Hydrogen Sensors Based on Electrophoretically Deposited Pd Nanoparticles onto InP

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Metal nanoparticles (MNPs) form a bridge between bulk materials and atomic or molecular structures. Bulk metals show constant size independent physical properties while the properties of MNPs are driven by their size, shape, and inter-particle distance. Surface properties are crucial because the number of surface atoms becomes significant as the MNP reaches the nanoscale limit [1]. III-V semiconductors have established their position in electronic devices thanks to their unique properties. As compared to silicon, they offer higher operating speeds, lower power consumption, or higher light emission efficiency. However, to fully exploit their properties, there is one key point remaining to be solved. III-V semiconductor structures suffer from a high density of surface/interface states causing so called Fermi level pinning [2]. The Fermi level pinning leads to low Schottky barrier heights (SBH) on n-type III-Vs, which are metal independent when prepared by standard evaporation techniques [3]. In this paper we report on the preparation of Schottky barriers on InP substrates with increased SBHs by the electrophoretic deposition of palladium NPs. We also demonstrate their application in hydrogen sensors.

Pd nanoparticles with the diameters of 7 and 10 nm were prepared in isooctane colloid solution by the reverse micelle technique [4]. The electrophoretic deposition from the colloid solution took place in a cell with two parallel electrodes. The upper electrode was made from a high-purity graphite, the lower electrode was formed by an InP substrate of n-type conductivity with the background concentration of about 6×10^{15} cm^{-3}. Pulsed DC voltage with a duty cycle of 50 % was applied for a selected period of time to deposit a Pd nanolayer.

We discuss the influence of (i) the final substrate surface treatment, (ii) the properties of the deposited colloid solution, (iii) the elecrophoretic deposition conditions (time, electrode polarity, applied voltage), and (iv) the post-deposition treatment of the layers (chemical treatment in peroxide and annealing at elevated temperatures) on the morphology of the deposited layers, their electrical properties, and their sensitivity towards hydrogen.

Layers of nanoparticles were observed in JEOL JSM 7500F scanning electron microscope and by AFM. Selected layers were contacted by the spots of a conductive silver or graphite colloid paint. These structures were further characterized by the measurement of current-voltage characteristics and their detection towards hydrogen was tested in a cell with a through-flow gas system.

The coverage of the surface strongly depends on the applied voltage. The higher the voltage, the better the coverage and the smaller the size of deposited clusters. Figure 1 shows the morphology of the layers deposited at 100 V for 1 hour and 18 hours respectively. The high values of SBH reaching 0.9 eV – in comparison with thermally evaporated Pd reaching 0.45 eV only – indicate a very low degree of Fermi level pinning. This is further proved by the hydrogen detection measurement. The best results reached for a mixture of hydrogen (20 %) and nitrogen gases show an increase of current by six orders of magnitude (see Figure 2). The hydrogen molecules are absorbed and dissociated at Pd surface, atomic hydrogen rapidly diffuses to the Pd/InP interface, where the dipole layer develops. Subsequently, the Schottky barrier height decreases and the electric current increases.

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References

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Figures

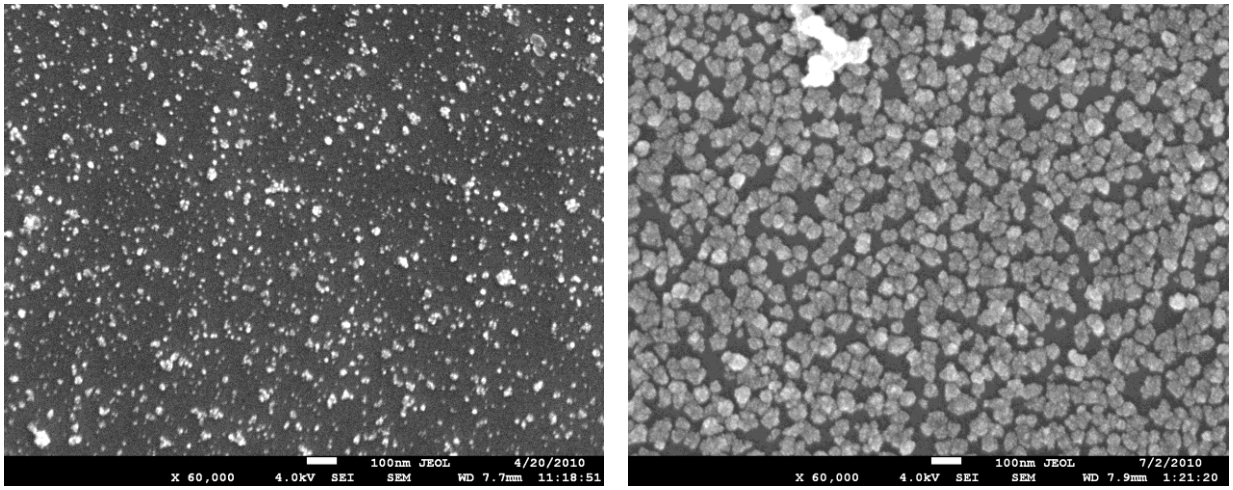

Figure 1: SEM images of Pd NPs deposited onto the InP substrate with the applied voltage of 100 V with different deposition times: 1 hour (left panel) and 18 hours (right panel).

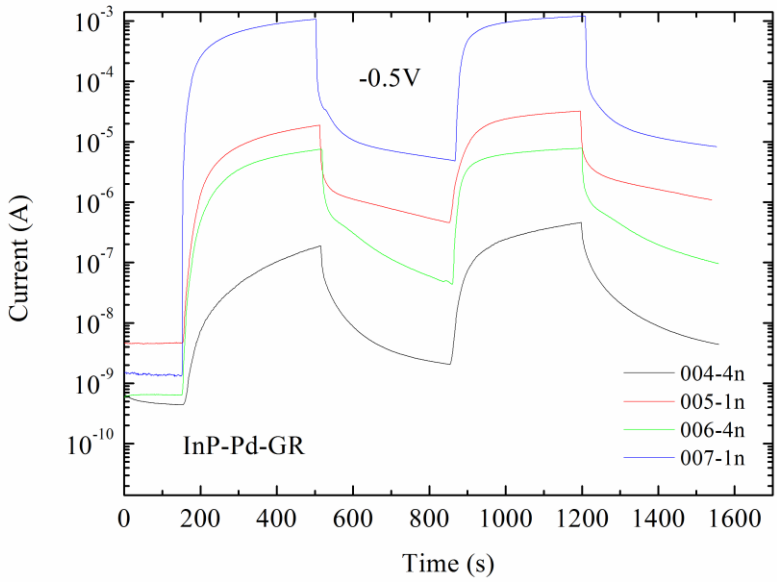

Figure 2: Current-transient characteristics of Pd-InP Schottky diodes exposed to hydrogen/nitrogen gas mixture. Samples 004 to 007 were deposited at a different applied voltage ranging from 30 V to 100 V.