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Evidence for WKB Failure in Contemporary Magnetic Tunnel Junctions[1]

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This work describes evidence for the failure of the WKB approximation in state-of-the-art magnetic tunnel junctions. Surprisingly, the tunneling conductance of three varieties of CoFeB/MgO/CoFeB magnetic tunnel junctions depends quadratically on the applied voltage to anomalously high biases: the parabolic conductance persists to 2 V, greater than half the theoretical MgO barrier height. Within the framework of WKB, these data imply unphysical barrier parameters. We show that the origin of this breakdown is a distribution of barrier thicknesses consistent with experimentally feasible interfacial roughness, possibly in conjunction with the tunneling electron sensing the MgO band structure. Additionally, well defined and reproducible bias-dependent conductance oscillations are observed in CoFeB/MgO/NiFe devices. These oscillations are mediated by the reflection of tunneling electrons from the sharp MgO/NiFe interface, which allows electron standing waves to form within the MgO barrier. The oscillation amplitude is enhanced in the antiparallel state, which gives rise to oscillations of the tunneling magnetoresistance. A model employing spin-split free electron bands and the exact solution to the Schrödinger equation demonstrates qualitative agreement with the data. This work implies that using existing WKB-based models may lead to physically incorrect barrier parameters for contemporary tunnel junctions, which may underscore the imminent necessity for first principles analyses of contemporary tunneling devices with textured or epitaxial barriers, MgO or otherwise.

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