Characterization of Electrodeposited Copper Films by Scatterometry

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The use of total integrating scatterometry for the characterization of silicon surfaces after cleaning, macro-slip detection, and epitaxial film deposition has become popular. In this paper, the application of laser scatterometry to electroplated copper films for the purposes gaining additional insight into the factors controlling the electrodeposition as well as process control is explored. In such measurements the specularly scattered light as well as the diffusely scattered light is collected by an integrating sphere. The ratio of the diffuse scattering to the specular scattering is used to compute the surface roughness. Surface roughness has received only scant attention in previous publications on copper plating, even though deposit morphology is critically important. The majority of these previous surface roughness measurements were performed by scanning probe techniques such as AFM (1) and confocal scanning beam laser microscopy (2,3). The more popular AFM technique is both time consuming and in general restricted to a very small percentage of the plated area of the wafer. The roughness measured by integrated scattering is shown in this paper to be correlated to AFM measurements. The previous studies have reported large variations in surface roughness of electrodeposited films from different tools and processes. It is noteworthy that West (4) predicted from his simulations of copper electrodeposition that the randomness of a filling process could be predicted from the surface roughness of a blanket film. For a process to be robust for bottom-up filling, according to West, the difference in deposition rate between the top to the bottom of the feature must be sufficient to overcome the randomness in deposition rate. Thus, the surface roughness of a plated copper film may prove to be predictive of the filling capabilities of that process.

In this paper measurements are presented for both 200 and 300 mm blanket copper films with different plating chemistries and with different additive concentrations. Measurements on patterned wafers are also included for comparison. It was shown that the PVD copper seeded wafer is extremely smooth, but a large amount of surface roughness and changes in surface morphology over a large scale are introduced by the plating process. The surface roughness is highly dependent on the nature of the plating chemistry. In an experimental design for a plating chemistry, which does not employ a leveler, it is shown that the derived average surface roughness (RMS) is dependent upon the concentrations of the brightener and the chloride concentration, and shows little dependence upon the suppressor concentration as illustrated in Table 1. In addition, the effects upon the surface roughness of different current waveforms are presented. Specifically, pulse plating is compared to processes consisting of multiple DC current steps with hot entry. The advantages of using multiple DC current steps to achieve initially conformal plating at low currents followed by plating a higher currents to achieve filling of features has been previously discussed by Reed et al. (5).

The results presented in this paper reveal that scatterometry measurements are extremely sensitive to all the plating parameters tested.. In addition to those already mentioned, the surface roughness of electrodeposited copper films is dependent upon the method of wafer introduction into the bath, rotation rate, electrolyte flow rate, and even nature of the electrical contact during the plating process .

It is concluded that scatterometry is potentially useful for process development as well as process monitoring of copper electrodeposition processes.

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Table 1. Experimental design and response measured

Suppressor Conc. (ml/liter)	Accelerator Conc. (ml/liter)	Chloride Conc. (ppm)	Ave. RMS Roughness (Å)
25	1	25	129
10	1	50	157.5
25	3	25	157.4
25	3	75	135.5
10	3	25	158.9
25	1	50	154.6
10	3	75	144.2
10	3	50	140.0
25	3	50	142.8
10	1	25	125.7
10	1	75	192.5
25	1	75	178.5