Chapter VI: Overview of the present work and Future prospects
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6.1. Summary

The work presented in this thesis is mainly focused on the study of structure, microstructure and optical properties of Ag and Au metal thin films. One of the main objectives of the work was to deposit very thin self assembled nanostructured films by ion beam sputter deposition (IBSD) technique at very low ion energy. The summary is categorized in two sections,(1) microstructure and structure and (2) optical response of single and bilayer metal thin films.

6.1.1. Microstructure and structure

In summary it has been shown that the IBSD technique offers very fine control over growth of the films compared to DC sputtering and thermal evaporation techniques. It is observed that IBSD offers a great degree of control over the size, shape and interparticle spacing in the nanostructures and nanostructured films. Growth is found to be discontinuous at low ion energy and the process of growth mechanism is very well explained by the theory of growth of thin films. Varieties of nanostructures such as non-regular arrays of nanoparticles, nanoneedles and nanoclusters have been realized. In the growth process, two different coalescence regimes are observed depending on the substrate roughness. Normal coalescence, defined as the regime where grain coarsening as a function of increasing deposition duration and temperature is observed on smooth BSG substrates. Abnormal coalescence defined as the regime where the cluster sizes decrease as a function of increasing deposition duration and temperature is observed on rough CCG substrates. It is observed that gold films are less discontinuous than the silver films with lower island density. At room temperature, the Ag nanoparticles are nearly spherical in shape with interparticle separation that is larger than the particle diameter. The Au particles cluster together to form the boot-shaped aggregates. The number density of these aggregates is small and the separation is smaller than their size on average. As substrate temperature increases, the size of particles, in Ag and that of aggregates in Au decreases. It appears that the number density decreases in Ag but remains constant in the case of Au. Both films show polycrystalline nature.
6.1.2. Optical response

The surface plasmon resonance (SPR) peak of single layer Ag and Au films are found to be red shift with the increase of ion energy and the duration of deposition time which causes in increase in thickness and grain size. Thus the shift here is due to the increase in the thickness of film and grain size. In the case of Ag and Au thin films deposited at different temperatures, the surface plasmon resonance peak shifts towards blue with the increase of the deposition temperature which is due to the decrease in the particle size with the increase in deposition temperature. In the case of Au films deposited at 300°C for different durations, the surface plasmon resonance peak shifts towards red with the increase of the deposition time and this is attributed to the increase in film thickness.

In the case of metal-metal bilayer for Ag/Au (Ag as top layer) and Au/Ag (Au as top layer) thin films, it is observed from AFM images that the films become denser in the case of Ag/Au and Au/Ag bilayer than the single layer of Ag and Au. Their optical response shows that the surface plasmon resonance peak shifts towards red in both the bilayer case and this shift is very well explained by a model called the plasmon hybridization model.

In the case of Ag/In bilayer thin films, microstructure showed a large grain size with the columnar growth in single layer films and in bilayer, microstructure showed aggregation and forming large grains. It is observed in single layer In films that the SPR shifts towards red with splitting with the increase of the In thickness and in the case of bilayer Ag/In thin films, initially the SPR shifts towards blue and splitting with the increase of In thickness and at higher In thickness, SPR shifts towards red vanishing the splitting. The observed behavior of SPR is also very well explained by plasmon hybridization model.

In the case of Ag/TiO$_2$, ZrO$_2$ and Au/TiO$_2$, ZrO$_2$ bilayer thin films, it is observed from the AFM image that the dielectric layer films are densely packed. Morphology of Bilayer Ag/TiO$_2$ thin films were found to be discontinuous where as Ag/ZrO$_2$ thin films was continuous and dense. The opposite is observed in the Au/dielectric bilayer case. This is due to the difference in wettability of Ag and Au to the different dielectric materials. In optical response it is observed that there is enhanced light absorption in UV region in the
bilayer films. Metal/dielectric bilayer exhibits red shift in SPR peaks with increase in refractive index of dielectric underlayer and it is found that the optical absorption in the NIR region can also be controlled by controlling the refractive index of the dielectric layer.

The current work demonstrates the feasibility of ultra-low energy ion beam sputter deposition as a technique for the deposition of discontinuous metal thin films with controllable shape, size and separation of particles leading to tunable optical response in the UV-Visible-NIR region of the electromagnetic spectrum.

6.2. Future prospects

Ion beam sputter deposition offers a very fine control over the growth of thin films as observed from the recent experiments. We have achieved nanostructured metal thin films by depositing at low ion energy. The future prospects include deposition of ordered or patterned nanostructure thin films by controlling various parameters of IBSD system.

Random nanostructure is characterized by a wide distribution in sizes and shapes of metallic clusters and they exhibit a broad plasmon resonance that can cover from visible to infrared spectra. Local field enhancement for this kind of structure exists over this entire spectrum and the magnitude of this enhancement is difficult to predict. Therefore, the near field optical properties and to map the local field enhancement of these nanostructures by scanning nearfield optical microscope (SNOM) would be very interesting.

Another area could be to use these materials in the study of non linear optical properties because Ag and Au embedded in different dielectric shows interesting non linear optical properties. It is known that surface plasmon resonance is very sensitive to its shape, size and the environment in surroundings and iodization of ultra thin metal films causes a controlled depletion of electron density leading to a gradual disappearance of plasmons. This could be interesting to study the optical properties by iodizing these metal films.

Another area that is of extreme importance in nanophotonics is the area of sensors and waveguides. Such applications can also be explored in the future.