Localized surface plasmon resonance phenomenon of Ag-Au alloy nanoparticles in metal oxide media

Ye. Mukhametkarimov[1]*, A. Koshanova[1], G. Ismailova[1], R. Nemkayeva[2], N. Guseinov[2]
[1]al-Farabi Kazakh National University, al-Farabi, 71, 050040 Almaty, Kazakhstan
[2]National Nanotechnology Laboratory, al-Farabi, 71, 050040 Almaty, Kazakhstan
*e-mail address: yerzhan.mukhametkarimov@kaznu.edu.kz

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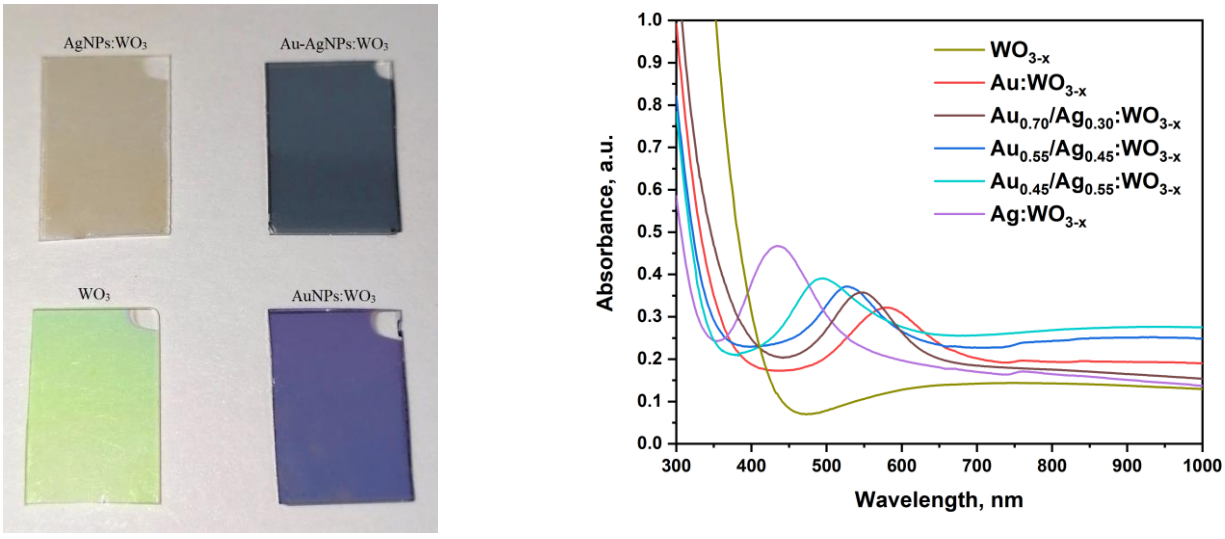
Noble metal nanoparticles continue to attract considerable attention from researchers due to their unique plasmonic properties. A prominent plasmonic feature of these nanoparticles is localized surface plasmon resonance (LSPR), which is observed as the resonant absorption of incident light in the visible range resulting from the strong interaction between light and the collective oscillations of electrons in the metal [1,2]. The frequency of resonance absorption depends on the size, shape, and composition of the nanoparticles, as well as their surrounding environment. These variations pave the way for the development of plasmonic sensors, filters, and other functional layers [3,4].

In this paper we have investigated a plasmonic composite thin film composed of metal oxide matrices (TiO_2, WO_3 and ZnO) and bimetallic Ag-Au alloy nanoparticles [5]. The films were prepared by ion plasma magnetron sputtering of the composite targets. Post-deposition annealing led to crystallization of the metal oxide matrices and reorganization of the noble metal nanoparticles.

As shown in Figure 1a the obtained plasmonic composite thin films exhibited plasmonic coloration due to a narrow absorption band in the visible spectra. Depending on the metal composition, the absorption maximum could be fine-tuned in the range of 420-580 nm as shown in the absorption spectra of Ag-AuNPs:WO_{3-x} thin films.



a) b)

Figure 1 – Photography of annealed thin films with plasmonic coloration (a) and absorption spectra of WO_{3-x} thin films with pure and alloy nanoparticles (b)

This observation in the optical properties can be explained and estimated using the traditional Mie scattering theory. According to this theory, the absorption intensity for Ag nanoparticles should be higher and the peak half-width lower compared to that of nanoparticles of Au/Ag alloy and pure gold Au [6-8]. In general, theoretical assessment qualitatively correlates with experimental results. Nevertheless, some discrepancies in the position of absorption maxima were observed for Ag nanoparticles embedded in a tungsten oxide matrix. We believe that this discrepancy arise from the non-uniform interface between the metal and the oxide, requiring consideration of additional effects to accurately describe such systems. On the other hand, the Raman spectra of the studied composite films show dependence on the excitation laser photon energy. Specifically, it was found that the Raman peak corresponding to defects appears only when the system is excited by a laser with the energy that does not exceed the energy of interband transitions of metal nanoparticles. The presence of the defect peak also indicates that energy transfer processes may occur at the metal oxide/nanoparticle interfaces.

References

1. Quinten M. Optical Properties of Nanoparticle Systems // Weinheim: Wiley, 2011. – 488 p.
2. Bohren C.F., Huffman D.R. Absorption and Scattering of Light by Small Particles // Weinheim: Wiley, 1998. – 529 p.
3. Khurana K., Jaggi N. Localized Surface Plasmonic Properties of Au and Ag Nanoparticles for Sensors: a Review // Plasmonics. – 2021. – Vol. 16, № 4. P. 981–999.
4. Pilot et al. A Review on Surface-Enhanced Raman Scattering // Biosensors (Basel). – 2019. – Vol. 9, № 2. P. 57.
5. Prikhodko O., Dosseke U., Nemkayeva R., Rofman O., Guseinov N., Mukhametkarimov Y., Localized surface plasmon resonance phenomenon in Ag/Au-WO_{3-x} nanocomposite thin films // Thin Solid Films. – 2022. – Vol.757. - 139387.
6. Rioux D., Vallières S., Besner S., Muñoz P., Mazur E., Meunier M. An analytic model for the dielectric function of Au, Ag, and their Alloys // Adv. Opt. Mater. –2014. –Vol. 2. – P. 176–182.
7. Peña–Rodríguez O., Caro M., Rivera A., Olivares J., Perlado J.M., Caro A. Optical properties of Au–Ag alloys: An ellipsometric study // Opt. Mater. Express. -2014. -Vol. 4. -P. 403.
8. Pal U., Caro M., Rivera A., Olivares J., Perlado J.M., Caro A.Synthesis and optical properties of Au–Ag alloy nanoclusters with controlled composition // J. Nanomater. –2008. –Vol. 2008(1).