X-ray microscopy studies of electromigration in integrated circuits

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State-of-the-art high-performance microprocessors contain more than 100 million transistors which are connected using metal on-chip wires (interconnects). Further increased clock rates while continuing to down-scale transistor feature sizes requires a highly sophisticated interconnect design in combination with new technologies and materials, in particular to minimize the so called RC (Resistance x Capacitance) delay time. This task includes development and implementation of interconnect materials with lower resistivity and of isolating interlayer material with low permittivity. The aluminum-based interconnects have been replaced by inlaid copper providing reduced electrical resistivity and improved electromigration behaviour [1]. Currently, technology development is focussing on insulator materials with lower dielectric constant than silicon dioxide. Electromigration, stress-induced degradation and mechanical weakness in case of low-k materials are reliability concerns for inlaid copper interconnects. Formation of voids in copper lines induced by electromigration during microprocessor operation will cause an interconnect open or high resistance resulting in malfunction or speed degradation [1]. Stress-induced degradation phenomena are not well understood so far. Particularly, fast diffusion paths have to be identified, and failure mechanisms based on the directed transport of atoms have to be understood.

Optical microscopy does not provide the necessary spatial resolution. Transmission electron microscopy can only image thin layers with significantly less than 1 micron thickness. Scanning electron microscopy is more surface sensitive, and requires a very precise sample preparation [2]. Additionally, the structures of the Cu/low-k structures shrink extremely during observation in a state-of-the-art scanning electron microscope which is usually operated in the several-kV voltage range for achieving the required spatial resolution. X-rays have the advantage that they penetrate samples which are several micrometers thick without significant sample damage, and that they provide a chemical image contrast between different dielectric layers of the Cu/low-k on-chip interconnect stack.

In this report, results of x-ray microscopy studies on state-of-the-art microprocessors are presented to demonstrate that x-ray microscopy has the potential for a new powerful analytical technique in semiconductor industry.

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