Electromigration Mitigation in Metal Interconnects via Hexagonal Boron Nitride

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Electromigration in metal interconnects remains is a significant obstacle hindering the miniaturization of integrated circuits towards single-nanometer nodes. The Electromigration phenomenon creates atomic-scale dislocations that result in diffusion and void/hillock formation[1] leading to reduced transistor performance, shortened device lifetime, and eventual device failure.[2] Although conductive copper (Cu) interconnects are conventionally used, they require barrier layer materials due to their vulnerability to electromigration.[3] The conventional barrier layer and conducting metal damascene architectures cause compromise between device performance and feature dimensions. An alternative to current barrier materials (e.g., Co, Ta, and Ru) is needed, with ultrathin and passivation properties to mitigate electromigration effectively.[4] At the ultimate atomically thin limit, 2D materials are promising candidates given their exceptional mechanical properties and impermeability.

Demonstrated in this work, a facile and effective approach is presented to mitigating electromigration in Cu interconnects via passivation with insulating monolayer, single-crystal 2D hexagonal boron nitride (hBN). The hBN barrier layer material was prepared via mechanical exfoliation as it has demonstrated higher quality than other approaches (chemical vapor deposition or chemical/liquid-assisted exfoliation). The Cu interconnects were prepared using a standard photolithography lift-off process. Devices were fabricated via a contact transfer technique, consisting of picking up exfoliated hBN and stamping it onto the Cu interconnects. In order to characterize the electrical performance of the hBN-passivated Cu interconnects, breakdown current density and time-to-failure (TTF) were measured. The performance values were compared to values acquired from bare Cu interconnect devices. Additionally, the mechanical integrity of the hBN films were evaluated via observations of their conformal contact with Cu interconnects before and after electrical performance testing.

The electrical properties of the hBN-passivated Cu interconnect devices were studied in a DC circuit with the aid of a sourcemeter. A constant break in current was supplied prior to testing to improve the homogeneity of each individual interconnect.[37] Breakdown testing was performed by applying an increasing voltage over time until electrical breakdown. TTF testing was accomplished by applying a constant current through the interconnect until failure. A comparative analysis was completed by performing breakdown and TTF testing on bare Cu interconnect devices. The hBN-passivated Cu interconnects, compared to otherwise identical but bare Cu interconnects, exhibit on average a >20% higher breakdown current density and a >2600% longer lifetime (at a high current density of 5.4×10^7 A cm^{-2}). Post-mortem metrology elucidates uniform conformal contact between the hBN-passivated Cu interface and common failure features due to electromigration.

The mechanical integrity of hBN-passivated Cu interconnects were evaluated through the use of optical microscopy (OM), interferometric optical profilometry (OP), scanning electron microscopy (SEM), atomic force microscopy (AFM), and Raman spectroscopy. The evaluations served to observe the conformal contact of hBN with changes in surface topography before and after electrical testing. OM and OP results demonstrated the hBN uniformity covered the entirety of the Cu interconnect. Furthermore, the cleanliness of the interface observed with SEM and AFM. Raman is used characterize the monolayer nature of the exfoliated hBN, via measurement of E_{2g} peaks at 1366 cm^{-1}.

The demonstration of the electromigration mitigation capabilities of angstrom thin hBN was accomplished in this work. We completed electrical testing on hBN-passivated Cu interconnect devices, characterizing their breakdown and TTF performances. In addition, hBN-passivation was demonstrated to enhance the lifetime of Cu interconnects when compared to bare Cu interconnects. Furthermore, using various microscopy, profilometries, and spectroscopies, we observed that the hBN maintained its mechanical integrity after electrical testing. As a barrier layer material, hBN is a potential candidate for future electronics applications. Additionally, investigations into synthesis and preparation need to be completed to demonstrate scalable, practical approaches.