Stretchability of freestanding and polymer-supported serpentine thin films

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ABSTRACT

High-performance flexible electronics integrate high-quality inorganic electronic materials such as metal, semiconductor, and oxide with deformable polymer substrates. To minimize strains in inorganic materials under large deformation, metals, and ceramics can both be patterned into meandering serpentine structures. When the polymer substrate is stretched, the serpentines can rotate and twist to accommodate the applied deformation, resulting in greatly reduced strains in the inorganic materials as well as the system-level stiffness. Reported stretchability of serpentines spans from 25% to 1600%, whereas a fundamental understanding of such big variations is still missing. We have conducted a systematic investigation of the effects of geometry and substrate stiffness on the stretchability of serpentines through both analytical and experimental means. For freestanding serpentines, closed-form analytical results are obtained and validated by experiments. To investigate the effect of substrates, ITO serpentines are patterned on both polyimide and elastomeric substrates with systematically changing geometries. On the one hand, stiff substrates, such as polyimide, almost completely prevent the rotation or twist of the serpentines and hence the effect of the serpentine geometry is minimal. On the other hand, soft substrates, such as elastomer, can provide serpentines with reasonable freedom of rotation and twisting, which yields stretchability much higher than the ones bonded to stiff substrates but lower than the freestanding ones. Experimental measurements on polymer-supported ITO serpentines are found consistent with FEM results and empirical equations are proposed to analytically capture the geometric effects.