Discovery of carbons as electrets and piezoelectrets (Carbon fibers and composites)

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This paper reports the discovery of the electrets and piezoelectrets in carbons, which include PAN-based carbon fiber, nickel-coated PAN-based carbon fiber, continuous carbon fiber polymer-matrix composite (in-plane), carbon-carbon composite (in-plane), isotropic graphite and exfoliated-graphite-based flexible graphite (in-plane). The electrets provide inherent electric fields, which are useful for voltage-driven devices. The piezoelectrets (akin to the piezoelectric effect) enable the sensing of stress/strain based on the measurement of the electric field or capacitance. The electrets are supported by electric field measurement and the observed polarization-induced increase in the apparent resistance. Among the carbons, the apparent resistance increase correlates with the relative electric permittivity κ. It is undesirable for conduction-related applications, including electrochemical electrodes. The piezoelectrets are supported by the directional asymmetry in the polarization-induced increase in the apparent resistance upon polarity reversal and the change of the electric field and capacitance with the applied tensile stress. The polarization is due to charge carrier movement, with the fraction of carriers that participate decreasing with increasing inter-electrode distance. It is also supported by the measurement of κ, which is high for all the carbons and changes with the stress. The electric field, capacitance, permittivity and resistivity all change reversibly with the stress in the elastic regime, thus allowing stress/strain self-sensing. The reversibility applies to all the carbons except flexible graphite, which has slight irreversibility in the κ increase when the stress exceeds 2.1 MPa, due to a microstructural change that does not affect the strain or resistivity reversibility, but increases κ.