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Hydrogen Sensing with Metal Nanoparticles Electrophoretically Deposited onto Epitaxial Layers of III-V Semiconductors

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III-V semiconductor materials have established their position in electronic and photonic devices thanks to their unique properties. As compared to silicon, they posses higher operating speeds, lower power consumption, or higher light emission efficiency. Metal-semiconductor interfaces formed by thermal evaporation on n-type InP are known to show low Schottky barrier heights (SBH) [1]. Attempts to increase the SBH by depositing metals with a large work function fail because of the strong Fermi level pinning (FLP) [2]. High-energy deposition processes cause large disorder at the interface and thus a high level of FLP [3]. Substantial improvements can be reached by low energy deposition techniques [4].

There are two basic reasons for the investigation of Schottky barriers on epitaxial layers. First, semiconductor wafers undergo, as a final step, a polishing of the surface. Such a treatment produces damage to the semiconductor lattice many layers below the surface. As a consequence, substrate position dependent intrinsic surface states within the bandgap can be created resulting in Fermi level pinning. Second, by alloying, compositions of epitaxial layers can be easily varied and thus their physical properties can be tuned towards the required application.

A number of hydrogen sensors reported to date are based on the selective absorption of hydrogen by catalytic metals (Pd, Pt), which results in the reversible formation of metal hydrides. Several properties of these metals, including their work function, conductivity, lattice constant, and optical properties are modulated by the hydrogen absorption. A large group of sensors is based on Schottky barriers to semiconductor materials. The hydrogen detection sensitivity and the Schottky barrier quality can be improved by reducing the metal grain size.

We describe the role of the EPD conditions (time, polarity, applied voltage regime) on the quality of graphite/MNPs/InGaAsP Schottky barriers and their hydrogen sensing properties. We show that the Schottky barrier height (SBH) can be greatly increased as compared to conventionally evaporated metals and that Schottky-based hydrogen sensor elements with excellent sensitivity response can be fabricated.

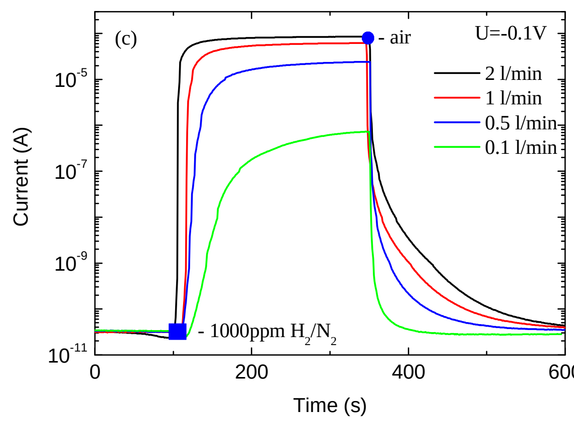
Pt and Pd NPs dispersed in isooctane solution were prepared by the reverse micelle technique. The presence of Pt NPs was evaluated by the measurement of optical absorption. Schottky contacts were created by printing colloidal graphite at room temperature. A drop of commercial colloidal graphite suspension was deposited with a teflon rod and let dry. The contact area was checked by optical microscopy to maintain the diameter close to 1 mm. Layers of MNPs and colloidal graphite contacts were observed by scanning electron microscopy and by atomic force microscopy. The Schottky structures were characterized by capacitance-voltage (C-V) measurements and by the current-voltage (I-V) measurements and their detection towards hydrogen was tested in a cell with a through-flow gas system (Fig. 1). A summary of electrical characteristics of InP and GaAs Schottky sensors is given in Table 1. The measured data clearly show that much better parameters of Schottky diodes as well as hydrogen sensing elements were achieved on InP as compared with GaAs and InGaAs (data not presented).

Table 1: Summary of electrical characteristics of InP and GaAs Schottky diodes. R is the rectification ratio, SBH is the Schottky barrier height, n is the ideality factor, and S is the sensing response.

	sample	R	SBH (eV)	n	S
(a)	InP_Pd(TE)	2.7E2*	0.52***	1.16**	1.2
(b)	InP_Pd(EPD)	3.3E8**	0.95	1.06	9.3E5
(c)	InP_Pt(EPD)	1.2E8**	1.00	1.15	4.3E6
(d)	GaAs_Pt(TE)	1.6E6*	0.88	1.03	4
(e)	GaAs_Pd(EPD)	1.4E7**	0.98	1.32	25

*at 0.4V, **at 1.5V, ***estimation

Figure 1: Current-transient characteristics of the graphite-Pt/InP Schottky diode measured with a different hydrogen flow rate.



Electrophoretic deposition of Pt and Pd nanoparticles from colloidal solutions followed by the deposition of graphite contacts allowed to fabricate high quality Schottky barriers with low leakage currents and ideality factors close to one. These Schottky diodes were shown to be capable of detecting hydrogen/nitrogen blends with low hydrogen content.

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