Experiments, Modeling and Computations of Pulsed Laser Induced Dewetting in Thin Metallic Films

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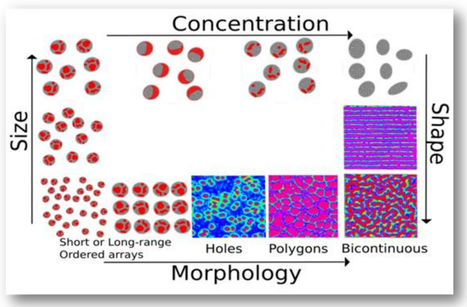
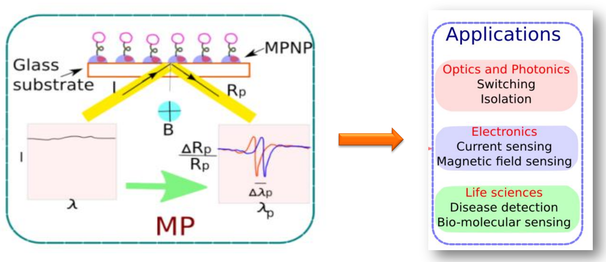
Abstract:-

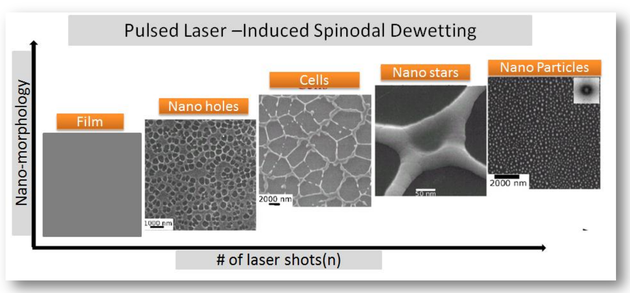
Self-organized multifunctional nanoparticle arrays from pulsed laser induced dewetting in thin metallic films have the potential for applications in biosensing, biocatalysis, high-density magneto-optical technologies, and in electronic materials with photon and spin-dependent electronic behavior. This presentation will describe the nonlinear PDE-based model of self-organization in the periodically melted, single & bilayer thin films. In the presence of long-range intermolecular interactions with the substrate and between the layers, in-plane non-uniformity of heating due to beam interference and thermocapillary effects, the liquid flow in the film gives rise to surface and interface deformation and film dewets into nanoparticle arrays with well-defined length scales and composition. We used linear stability analysis, and 2D computations of film height dynamics to determine dependencies of key quantities of interest (spacing, morphology, composition) on physical and process parameters.

Motivation:-



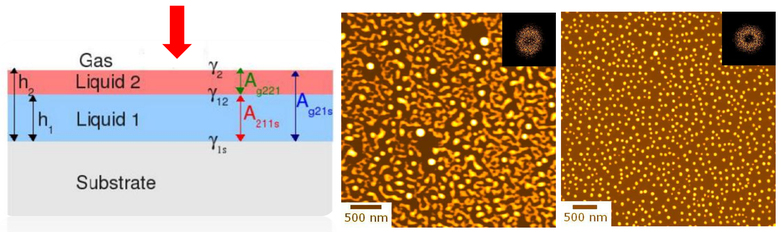


Overview of Pattern Formation:-



Experiments:-

- Layered thin films of Co and Ag on SiO_2 were deposited using e-beam evaporation and pulse laser deposition in vacuum ($1x10^{-8}$ torr) followed by single beam irradiation with *ns* laser pulses using 266 nm ND:YAG laser to create array of hemispherical Ag-Co nanoparticles.
- Morphology and microstructures were analyzed using SEM, AFM and STEM for Ag-Co nanoparticle arrays.



SEM images for morphological evolution after irradiation in bilayer Co-Ag films with 1.5 nm of Co (top) and 5 nm Ag (bottom) layers. following 100 and 10000 laser pulses respectively. The inset of each image shows the FFT of the corresponding SEM image. The annular shape in each FFT is the indication of presence of short range order in the spacing of the features.

Model and Computations:-

- Evolution equations for layer thicknesses, derived using the lubrication approximation of the Navier-Stokes system of fluid flow equations.

$$\partial_t h_1 = -\partial_x \left[F_{11}\partial_x P_1 + F_{12}\partial_x P_2 + \Phi_{11}\partial_x \sigma_1 + \Phi_{12}\partial_x \sigma_2\right],$$
$$\partial_t h_2 = -\partial_x \left[F_{21}\partial_x P_1 + F_{22}\partial_x P_2 + \Phi_{21}\partial_x \sigma_1 + \Phi_{22}\partial_x \sigma_2\right]$$

Here $F_{\ell m}(h_1, h_2 - h_1)$ and $\Phi_{\ell m}(h_1, h_2 - h_1)$ are certain polynomials of a degree at most three

Pressures:

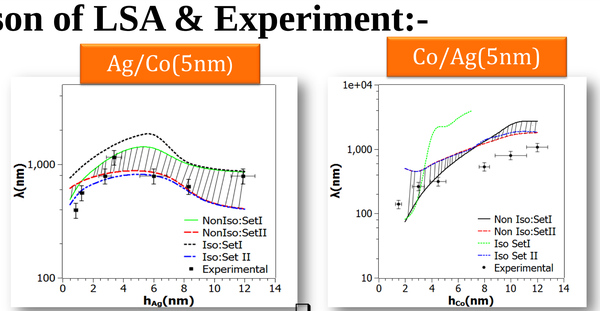
$$P_1 = -\sigma_1\partial_{xx}h_1 - \sigma_2\partial_{xx}h_2 + \Pi_1 + \Pi_2 + \rho_1 g h_1 + \rho_2 g(h_2 - h_1),$$
$$P_2 = -\sigma_2\partial_{xx}h_2 + \Pi_2 + \rho_2 g h_2$$

Disjoining pressures:

$$\Pi_1(h_1, h_2 - h_1) = \frac{A_{s2}}{h_1^3} - \frac{A_{g2}}{(h_2 - h_1)^3} + \frac{S_1 \exp\left(-\frac{h_1}{\ell_1}\right)}{l_1} - \frac{S_2 \exp\left(-\frac{(h_2 - h_1)}{\ell_2}\right)}{l_2},$$

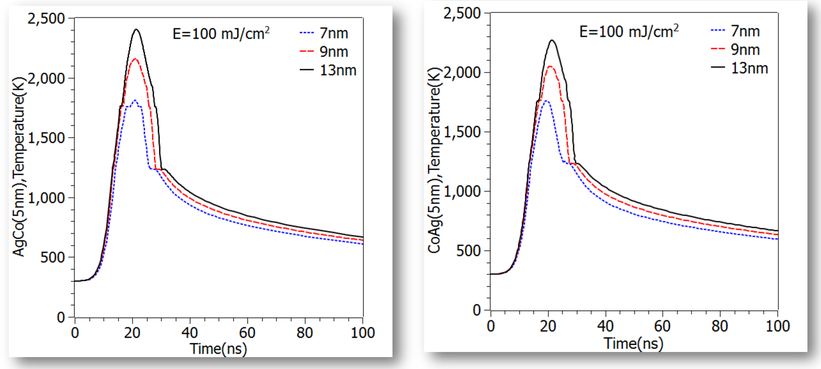
$$\Pi_2(h_1, h_2 - h_1) = \frac{A_{g2}}{(h_2 - h_1)^3} + \frac{A_{sg}}{h_2^3} + \frac{S_2 \exp\left(-\frac{(h_2 - h_1)}{\ell_2}\right)}{l_2}$$

Comparison of LSA & Experiment:-

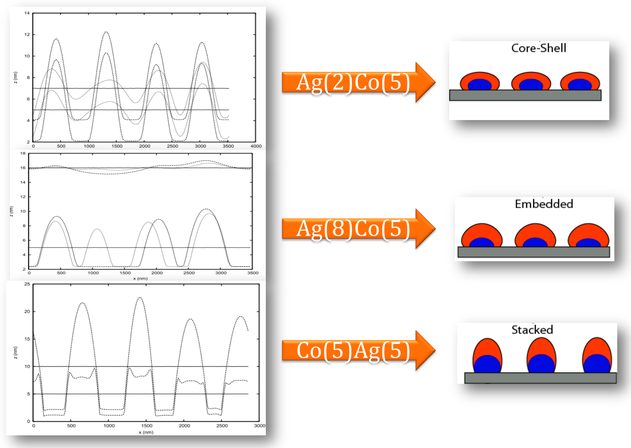


- Non-isothermal calculation is a better overall predictor of the experimental data.

Thermal Model :-

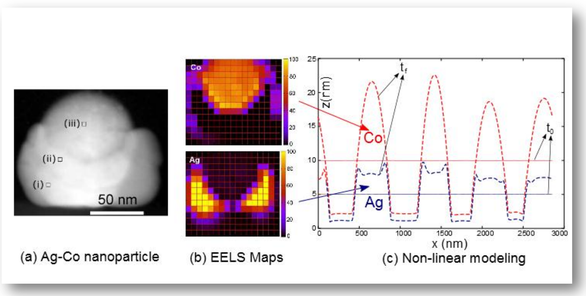


Non Linear Dynamics: Computational:-



- Bilayer films evolve towards formation of different morphologies

TEM Analysis:-



Summary

In this poster, the nanostructure-forming dynamics in pulsed-laser irradiated Ag/Co and Co/Ag thin bilayer films on an optically transparent substrate with a reflective support layer has been studied by means of linear stability analysis and nonlinear simulations. A better prediction of experimental length scales was found for non-isothermal calculations. From Non linear analysis we found that system evolved towards the formation of core-shell, embedded and stacked morphologies

References

[1] [4] M.Khenner et al. Phys.Of.Fluids, 2011(In Press); [2] H. Krishna et al., "Self-organization in nanoscale multilayer liquid films: experiment and theory", 5,470,2011,ACS Nano; [3] R.Sachan et al. "Self organized route to tunable plasmonic-ferromagnetic applications" In preparation to ACS Nano;