated at 60 mA/cm^2 for 20 minutes is given in Figure 4. Results in this figure show that a stronger textured film produces smoother surfaces. Thus the stronger <111> texture caused the copper film to produce a smoother surface. It has been reported by S. Simon Wong et al [12] that the surface roughness of deposits is strongly related to

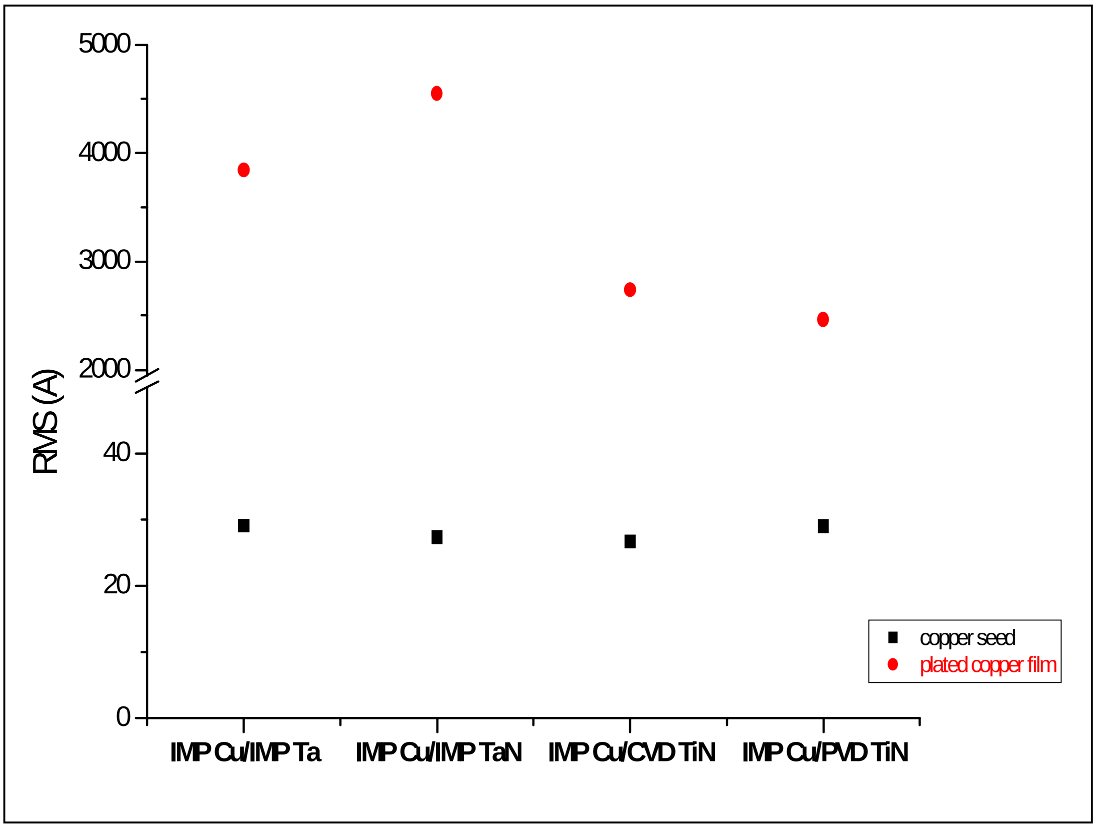


Figure 3: Surface roughness of copper seed and film on different substrate

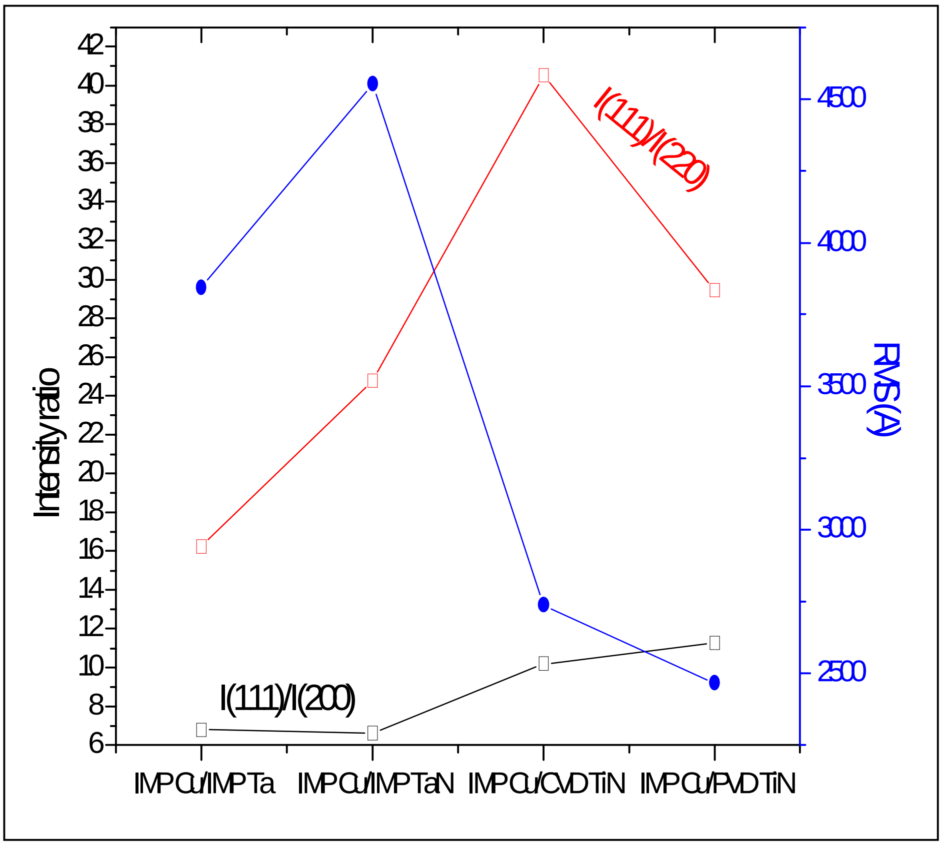
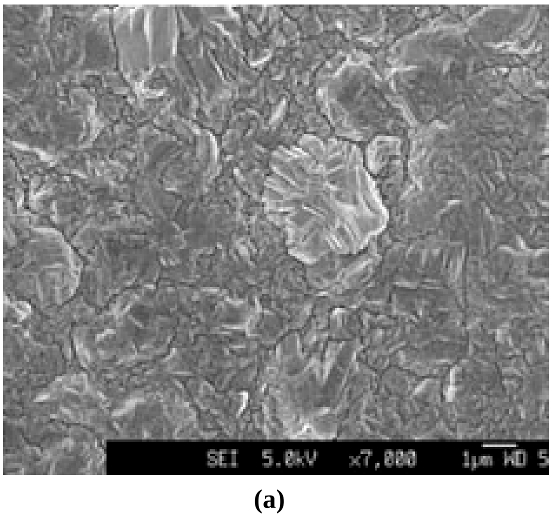


Figure 4: Correlation of surface roughness and texture of electroplated copper film.

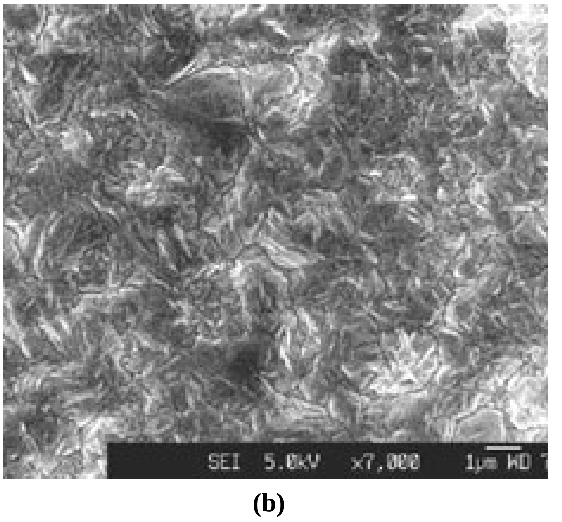
texture. A strong <111> texture in the deposits can only be obtained in smooth films. Randomly oriented grains tend to produce a rough surface as a result of nonuniform growth rate and growth direction. The wide range of grain sizes and sharp contour of the film on IMP Ta and IMP TaN are the result of nonuniform growth rate and growth directions. These effects caused the significant increase in the RMS values.

3.3 Surface Morphology

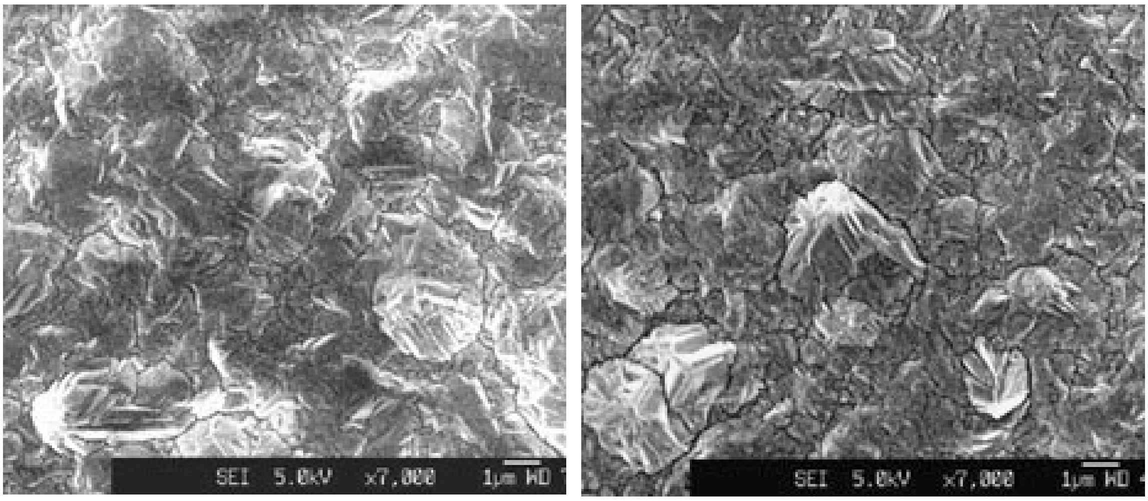
The surface morphologies of copper film deposited on different substrates are given in Figure 5. More uniform grains of copper film on CVD TiN and PVD TiN are seen in Figures 5a and 5b which resulted a smoother surface. Large grains are found in those films plated on IMP Ta and IMP TaN (Figures 5c and 5d). It can also be seen that copper film on IMP Ta and IMP TaN has a sharp contour, thus caused a higher RMS value.



(a)



(b)



(c) **(d)**

Figure 5: FESEM micrographs showing surface morphology of electrodeposited film on different substrates, (a) IMP Cu/CVD TiN, (b) IMP Cu/PVD TiN, (c) IMP Cu/IMP Ta, and (d) IMP Cu/IMP TaN,

4. CONCLUSIONS

- The copper seed deposit on TiN barrier layer has strong <111> orientation while on Ta and TaN barrier layers it is <220> direction.
- Cu films electroplated on different barrier layers have <111> preferred orientation. The texture of the underlying seed layer has little influence on the texture of thicker Cu films. However the growth rate of the film in <111> direction is greater on TiN barrier layer compared to those on Ta and TaN layers.
- The surface roughness of the electroplated Cu film is strongly related to the texture of the film. Stronger textured films produce smoother surfaces.
- Cu films on Ta and TaN barrier layers produced large grained structure compared to those films on TiN layer.

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