

An Optoelectromechanical Light Sensor at 1.55 μm
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Using light to sense mechanical changes is something that has been done ever since Michelson built his famous interferometer in 1887. However, using mechanical changes to sense light is relatively new. The detector we present here we refer to as OEM FOCUS (OptoElectroMechanical FOcalized Carrier aUgmented Sensor). The concept is based on earlier work our group has done on a FOCUS detector involving a large absorbing area with a nanoinjector sensing region [1]. A figure showing the original FOCUS and the OEM FOCUS is seen in Figure 1. The absorbing region of our OEM FOCUS is a 10 μm diameter circle, 1 μm thick region of InGaAs capped by 100 nm of GaAsSb. The GaAsSb acts as a trap for holes that are generated by the light absorption, which creates a surface potential. Instead of the nanoinjector sensing region, here we use the vibrating tip of an AFM as the injector. The potential difference between the tip and the surface creates a capacitive force, which pulls the tip closer to the surface. The tunneling current is then exponentially dependent on this distance, which in turn makes it very sensitive to the incoming photons. A plot showing distance and approximate tunneling current as a function of surface potential is shown in Figure 6. To generate this plot we used our theoretical model, described below, and reference 2. The bandgap of InGaAs allows our detector to detect light at 1.55 μm . A band diagram is shown in Figure 3.

Recently, people have begun using KFM to sense surface potential changes in a variety of materials, from organics [3], to semiconductors [4], to molecular systems found in plants and animals [5,6]. Our setup is shown in Figure 2, which is quite similar to a KFM setup. Here we have the device under test, which is either our detector or a piece of metal for calibration, mounted under the vibrating AFM tip. To activate the sample we either apply a changing voltage to the tip which generates an electrostatic force, or apply laser light to the sample which deforms the surface potential, altering the electrostatic force. With our AFM we feed the phase output of the vibrating tip to an oscilloscope and lockin amplifier. The lockin amplifier is synchronized with the function generator. This allows us to sense the phase change of the tip at the frequency of applied voltage or light. We monitor the phase change as opposed to the amplitude because it is much more sensitive to forces on the tip.

We have tested the phase change as a function of time by looking at the phase output of the AFM on an oscilloscope and comparing to our theoretical model, as described below. This comparison is seen in Figure 4. You can see an initial hump that lasts about 1.25 ms, 1 full period of which (2.5 ms) corresponds to a frequency of 400 Hz. We have observed a peak in the signal from the lockin amplifier at this frequency. We have also tested the surface potential generated by the photosensitive region as a function of incident power on the detector, and the results are pictured in Figure 5. You can see that there is a linear region at low power but the detector begins to saturate at higher power. We have measured a surface potential of 155 mV with a maximum incident power of 13.9 nW, down to a surface potential of 1 mV with an incident power of 32.6 pW.

To understand our setup, we have modeled the AFM cantilever with a modified mass on a spring differential equation. We use the equation of motion for a forced, damped harmonic oscillator, but add an electrostatic force term to address the electrostatic force between the tip and the sample. We use the frequency response curve of the equation without the KFM term to fit for the mass and friction parameters in our experiment. The spring constant of the cantilever is provided by the manufacturer. We then solve this equation numerically using *Mathematica*. We know the amplitude of oscillation from our experimental setup, about 30 nm, and can use this parameter to extract the magnitude of the driving force and the electrostatic force term. We find that the magnitude of the driving force is ~ 600 pN and the KFM force ~ 200 pN needed to cause the phase change created by 13.9 nW illumination, the maximum intensity we tested. For illustration, this Newton from Watt conversion is over 4 million times the photon radiation pressure exerted by the same illumination intensity.

In the future, we would like to microprocess devices which have a known distance from the tip to the sample and also allow us to more easily measure the tunneling current. We believe that this step is essential to the realization of a practical device, and possibly to the formation of arrays of such devices, similar to to DPN arrays already being built [7].

References

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Figures

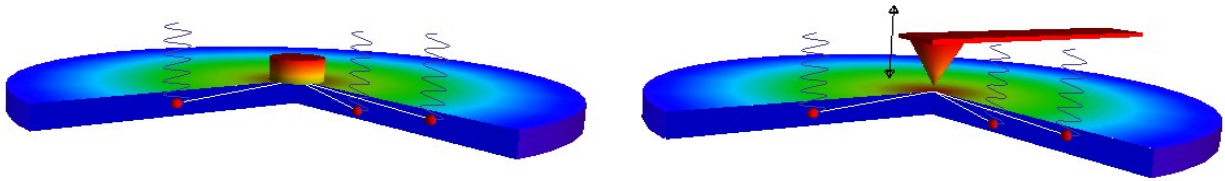


Figure 1 – Schematic diagram of original FOCUS detector (left) and OEM FOCUS detector.

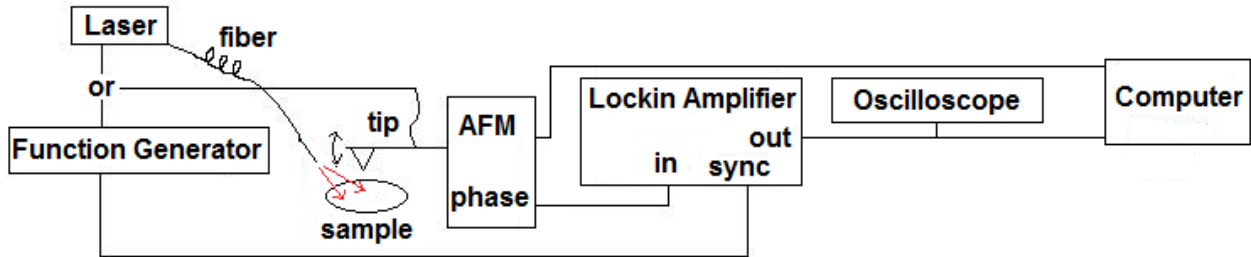


Figure 2 – Experimental setup.

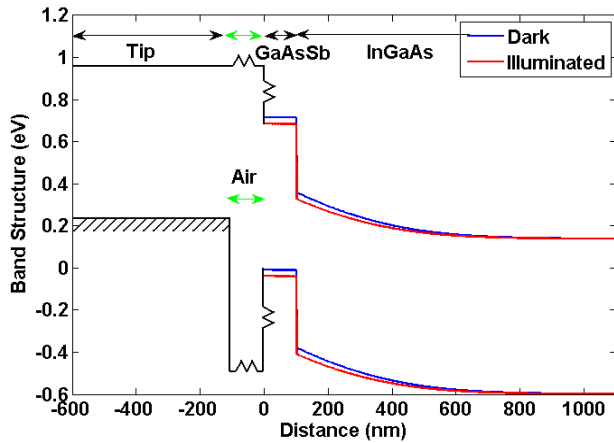


Figure 3 – Band diagram in darkness and under illumination, also shown is the variable air gap.

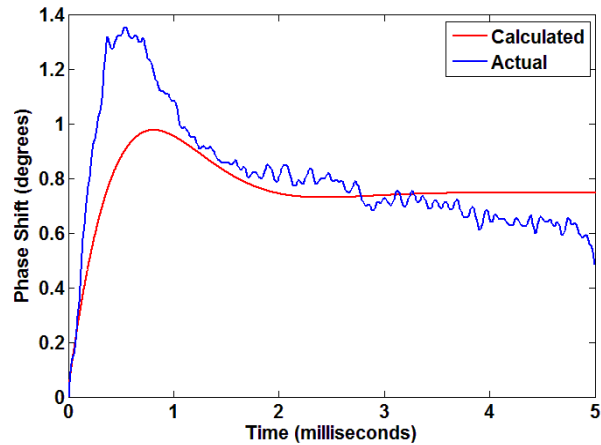


Figure 4 – Comparison of calculated and actual phase shifts.

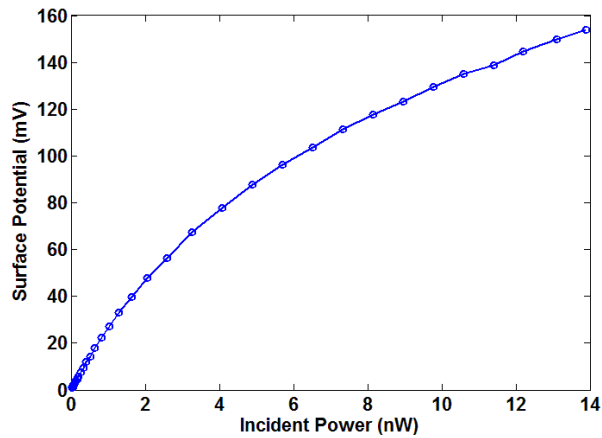


Figure 5 – Surface potential as a function of incident power. You can see the detector is beginning to saturate at high power.

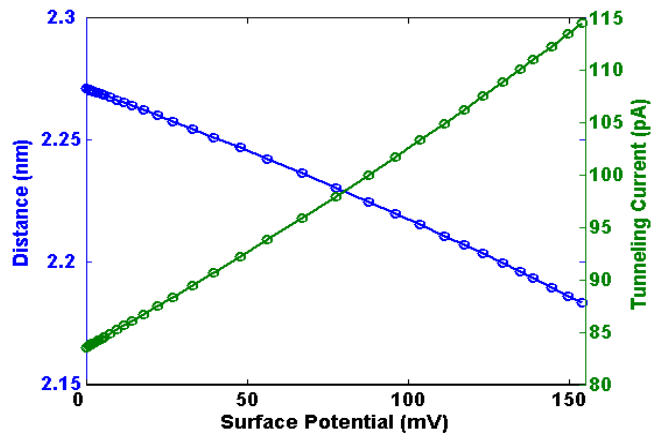


Figure 6 – Plot showing calculated air gap and tunneling current as a function of surface potential. This assumes a 2.5 nm nominal distance to the surface and -1.2 V DC bias on the tip.