Strain Color Coding Using Localized Surface Plasmon Resonance of Gold Nanoparticles

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Abstract:

Current methods for measuring and quantifying strain are generally only applicable at the macro and upper micro scale. Consequently many disciplines that require small scale strain measurements rely on simulation-based data. A previous study of localized surface plasmon resonance (LSPR) of gold nanoparticles (AuNP) led to the development of a plasmon ruler equation that relates plasmon peak shift with interparticle separation and particle diameter.

The current project optimizes this methodology to develop a novel technique involving AuNP that could potentially be used for lower micro and nano scale strain measurements. AuNP were deposited onto polydimethylsiloxane (PDMS) using thermal evaporation. Strain was systematically applied to the coated PDMS and the plasmon shift was measured using ultraviolet-visible (UV-Vis) spectroscopy. Six different AuNP depositions were investigated to determine the effect of AuNP size and distribution on the sensitivity of strain measurements: 2, 5, 9, 12, 17, and 20 nm. The 9 nm deposition sample allowed for sensitive measurements between 0.2 and 16.5 percent strain. If this method was applied to a smaller scale, it would allow for sensitive nano scale strain measurements. This novel approach could lead to the development of a new style of strain gauge that could quantify deformation over extremely small distances.

Introduction:

Strain is a unit-less quantification of localized deformation as a material is stretched or compressed. Current devices used to measure strain are extremely useful and accurate for measuring macro and upper micro level strain. However, size constraints, temperature dependence, single directional capabilities, and adhesion interference makes it difficult to apply these methods for use at the micro and nano scale.

LSPR is a phenomenon that occurs as the electrons of metal nanoparticles resonate with respect to one another resulting in the absorption of the light with a frequency equal to that of the respective plasmonic resonance [1]. Jain, et al., modeled this interaction with the development of the plasmon ruler equation which allows for the calculation of interparticle separation based on plasmonic shift as modeled in Figure 1 [2]. The current project optimized this interaction in order to show that LSPR could be used in order to quantify micro and nano strain.

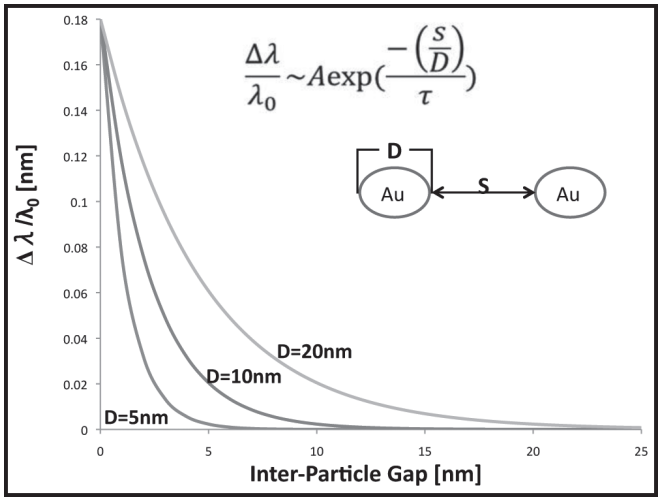

Figure 1: Plasmon ruler equation modeling for different particle diameters.

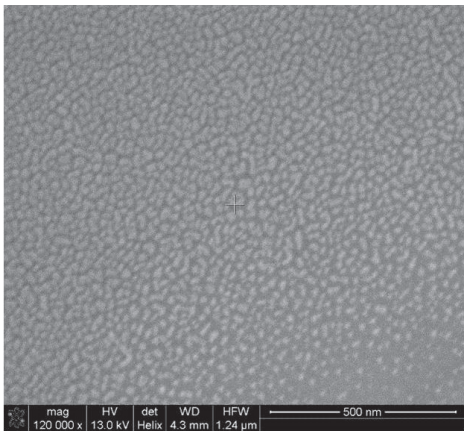

Figure 2: SEM image of thermally evaporated AuNP on glass.

Experimental Procedure:

PDMS was prepared using a Slygard 184 Elastomer kit in a 9:1 ratio of elastomer to hardener. The PDMS mixture was first placed in vacuum below and brought back to atmospheric pressure multiple times to ensure that all bubbles were voided, and then allowed to cure at 100°C for 35 minutes until thoroughly hardened.

Each cured PDMS sheet was cut into dog-bone structures typically used for strain testing. Next, AuNP were deposited on the samples using thermal evaporation. Figure 2 shows two scanning electron microscope (SEM) images of thermally evaporated AuNP on glass, demonstrating the uniformity of distribution achieved. Six samples, each with increasing depositions, were produced; 2, 5, 9, 12, 17, 20 nm. The samples were mounted onto a designed strain holder and multiple strains were systematically applied. The absorbance spectrum during each stretch was observed and recorded using UV-Vis. A stationary camera was used to record an angle of rotation of the cylindrical piece of the holder during each stretch. The angle was then measured using ImageJ photo software and used to calculate the applied strain as is demonstrated in Figure 3. Four samples of each deposition, each placed in slightly different orientations within the thermal evaporator, were produced in order to determine reproducibility and sensitivity.

Results and Conclusions:

Each sample was analyzed through observation of the changing plasmon peak with respect to the applied strain allowing for the following conclusions. A comparison of the unstretched samples showed increasing absorbance as well as a red-shift of the plasmon peak for each increasing deposition. Figure 4 shows the plasmonic shift data of one of the 5, 9, and 12 nm samples, which show conclusive evidence that the method was successful in measuring strain with blue-shifts of the plasmon peak for each increasing strain. The 17 and 20 nm samples yielded no apparent trends. It was first concluded that there is an optimal range of deposition of AuNP for strain testing purposes. Second, the sample B of the 9 nm deposition was determined to be the most sensitive, allowing for deformation quantification between 0.2 and 16.5 percent strain. In our particular setup, this allowed for strain measurements between 200 μm and 1 mm, however, if applied to a smaller scale, this method could allow for sensitive nano scale strain measurements.

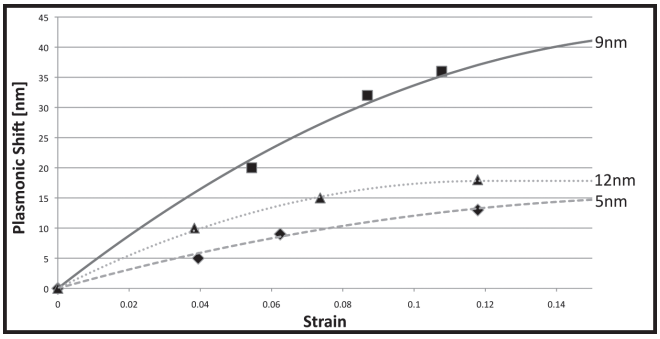

Figure 4: One of the 5, 9, and 12 nm AuNP deposition samples showing plasmon peak shift vs. strain applied.

Future Work:

Further characterization of the procedure is necessary to determine the effects of deposition on sensitivity and repeatability. Continued experimentation needs to be conducted with attempts to control particle size and separation. This would theoretically allow for narrower plasmon peaks and thus more accurate readings of plasmon peak shifts. Last, using polarized light to perform absorption testing would allow for plasmon measurement along a single direction.

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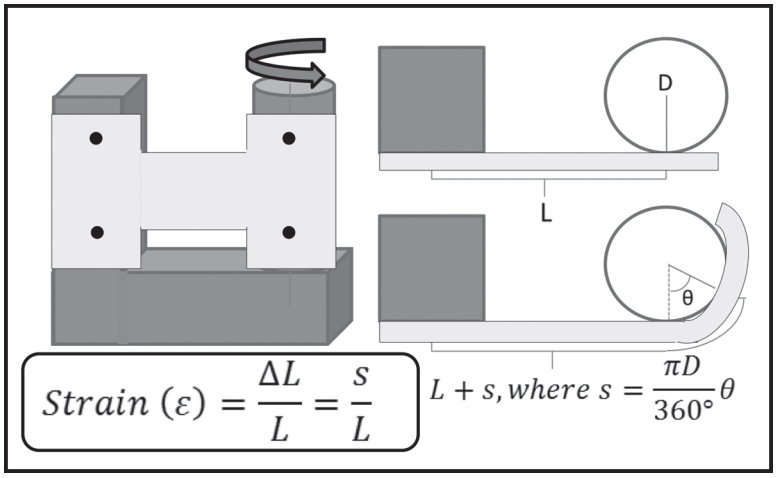

Figure 3: Strain holder setup and demonstration of strain calculation.

References:

[1] Barnes, W.L., Dereux, A., Ebbesen, T.W., "Surface Plasmon Subwavelength Optics", Nature, vol. 424, pp. 824-830, 2003. DOI: 10.1038/nature01937.

[2] Jain, P.K., Wenyu, Huang, Mostafa E.A, "On the Universal Scaling Behavior of the Distance Decay of Plasmon Coupling in Metal Nanoparticle Pairs: A Plasmon Ruler Equation", Nano Letters, vol. 7, pp.2080-2088, 2007. DOI: 10.1021/nl071008a.