



## » Conductive Polymer Blends for 3D Printing

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Composites that are light weight, mechanically flexible, durable, and have tunable conductivity are of considerable interest for numerous applications which include electrostatic dissipation, EMI shielding, and soft conducting material applications. 3D printing of these materials into complex shapes such as grids, strain gauges, and thermocouple interfaces would be greatly useful for measuring temperature, strain, and strain rate of materials. The unique redox properties of conjugated polymers (CPs) allows for this type of material utility to be possible. Here, we report on the direct ink write printing of our choice CP, polyaniline (PANI). We employ dinonylnaphthalene sulfonic acid as a surfactant, dopant and bulky counterion to endow solubility to PANI in a range of organic solvents (e.g. toluene, xylenes). We utilize this solubility to employ different additives and processing conditions to tune

the rheological behavior of the ink, and the electromechanical properties of the resultant printed structures to advance the production of 3D conductive PANI devices. Specifically, we take advantage of fumed silica and ultra-high molecular weight polystyrene (PS) to tune the rheological and mechanical properties of the resulting composites. We demonstrate the ability to tune the conductivity of these printed structures over a range of eight orders of magnitude ( $10^{-8}$  –  $10^{-1}$  S/cm), which is decidedly apt for many of the aforementioned applications. Our approach provides an effective and simple approach to printing PANI-based 3D architectures that will contribute to the ongoing effort of bringing the promising properties of CPs to the future of micro- and nano-electronic devices.

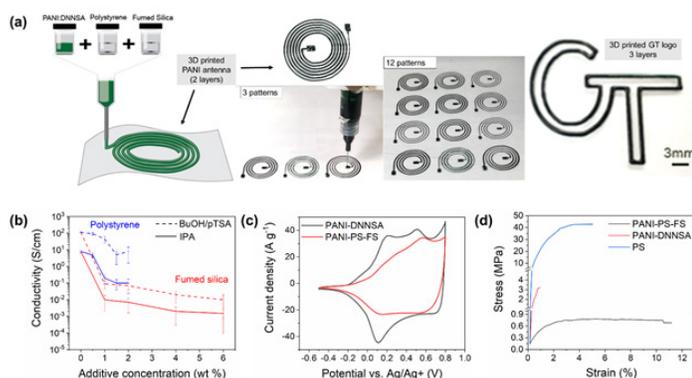


Figure 1. (a) 3D printing of PANI-PS-FS (45, 1, and 3 wt%, respectively). (b) Solid-state conductivity dependence on both PS (blue) and FS (red) additive concentrations in PANI-DNNSA blends. These formulations were printed and treated with IPA (solid) and BuOH-pTSA (dashed, 5 wt% pTSA) to determine optimal treatment concentrations. (c) Cyclic voltammograms of PANI-DNNSA (black) and PANI-PS-FS (red) on the 50th cycle plotted as a function of current density scanning at 50 mV/s. (d) Stress-strain curves of PS (blue), PANI-DNNSA (red), and PANI-PS-FS (black). The PANI-DNNSA and PANI-PS-FS were lightly treated by dipping into a solution of IPA to remove excess DNNSA.

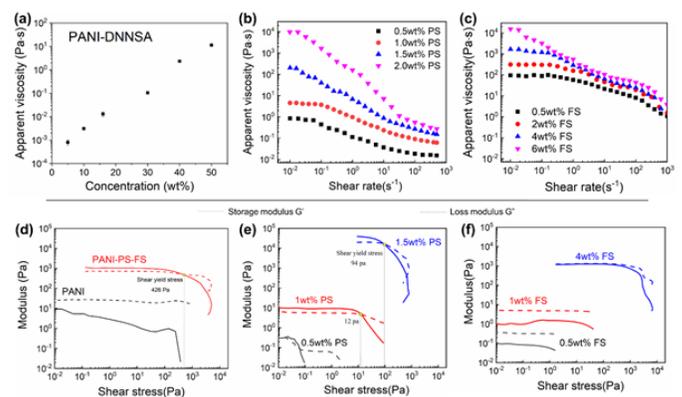


Figure 2. Data comparing rheology of varying inks comprising toluene as the primary solvent. (a) Apparent viscosity as a function of PANI-DNNSA concentration. Apparent viscosity as a function of shear rate for varying concentrations of (b) PS and (c) FS. (d) Rheological properties of PANI-DNNSA (85 wt% in toluene) and PANI-FS-PS (50-3-1 wt%, respectively) were compared to understand the contribution of PANI to viscoelasticity of CP inks. Rheological characterizations of CP inks with various concentrations of (e) PS and (f) FS. Storage and loss moduli were determined using a linear stress sweep technique, where shear yield stresses for viscoelastic inks were identified where the two moduli intersect. The concentrations of PANI-DNNSA in independent PS (b,e) and FS (c,f) formulations were 50 and 10 wt%, respectively.