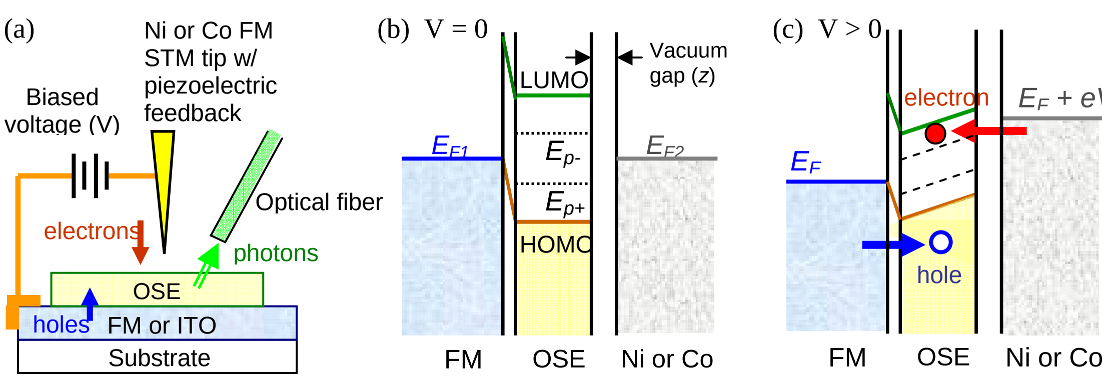
Spin and Charge Quantum Transport in Organic/Magnetic Heterostructures for Spintronics and Optoelectronic

This research project is one of the Seed Projects of the Caltech Center for Science and Engineering of Materials (CSEM) and is in collaboration with three other research groups led by Professor Julia Kornfield (Chemical Engineering), Professor Oskar Painter (Applied Physics), and Professor Marc Bockrath (Applied Physics). In this work, we want to address fundamental scientific issues relevant to optimizing the spintronic and optoelectronic properties of organic semiconductor/ferromagnet heterostructures. "Spintronics" is a new electronics paradigm based on manipulation and detection of the spin-dependent electronic properties in magnetic structures.[i] It has emerged as an active research area because of the potential advantages for high device integration densities and for better coherence required in quantum information technology. Similarly, organic semiconductors (OSE)[ii] have been intensively studied because they are highly adaptable and exhibit interesting properties for optoelectronic applications.[ii] The weak spin-orbit interaction and strong polaronic properties of the OSE are also suitable for incorporation into spintronics.[iii] Recent manifestation of significant tunneling magnetoresistance (TMR) in organic spin valves[iv] and electroluminescence (EL) of related structures[v] suggests promise of the FM/OSE/FM (FM: ferromagnet) heterostructures for spintronic and optoelectronic applications. However, the physical mechanisms of microscopic spin/charge transport and EL in these FM/OSE/FM tri-layer structures, which is paramount to the scientific and technological advances, remain little understood.

Our initial research will focus on fabricating basic OSE/FM heterostructures and conducting experiments to elucidate the underlying physics at the microscopic scale by using a microprobe system that consists of a cryogenic scanning tunneling microscope (STM) assisted with an optical scanning probe microscope (OSPM). The concepts of initial investigations are depicted in Fig. 1. Unlike the tri-layer planar heterostructures studied by others[iv,v], we shall replace the cathode with a FM STM tip, which eliminates serious pinhole problems encountered by an FM cathode layer above the OSE (such as Alq_3),[iv] so that the OSE layer can be made much thinner (within the spin relaxation length) to enhance the TMR and EL. Our approach also circumvents the band-bending problem of others that involves the formation of a dipolar layer[vi] at the OSE-metal cathode interface. Moreover, the vacuum tunneling barrier in our STM studies preserves the spin polarization of injected electrons[vii,viii,ix] and enhances the EL from the OSE by eliminating the coupling of emitted photons to the surface plasmons of a layered cathode. The resolution of the STM not only elucidates the nature of pinholes but also provides spatially resolved TMR and EL for revealing the spin/charge quantum transport properties[vii,viii,ix,x,xi].



<u>Figure 1</u>: (a) Schematics of OSE/FM probed with an STM tip as the cathode[33-35] and an OSPM incorporated in the cryogenic STM system to collect EL, under varying temperatures and magnetic fields. (b) Heterostructure band diagram at V = 0.[29,30,32,33,40] and at (c) V > 0. The polaron states between the lowest unoccupied molecular orbit (LUMO) and highest occupied molecular orbit (HOMO) of the OSE may be important to the quantum transport.

We will use single-crystal Ni [110] for spin polarized electron injection;[viii,ix] and either sublimed molecular films of (Alq_3) or copolymers for the OSE[ii,iv]. Half-metallic FM of $La_{0.7}Sr_{0.3}MnO_3$[iv] and $La_{0.7}Ca_{0.3}MnO_3$[xi,xii] will be used as the FM anode because carriers are ~ 100% spin polarized below the FM transition temperature T_{Curie}, with the spin orientation controlled by the temperature [xiii] and applied magnetic field. Epitaxial FM films will be made by Yeh and an experienced JPL collaborator R. P. Vasquez using pulsed laser deposition (PLD),[xii,xiv,xv] followed by OSE film deposition by Kornfield. Installation of the OSPM into a cryogenic STM will be implemented through the joint effort of Yeh and Painter, and the OSE/FM heterostructures will be studied using the microprobe system to provide information for the nano-scale resolved TMR and the exciton binding energies within the OSE that elucidate the quantum charge/spin transport channels. The spin-dependent EL efficiency controlled by an applied field will also be determined, and much higher EL is expected for injected electrons and holes of opposite spins. Other conjugated OSE with high luminescence efficiencies will be explored for better EL, longer spin relaxation length, and minimum pinhole problems. Various half-metallic FM of higher T_{Curie} and better TMR will be experimented, and different spin/charge injection tips besides Ni [110] can also be explored by Bockrath. Fabrication of nano-scale spintronic devices (e.g. spin-valves with spin-controlled TMR and EL, spin-transistors) will be attempted using the stamping[xvi] and lithographic techniques by Bockrath. Thus, a new frontier of spintronic/optoelectronic studies will be initiated by this seed project, including new nano-scale instrumentation, optimization of OSE/FM heterostructures, revelation of quantum charge/spin transport, and device development.

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