Integrating magnetic plastics into next-generation electronic devices

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An organic-based magnet is integrated with a compound semiconductor to create the first hybrid organic/inorganic spintronic device with magnetic functionality within the organic layer.

While modern electronics relies on using the electron’s charge to do various operations (transistors, capacitors, etc.), ‘spintronics’ describes devices that rely on the electron’s magnetic moment, or spin, for functionality. The energy cost associated with changing the electron’s spin state is much lower than the cost of manipulating its charge. In addition, it is predicted to be much faster to manipulate the spin (think of flipping a tiny bar magnet from ‘north’ to ‘south’). Given these characteristics, scientists have for some time focused on the potential of spintronics to deliver fast, low-power computing. However, progress in the area of computer logic and information processing has been delayed by the lack of appropriate materials and the difficulty in developing a spin-dependent analog of the gain—or signal amplification—found in traditional charge-based computing.

In parallel, the field of organic-based ferromagnets has seen remarkable progress in the development of plastics with magnetic ordering (that is, with electrons in a material all lined up with their spins pointing in one direction) that extends well above room temperature. The reason such a property is important in spintronics has to do with the ability to generate a ‘spin current’ that plays the same role as the charge current for conventional electronics. If we pass an electronic current through a magnetically ordered material, then the electron current that comes out the other end has a preferred spin orientation, a spin current. By, for example, linking the small molecule tetracyanoethylene (TCNE) with various transition metals (iron, cobalt, vanadium), researchers have demonstrated the ability to synthesize plastic films that have room temperature magnetic ordering and semiconducting electronic properties.1 These characteristics are an excellent match to the materials requirements for spintronic logic, and it is that opportunity that we are exploiting in the development of hybrid organic/inorganic spintronic devices (see Figure 1).2

The specific organic-based magnet that we selected is vanadium tetracyanoethylene (V[TCNE]$_2$). This material is an organic semiconductor with a conductivity of $10^{-2}$ S/cm and a magnetic ordering temperature greater than 400K (the highest temperature reported in the metal-TCNE family of compounds).1 One of the biggest challenges in fabricating these devices is the constraint that once the V[TCNE]$_2$ is deposited,
Under typical operating conditions, an electrical bias is applied between the top contact and the p-layer of the LED (see Figure 1). This drives a spin-polarized electron current from the V[TCNE]₂ layer into the LED, where the electrons recombine with either the heavy- or light-holes injected from the p-contact. The optical polarization of the light emitted from the LED is defined as \( P = \frac{I_{\text{RCP}} - I_{\text{LCP}}}{I_{\text{RCP}} + I_{\text{LCP}}} \), where \( I_{\text{LCP}} \) and \( I_{\text{RCP}} \) refer to the intensity of left-circular polarized and right-circular polarized light. This quantity directly measures the number of spin up versus spin down electrons created by the V[TCNE]₂ layer. Panel (b) of Figure 2 shows this polarization as a function of applied magnetic field for light emitted by the heavy-holes (red triangles) on the same graph as the magnetization of the V[TCNE]₂ layer (green line). The heavy-hole polarization tracks exactly with the magnetization, demonstrating successful spin injection across the hybrid organic/inorganic interface.

While the polarization signal in these first-generation devices is relatively weak, it is easily detected by our sensitive spin-detector. More importantly, this proof of principle demonstration opens the door to a new era of hybrid organic/inorganic spintronics. The hybrid interface in these early studies has not yet been optimized, and we expect improvement over the next several years as we apply various strategies (based on both chemistry and semiconductor engineering) to improve the spin transmission efficiency. These aspects represent the focus of our future work. We anticipate that the flexibility offered by these hybrid structures will contribute to the development of spintronic technologies ranging from next-generation electronics to potential applications such as flexible electronics and chemical sensing.

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Continued on next page
References