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Cascade of impedance instabilities of the structure Pd-surface-oxidized-InP

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Multiple instability was found on the volt-ampere characteristic of the palladium-surface-oxidized indium phosphide structure. The effect is recorded when recording the dependence of differential conductivity and differential capacitance on the applied external voltage. A mechanism for the appearance of instabilities is proposed..

Keywords: palladium, VAC, instability, impedancometry.

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„Palladium on indium phosphide" structures have the potential to be applied as hydrogen detectors. The characteristics of various designs of such devices have been studied extensively (see, e.g., [1–3]). The schematic diagram of the cross section of structures examined in the present study is shown in Fig. 1.

The characteristics of AC conductivity of these structures were examined. Such studies are known as impedance spectroscopy [4]. The instruments used in our experiments (Solartron 1260 and Solartron 1287) output measurement data in the form of real component Z' of the complex impedance and the impedance component shifted by 90° (Z''). These quantities are related to the conductivity and capacitance by the following well-known formulae:

$$Z' = 1/\sigma, \qquad Z'' = 1/\omega C. \tag{1}$$

In what follows, we present the results in terms of Z' and Z'' (i.e., the quantities output directly by the measurement equipment). Experiments were performed at room temperature.

Figure 2 presents an example of multiple instabilities observed in these experiments.

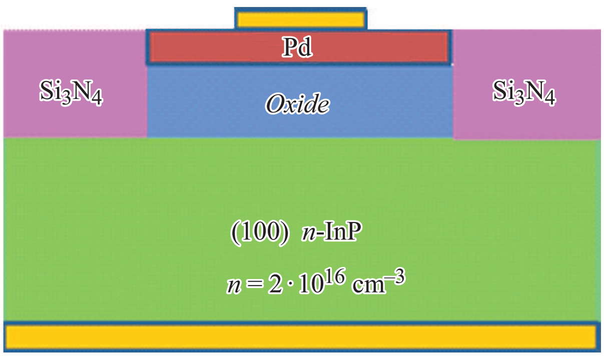

Figure 1. Cross section of the studied Pd–surface-oxidized InP structures. Ohmic contacts (Au) are not indicated in the figure.

It should be noted that the indicated features were observed almost for all the studied samples, but their parameters and the parameters of volt–ampere characteristics (VACs) differed from one sample to the other and could differ somewhat even in consecutive DC voltage scans performed for one and the same sample. The latter observation is in line with the drift of VAC curves recorded in multiple passes (Fig. 3).

Instabilities manifest themselves as abrupt impedance jumps (and are observed for individual impedance components as well). A single jump has the form of a sharp differential resistance reduction coupled with a simultaneous increase in differential capacitance (Fig. 2). As the (negative) voltage at the palladium electrode increases further following a jump, Z' grows continuously, while Z'' decreases until the next jump occurs. The period of observed oscillations of the applied DC voltage magnitude in Fig. 2 remains approximately the same at about 0.25 V.

It should be noted that the indicated features manifest themselves within a specific voltage interval. It can be seen from Fig. 2 that the first jump occurs at approximately -1.2 V as the voltage increases, and the dependence returns to its continuous form at approximately -0.55 V in a reverse scan. Owing to the risk of an irreversible breakdown of structures, experiments at voltages higher than the ones presented in Figs. 2 and 3 were not performed. It bears repeating that the indicated values correspond to specific samples. The results of experiments for other samples were similar.

It is not possible to interpret thoroughly the observed instability cascade at this stage, not least of all due to the lack of understanding of the structure of the studied object. The case is also complicated by the fact that the observed phenomenon incorporates several effects of various nature. One needs to find an explanation, first, for the first abrupt jump (the transition from a continuous dependence to the region of instabilities) and, second, the existence of several consecutive manifestations of instabilities. In our view,

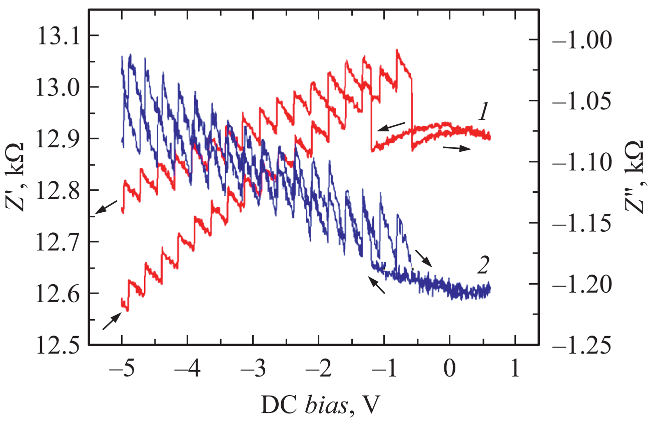

Figure 2. Curves for Z' (*1*) and Z'' (*2*). Measurements were performed at a frequency of 100 kHz. The sign of voltage plotted on the abscissa axis corresponds to the sign of voltage at the palladium electrode.

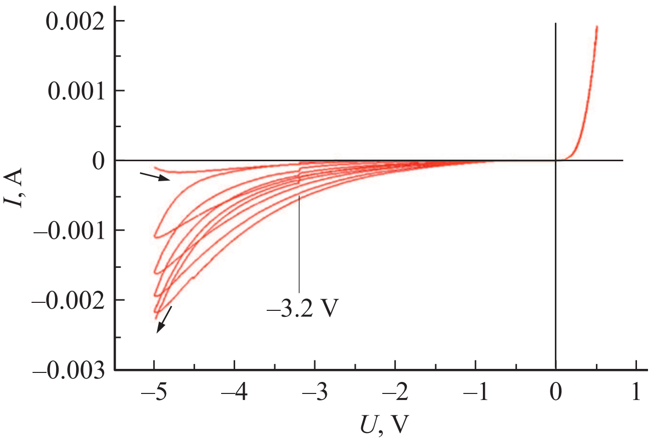

Figure 3. Set of volt–ampere characteristics of a Pd–surface-oxidized InP sample. Repeated scanning. An instability cascade is not visible; it is revealed only in AC measurements.

the latter effect is the more intriguing one. A significant VAC drift is also observed. It should be immediately noted that, in our view, impedance jumps are likely to be a manifestation of electric breakdown of a certain kind; however, this breakdown is apparently not an impediment to a further increase in voltage.

A formal explanation for this voltage behavior may be found if one assumes that the sample is similar in structure to a circuit of two series capacitors, and one of them undergoes reversible breakdown when the voltage exceeds a certain threshold. One of these capacitors then discharges as a result of breakdown, and its charge its transferred to the second capacitor. The charge accumulated at this second capacitor is retained and even increases slightly due to the influx of additional charge. In accordance with the laws of electrostatics, a further increase in external voltage is redistributed between two capacitors in inverse proportion to their capacitances. Therefore, the voltage across the first „weak" capacitor starts increasing from zero and may again reach the breakdown level. Contrary to expectations, the overall voltage across such a sample consisting of two capacitors does not drop to zero at breakdown.

The available data do not provide a clear indication of what is specifically inducing the two capacitances. The possibility of existence of intermediate phases at the Pd–InP interface was noted in earlier studies into the nature of Pd–InP contacts [5,6]. The needed capacitances may form at the boundaries of the oxide layer or at the interfaces of intermediate phases.

The nature of breakdown also remains unclear at present. A nonlinear element providing a positive current feedback is needed for a sharp breakdown. A common thermal breakdown is likely not relevant to the present case. This process does indeed result in a conductivity increase and a sharp current rise, but is almost certain to be irreversible.

It is known that current filamentation or other similar phenomena may act as nonlinear effects. Such effects were observed in high-power semiconductor devices (see, e.g., [7]), but appear to be unlikely in the present case, since currents through the structure are too weak, and current oscillations at the observed instabilities are even weaker.

In addition to the above-mentioned thermal breakdown, tunnel breakdown of the barrier at the palladium/insulator interface may yield positive feedback and ensure repeatability of the process (if the difference between the energy of a tunneling electron and the conduction-band bottom of the semiconductor exceeds the semiconductor band gap). An electron relaxing to the band bottom may then produce an electron–hole pair (Auger process). Electrons affected by the applied external field should contribute to the current and move to the positive electrode. Being considerably heavier than electrons, holes cannot tunnel efficiently through the barrier and are accumulated at the semiconductor/oxide layer interface. Since holes are positively charged, they enhance the effect of the external field, thus contributing to positive feedback and facilitating the „weak" capacitor breakdown.

Apparently, the VAC drift in Fig. 3 is not related directly to the instability cascade effect. At the very least, this drift does not appear to be the cause of the observed cascade. The drift itself may have several causes. One potential cause is the formation of charged centers in the insulating layer. The decomposition of water vapor at the voltage-carrying palladium electrode and the penetration of hydrogen into palladium is another possibility [8]. The determination of a specific VAC drift mechanism is beyond the scope of the present study. However, it should be noted that the possible relation between these two effects is a potential cause of a certain non-reproducibility of parameters of the instability cascade.

As a side note, a similarly named phenomenon („cascade of instabilities") has been observed and examined relatively recently in experiments with objects of a different nature: turbulent liquid flows [9]. We know of no papers focused on such phenomena in solid bodies.

Thus, the observation of a novel phenomenon (instability cascade in the palladium–surface-oxidized indium phosphide structure) was reported. A model providing an explanation for the possible existence of a sequence of features of impedance characteristics in a layered structure was proposed.

Conflict of interest

The authors declare that they have no conflict of interest.

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