Characterization of layers of metal nanoparticles

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Abstract

Colloid solutions with reverse micelles represent an efficient technology to prepare metal nanoparticles (NPs) which exhibit stable size and small size distribution. Both types of NPs interact with light due to surface plasmon resonance which could be used in quick characterization of NPs. Size of nanoparticles can be purposely changed by adjusting parameters of colloid chemistry. Preparation of stable colloid solutions with electrically charged nanoparticles having small distribution of shape and size is a prerequisite for successful deposition of nanoparticles on the semiconductor surface by using electrophoretic deposition. After deposition NPs make layer on surface. Properties of the layer highly depend on type of metal and coverage of surface.

Preparation of gold and palladium NPs

Metal NPs were prepared in reverse micelle in isooctane. Surfactant sodium bis-(2-ethylhexyl) sulfosuccinate (AOT) was used to stabilize water droplets. Two solutions of micelles, which were prepared from water solutions of metal chloride and reducing agent hydrazine, were prepared and then mixed in order to prepare metal NPs. Molar ratio between water and AOT was 8 for gold and 6 for palladium. Concentration of AOT in isooctane was 0,1M and concentration of metal chloride in water was 0,05M. Concentration of hydrazine in water varies size of NPs. It was need to stabilize gold NPs else they precipitate. So surfactant $C_{12}E_4$ was added to solution of AOT in isooctane [1]. Concentration of $C_{12}E_4$ in isooctane was 0,05M.

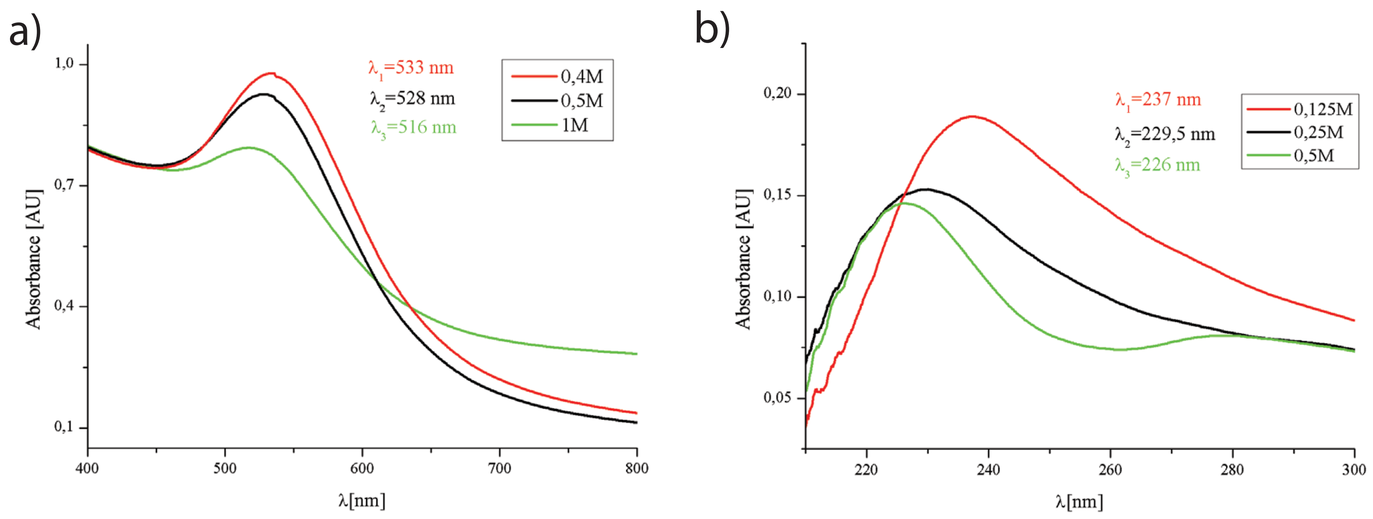
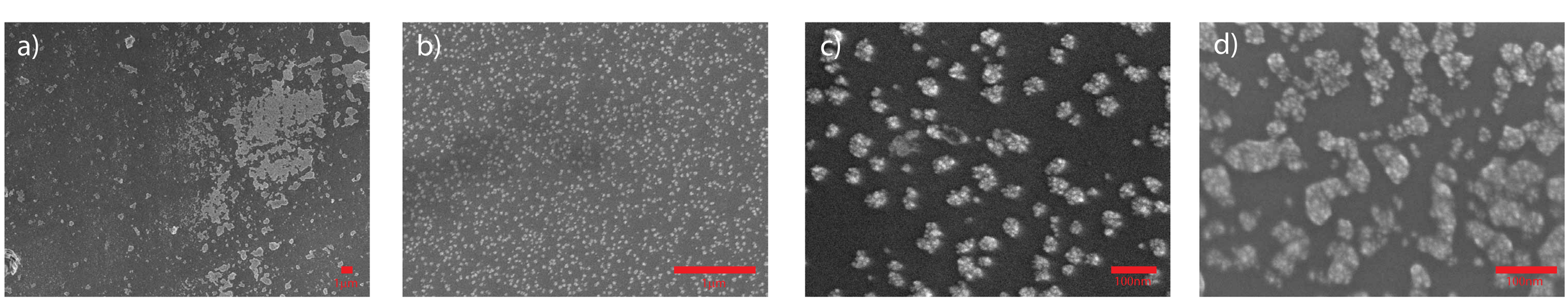


Fig. 1: Plasmon absorption peak occurs in absorption spectrum for metal NPs. Plasmon peak of gold NPs (a) is in visible spectra with maximum between 500 and 550 nm so solution change color to purple which is characteristic mark of successful preparation. Plasmon peak of palladium NPs (b) is mainly in UV spectra with maximum between 200 and 250 nm so solution change color slightly to brown. Shift of position of plasmon absorption peak is due to vary in concentration of hydrazine which change size of NPs.

Electrophoretic deposition

Metal NPs were deposited on InP substrates by electrophoretic deposition with dc voltage. A substrate from polished InP was provided with ohmic contact on back side. After deposition of NPs it is possible to make Schottky diode with small contact on front size of substrate [2]. Metal nanoparticles prepared by 0,125M solution of hydrazine were spherical shape of 10 nm diameter in case of gold and 6 nm in case of palladium with 10 % dispersion, as determined by scanning.electron microscopy.

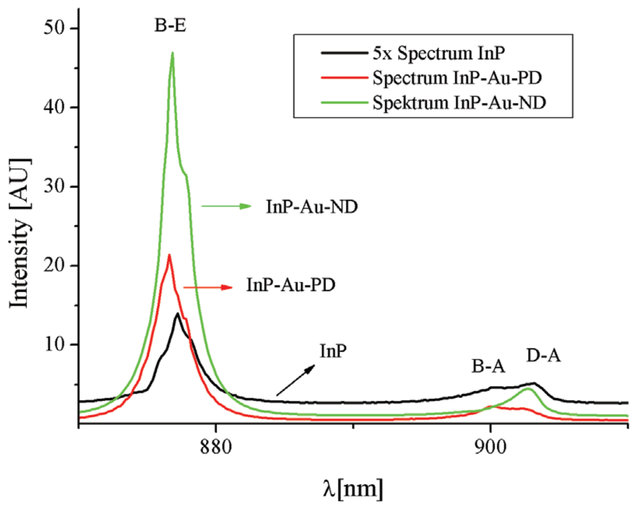
Fig. 2: Properties of layer depend on applied voltage during deposition. For gold NPs if substrate is on anode (PD) then big but non-regular coverage is prepared (a). If substrate is on cathode (ND) then homogenous layer is prepared (b). These layers are made from small aggregates of several NPs. Layers deposited by ND have similar structure for gold (c) and palladium (d) NPs.



Photoluminiscence (PL)

Substrates for measuring PL spectra were partly masked during the deposition. The mask was removed after the deposition so effect of the deposited layer on the PL could be compared to PL of InP. PL spectra were measured at 4 K with excitation by Ar laser at 514,5 nm. Enhancement from layer of palladium NPs was very low compared to layer of gold NPs.

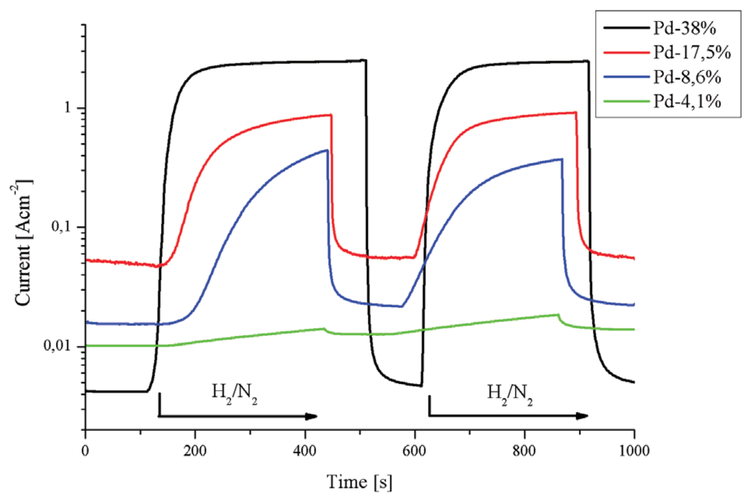
Fig. 3: On a figure there are spectra from unmasked substrate and from substrates with ND and PD deposited gold NPs. Each spectrum consists peaks at 875 nm (B-E) due to exciton transition, at 900 nm due to transitions between conduction band and acceptors (B-A) and at 903 nm due to transitions between donors and acceptors (D-A) [3]. Spectra from InP was multiply by 5. Enhancement at 875 nm was for ND substrate approx. 20 times and for PD substrate approx. 10 times.



Sensitivity to hydrogen

The prepared Schottky diodes with layer of palladium NPs were sensitive to hydrogen. It was measured under reverse bias with constant voltage 0,1 V.

Fig. 4: On figure is current density as a function of time after alternative opening and closing the flow of H2/N2 gas (100 ppm) and air for different coverage of substrate. For coverage 38% the 50% response and recovery times are 65 s and 1 s, respectively. For decreasing coverage of substrate is increasing the response time.



Conclusion

Layers of Au and Pd are homogenous if cathode is on substrate during the deposition. Prepared substrates with different metal have different reaction on PL and presence of hydrogen. Gold NPs, thanks to position of plasmon peak near excitation wavelength, enhance PL of InP substrate due to strongly coupled excitons and plasmons. The layers prepared from palladium NPs are sensitive on hydrogen. Palladium can dissociate hydrogen and this enable change of Schottky barrier and thus change in current.

Acknowledgements

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References

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