Ultralong metallic nanowire waveguides – a bridge between the nano- and macroworlds

To discuss the concept of a propagating surface plasmon we first need to understand what a plasmon is.

Metals conduct electricity because they have a bunch of “free” electrons that can move freely in the material. While the ions (charged atoms) stay fixed in the crystal lattice, the free electrons can be pushed through the material by an electric field, much as water in river is pushed through the landscape by the gravity. Light is also a form of the electric field – the one that oscillates very quickly – and it is because the electrons in metals are pushed back and forth by the light that metals are shiny and the light cannot penetrate into the metal. However, if a metal particle is much smaller than the wavelength of the light, the whole “cloud” of electrons in the particle will move back and forth like a droplet on a board that tilts from side to side. This collective motion of the electron cloud is what we call a plasmon. Because of the attraction between opposite charges the negative electrons are attached to the positive metal ions like on a spring. When the light is pushing the electrodes one way, the ions try to pull them back. When the frequency of the back-and-forth pulling of the light matches the frequency of the tugging by the ions the plasmon motion is extra strong, and this is known as the plasmon resonance. Depending on the material, size and shape of the particle this can happen at different wavelengths of the light. Silver and gold are popular for plasmonic experiments since the plasmon resonance happen to lie in the visible light range.

Nanowires are unique in that their diameter is much smaller that the wavelength of light, making them suitable for excitation of plasmons, but along their axis they can stretch for a long distance. This means that a plasmon that is generated by shining light on one end of a wire can travel down the wire in the way the sound of the train travels down the rail. And as the sound excites a reaction in your ear when you press it to the rail to hear if the train is coming, so a plasmon can excite a reaction in fluorescent emitters attached to the wire far down the line. The plasmon will cause the emitters to emit light, and by choosing emitters that only shine in the presence of certain interesting molecules, we want to use travelling plasmons for building a sensor that can detect molecules away from the position of plasmon excitation. This could be used for measuring the presence of a specific molecule in a sample, maybe inside a cell, where shining the strong excitation light directly onto the sample might damage it.

For the plasmons to travel down the wire efficiently the it needs to be of high quality without crystal boundaries. Growing nanowires of lengths approaching 1 mm (10000 times longer than their diameter) is no trivial task. Most method results in multicrystalline wires where the wire is “welded” together of shorter pieces like the old-time rails that gave rise to the da-dum-da-dum sound of train-travel. A large part of the project will be devoted to developing a method for controlled and efficient growth of high quality nanowires. Another challenge will be to attach proper emitters to the wire without changing it so much that the plasmons will no longer travel along it.

Combining these two tasks with construction of an optical setup using two microscope objectives to excite and detect the travelling plasmons means we have our work cut out for us.