2D Ultralow-k Amorphous Carbon

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Two-dimensional (2D) materials exhibit excellent properties at monolayer thickness and are viable replacements for various microelectronic components as scaling gradually approaches the atomic limit. Despite significant advancements in the ongoing 2D revolution of integrated circuits, one crucial building block, namely a 2D ultralow-k8 (ULK) dielectric, remains unreported. The challenge lies in achieving a dielectric constant (k) less than 3 as traditional low-k dielectrics are inherently unstable at the 2D limit due to their amorphous or porous nature. The realisation of ultrathin dielectrics with low-k is also needed to address current bottlenecks in integrated circuits scaling. Specifically, low-k materials are necessary to minimise parasitic capacitances as the distance between conductive elements shrinks below 10 nm. Here, we show that 2D amorphous carbon, as thin as 0.8 nm, is a mechanically robust 2D ULK dielectric with k of 1.35 and dielectric strength of 28-31 MV cm-1. The lack of any long-range order, its intrinsic 2D nature, sp2 carbon character and low density are all essential for minimising dielectric permittivity. Moreover, it overcomes the vulnerability of existing dielectrics to ion diffusion degradation with a record metal ion diffusion time to failure (TTF) of 10+10 s for even a single layer. Therefore, otherwise necessary additional layers occupying up to 3 nm can be eliminated, which is especially significant as metal line widths approach 10 nm. Combined with its low-temperature, direct and conformal growth even on a dielectric, these critical features enable substantial improvements in silicon-based semiconductor electronics and ensure compatibility with future 2D electronics.