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Harnessing Instabilities in Polymers under Electric Fields

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Subject to a voltage, a layer of a polymer reduces thickness and expands area, so the same voltage will induce an even higher electric field. The positive feedback may cause the polymer to thin down drastically, resulting in an electrical breakdown. This electromechanical instability has been long recognized in the electrical power industry as a major failure mode for polymer insulators. In this talk, we will present recent new observations and understandings of the electromechanical instability. For example, what will happen if the polymer is bonded on a rigid substrate to prevent the area expansion? We show that a new mode of instability will set in. Once the electric field reaches a critical value, the initially flat surface suddenly folds upon itself, deforming into a pattern of creases. As the electric field further rises, the creases increase in size and decrease in density, and strikingly evolve into holes in the polymer. The critical electric field for the creasing instability scales with square root of the polymer's modulus. We show that linear stability analysis overestimates the critical electric field for the instability. A theoretical model has been developed to predict the critical field by comparing the potential energies in the creased and flat states. The theoretical prediction matches consistently with experimental results. We further show that the instability can be harnessed with promising applications in many areas including high-breakdown-field organic capacitors, electrostatic lithography, dynamic pattern formations, fabrication of semi-permeable membranes, and energy harvesting.