Characterization and Mechanism of Device Failure due to Hollow Via Formation

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Advanced semiconductor manufacturing involves numerous process steps such as metal and oxide etches, deposition, photo-resist ashing and cleaning. Any one of these process steps may result in device failure and thus yield loss if not controlled properly. Recently an unexplainable yield loss was reported at die sorting on a few products. The Failure Analysis results attributed this device failure to the formation of "hollow vias" during the manufacturing process. Further analysis of the failing site using the SEM technique showed a material that protruded from the sidewalls of the metal lines into the via interconnect. This observation suggested an incomplete post-metal-etch cleaning. The residual polymer appears to fall on the top of the metal line and eventually prevents the deposition of the tungsten via. To understand the formation mechanism, fab experiments were conducted to recreate the hollow vias by exacerbating the problem through reduced post-metal-etch cleaning. These experiments successfully recreated the problem suggesting that incomplete post-metal-etch cleaning is a mechanism for hollow via formation.

Hollow vias were detected on the IMS tester. Idd on a good part tested higher than the Idd on the failing parts. The failing parts had latent outputs that would consistently fail the faster they were clocked. This result indicates that the failure was due to a resistive node affiliated with the failing input. The failing parts were decapsulated, depassivated, and mechanically probed. The location of the lost input signal was identified and cross-sectioned using the FIB (see Figure 1). Review of the location of these defects indicated that the hollow vias are formed at the end of isolated lines (bottom metal layer) and could be located visually by what appeared to be a hole in the upper metal layer. TEM analysis of the defective die indicated that an organic material covers the sidewall and top of the metal line into the void at the bottom corner of the hollow via (see Figure 2). These observations suggest that the residual polymer from post-metal-etch can interfere with the filling of the vias during liner/barrier deposition and tungsten fill.

Metal etch polymer is formed to achieve anisotropic etching of the metal lines (see Figure 3). Post metal etch cleans are designed to remove this polymer, however if ineffective the polymer can remain and interfere with the formation of the via interconnects. To confirm residual post-metal-etch-polymer can cause hollow via failures a series of split lot experiments between shortened, standard, and extended post-metal-etch-wet cleaning and hydroxylamine (EKC-265) cleaning were performed. Extended and hydroxylamine cleaning produced undetectable levels of hollow vias. With reduced cleaning times polymer remained and produced hollow vias. The defect densities were so high that a random sampling of just a few sites (vias over isolated metal lines) resulted in the detection of a hollow via.

This paper will present the results of the investigation and proposed mechanisms of device failures due to hollow via formation.

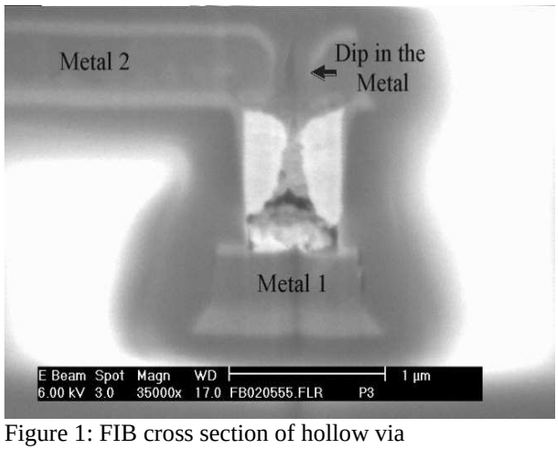

Figure 1: FIB cross section of hollow via

Figure 2: TEM analysis of hollow via. EDX (not shown) shows signs of carbon at locations 3 and 10, top and sidewall of metal line, respectively

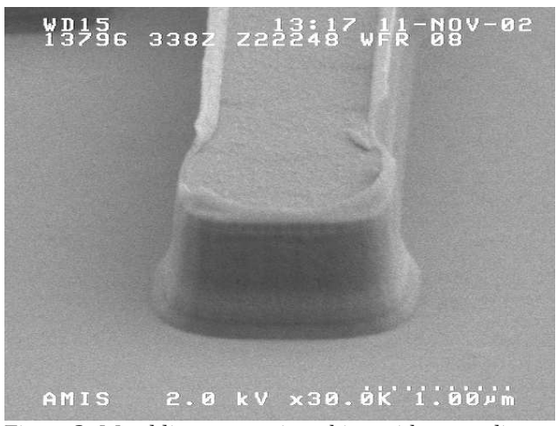

Figure 3: Metal line post resist ashing with protruding sidewall polymers