

Synthesis and Characterization of Plasmonic Structures for uses in Photocathode Technology.

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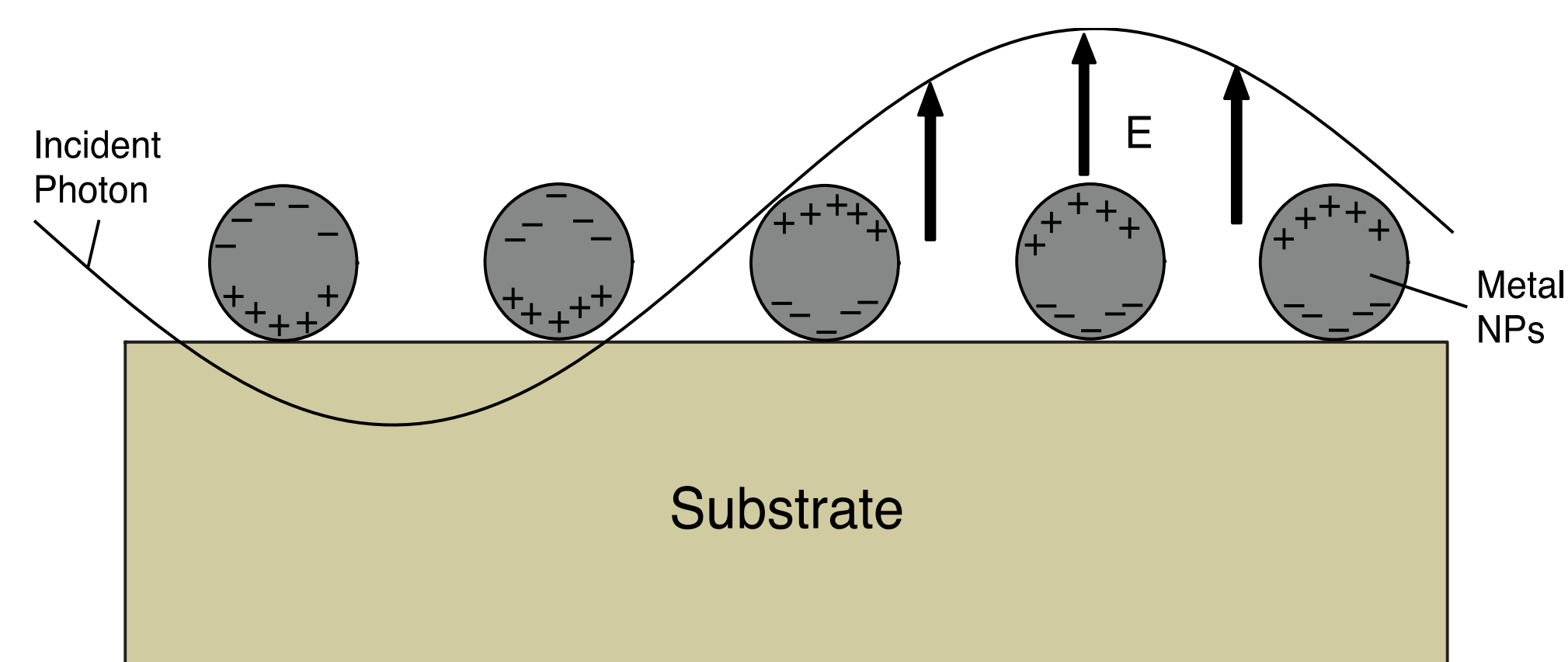
Motivation

Metal photocathodes have been the standard of accelerator research for many years now. It is primarily chosen for its robustness to the surrounding environment, fast response time, and high brightness. However, most metals have work function values around 4-5 eV, this corresponds to photons in the UV region. High power UV lasers are currently used to extract the electrons from the photocathodes, these lasers are expensive to build and maintain.

A recent development in nanotechnology is that metal nanoparticles can enhance the absorption of specific wavelengths of light. The absorption highly correlates to the shape and size of the nanoparticle and also the dielectric media surrounding it. When deposited on metals, silver nanoparticles can enhance absorption at green wavelengths. Because of the lower cost associated with green lasers, this is an attractive direction of research for commercial photocathode development.

What are localized surface plasmon resonances?

The collective oscillations of the conduction electrons can be quantized and are known as plasmons. Near the surface of a material, these plasmons can be coupled to an external electromagnetic field to form surface plasmons. If the surface is instead made of discrete size spheres, a resonance condition can be met when the frequency of the incident photon matches that of the electron cloud oscillating against the restoring force of the heavy nucleus. For particles with diameter(d) much smaller than the wavelength(λ) of the incident photon ($d \ll \lambda$), the plasmon enhancement is highly localized.



$$E_{out}(x, y, z) = E_0 \hat{z} - \left[\frac{\epsilon_{in} - \epsilon_{out}}{\epsilon_{in} + 2\epsilon_{out}} \right] a^3 E_0 \left[\frac{\hat{z}}{r^3} - \frac{3z}{r^5} (x\hat{x} + y\hat{y} + z\hat{z}) \right]$$

UV-Vis-IR Spectroscopy

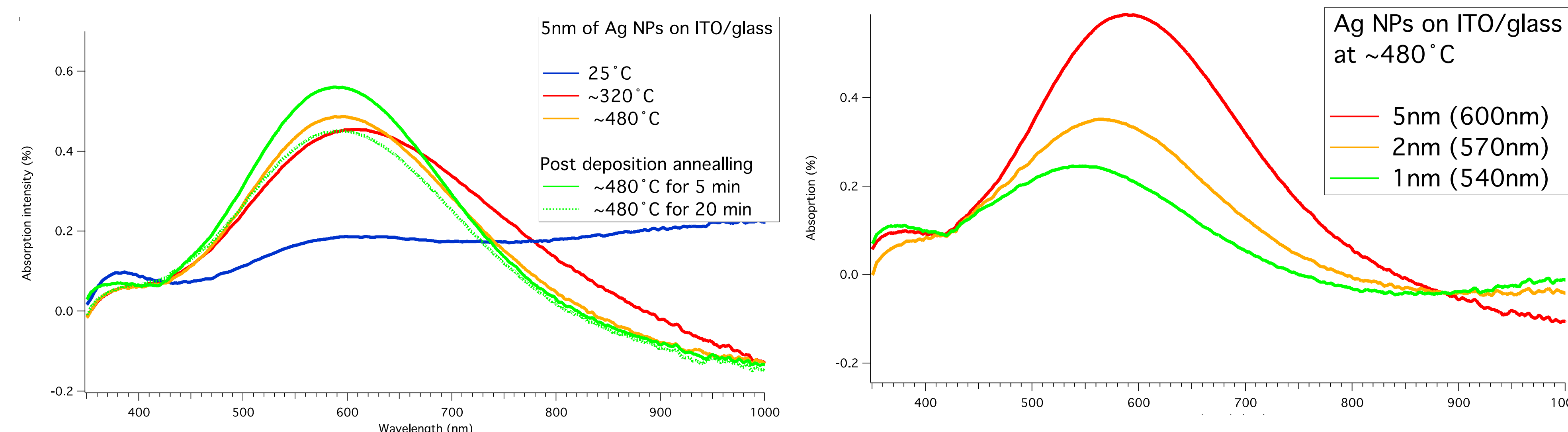


Figure 1: Absorption spectra of 5nm deposited Ag NPs on ITO/glass at different substrate temperature.

Figure 2: Absorption spectra of different thicknesses of Ag NPs deposited at ~480C.

The above figures shows the absorption intensity of silver nanoparticles on ITO/glass. The nanoparticles are grown using a dual laser, pulsed laser deposition (PLD) system. A secondary infrared laser is used as a means to anneal the substrate. Figure 1 shows the absorption spectra of 5nm of silver deposited on different temperatures of ITO/glass substrate. We can see that the absorption peak sharpens as the temperature of the substrate increases. This can be explained by the fact that high temperature provides surface energetics allowing the silver particles to move around until settling into a defect where other particles cohere around them. This allows the silver to form nano size particles rather than a smooth film. The absorption peaks in figure occur around 570-580 nm, which is the green region of the spectrum.

Figure 2 shows the absorption spectra of different thickness of silver nanoparticles deposited on the same substrate temperature. As the thickness is increased, we see a slight red shifting of the absorption peak, from 550 to 590 nm. This is likely due to the increasing sizes in the nanoparticles with increasing film thickness.

Scanning Tunneling Microscopy (STM) Imaging

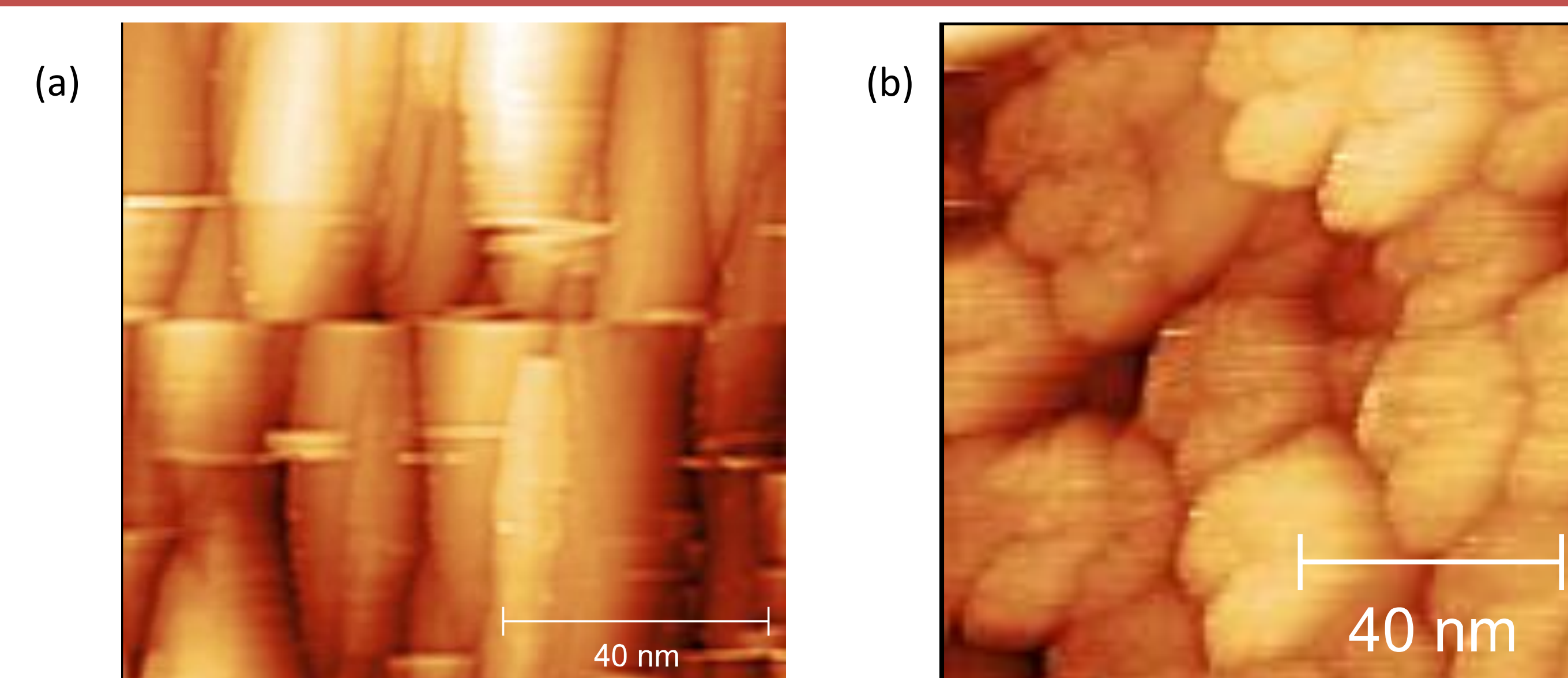


Figure 3: STM images of silver deposited on ITO glass at (a) room temperature and (b) ~500C. 100nmx100nm. Applied bias voltage = 1 V. Tip current = 1 nA.

The figure are of 1nm of silver deposited on ITO at different temperature. Figure 3(a) is deposited at room temperature and Figure 3(b) is deposited ~500°C. At room temperature, we can see that the silver forms an ellipsoidal shape that overlaps next to each other, while the one grown at high temperature shows a more round shape. This follows from the absorption data that high temperature forms smaller nanoparticles, therefore having a narrower absorption peak.

Work Function measurement

Now that we know the absorption peak is tunable and that it has different surfaces, we need to know how this affects work function. The table below shows different thickness of silver deposited at 500°C. For thin layers of silver, the work function is much higher than that of ITO or polycrystalline silver, but as the film thickens we start approaching the work function of polycrystalline silver. Next we can lower the work function by depositing a layer of metal oxide on the silver.

Sample	Thickness(Å)	Substrate Temperature(°C)	Work Function (eV)
ITO	-	-	4.657
Poly Ag	bulk	-	4.740
Ag/ITO	10	25	4.908
Ag/ITO	10	500	5.029
Ag/ITO	50	500	4.793
Ag/ITO	100	500	4.790
MgO/Ag/ITO	20/10	500	4.870
MgO/Ag/ITO	20/50	500	4.770

Future Plan

Some of the upcoming measurements we plan to take in the near future includes:

- 1) Deposit on photocathode materials such as copper.
- 2) Quantum efficiency measurements at multiple wavelengths.
- 3) Test the materials at high field gradient for beam characteristics, durability and performance degradation.
- 4) Coat surface with cesium telluride.

Conclusion

This work demonstrates the viability of creating enhanced absorption in the green region with the plasmonic effect using silver nanoparticles. The absorption is correlated to the structure of the nanoparticles, which can be tuned by changing the temperature and thickness layer of the silver. The structure is also checked by the STM technique. Work function measurements demonstrates for different surfaces we get tend towards silver's work function for thicker films. Lastly, MgO is used to lower the work function of the structure.