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Current–voltage and low-frequency noise characteristics of structures with porous silicon layers exposed to different gases

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Abstract

Current–voltage and noise characteristics of porous silicon (PS)/single crystalline silicon (SCS) samples were measured under exposure to dry air, air +0.4% CO, dry air +1.7% CO, and dry air + ethyl alcohol vapor. The samples have a sandwich structure comprising Al/PS/SCS/Al. For the dry air +CO mixtures, the noise level was sensitive not only to the presence of CO but also to its percentage, and an increase of the CO concentration led to a change in the spectral density function of the low-frequency noise.

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Keywords: Porous silicon; Gas sensor; Carbon monoxide; Ethyl alcohol; Noise

1. Introduction

Semiconductor sensors presently find important applications for the detection and characterization of a variety of gaseous media. Porous silicon (PS) is an interesting material in this context. It serves as a basis for many types of nano-dimensional heterostructures [1]. The applications lie mainly in optoelectronics and photonics, which follow from the very interesting and promising optical and luminescent properties of PS [1–7]. Studies of its physical properties [8–11] have shown that PS is very sensitive to exposure to gases, which is connected to the fine-grained nature of the Si nano-crystallites and the ensuing large surface area. An increase in the selectivity of sensors is possible, as follows from analyses of results of measurements of low-frequency noise whose value is determined mainly by the state of the surface in the case of nano-dimensional semiconductor films (see, for example, Ref. [8]). Such investigations [12–15] can lead to new ways to improve the performance of gas sensors.

The purpose of our present investigations is to show the influence of adsorption processes occurring on the PS surface on current–voltage characteristics (CVCs) and on low-frequency noise.

2. Sample preparation and measurement setup

The investigated samples comprise PS as well as single-crystalline silicon (SCS) and have a sandwich configuration according to Al/PS/SCS/Al. The PS layers were formed by electrochemical etching of heavily doped p^+-type (1 0 0)-oriented silicon wafers with a resistivity of 0.01 Ω cm. The samples were ~2 μm thick and had a porosity of ~50%. They were manufactured at the University of Trento. The back side of the wafer was coated with a 20–30 nm thick Al film. The top Al layer was deposited through a metal mask to form $1.4 \times 1.4\,mm^2$ area contacts to the PS surface.

Noise measurements were carried out by a direct filtration method. The low-frequency noise measurement

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setup (Fig. 1) comprised a specially designed bias supply employing an ultra-low-noise operational amplifier (REF102 and OPA37 from Texas Instruments and Burr Brown) [16], a gas chamber wherein the samples were located, an ultra-low-noise/high-resistance access port and wide-band preamplifier based on an operational amplifier (OP27 from Precision Monolithic Inc., USA), a Fast Fourier Transform (FFT) analyzer (the adapter to the computer HANDYSCOPE (2) from TiePie Engineering), and a computer. The frequency range of the measuring setup was 1 Hz to 10 kHz. Details of the input electric circuit and preamplifier were given in Ref. [17]. The input circuit and preamplifier had a self-contained power supply based on accumulators. The setup was encapsulated in a permalloy screen, as indicated by the dotted lines on the block diagram in Fig. 1. Dynamic CVCs were recorded on a Z TR-4805 characteristic tracer (from EMG, Hungary) by use of a digital camera. As mentioned above, a hermetic chamber was used for determining the influence of gaseous media; it provided adequate shielding of the samples against extraneous influences as well as a controllable interaction between the analyzed gas and the sample. To remove adsorbed residuals of a previous gas before a new measurement, the gas chamber was purged with clean air. Room temperature measurements were performed in the current generator mode.

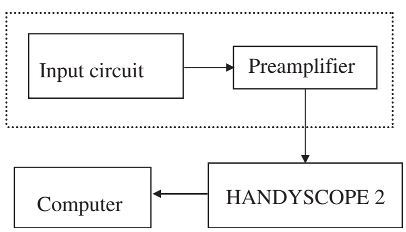

Fig. 1. Low-frequency noise measurement setup.

3. Experimental results

Fig. 2 shows CVCs of samples placed in dry air (a), dry air + ethyl alcohol vapor (b), and dry air + 1.7% CO (c). Voltage noise spectral density, $S_U(f)$, where U is applied

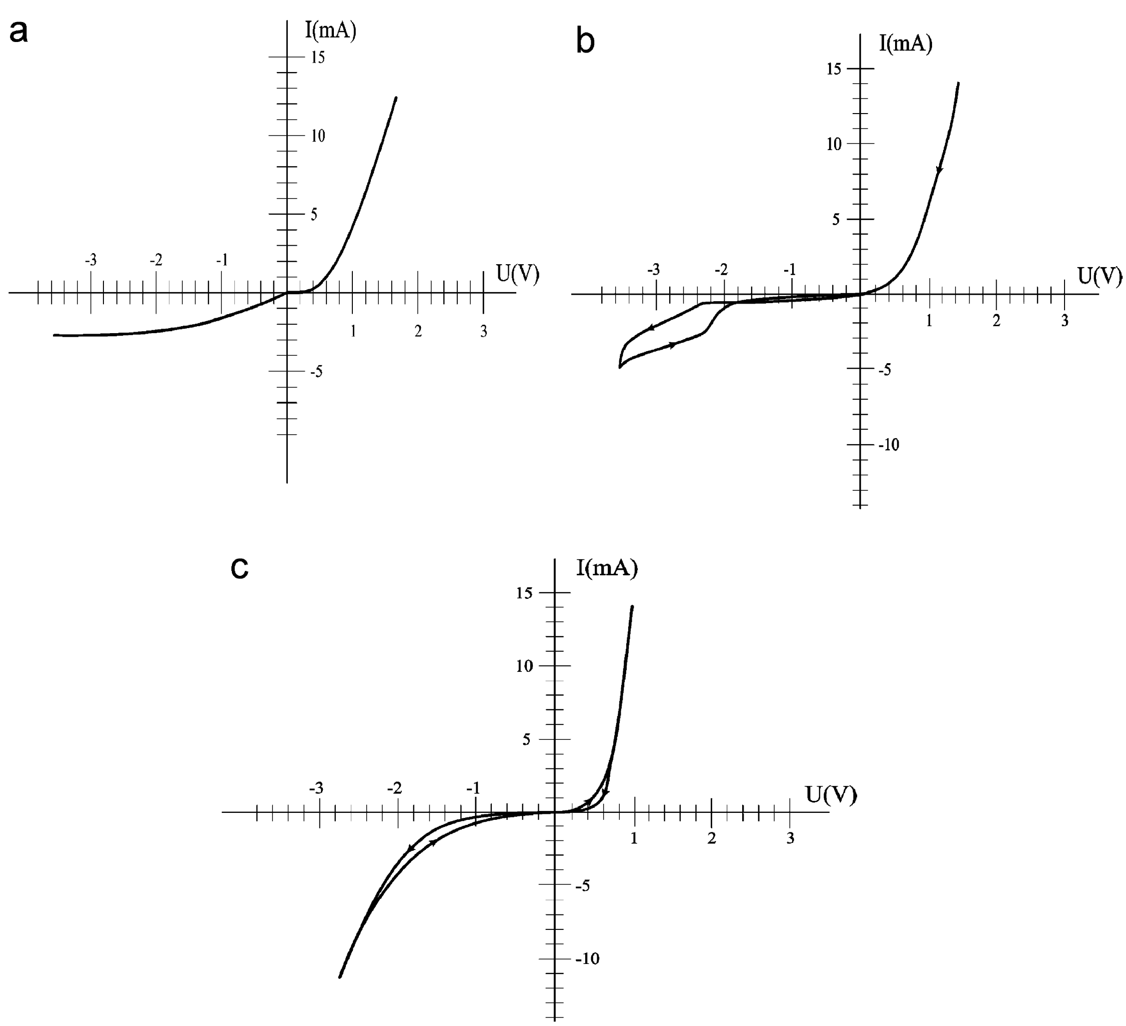

Fig. 2. Current (I)–voltage (U) characteristics of samples with PS layers, as specified in the main text. Samples were placed in air (a), air + ethyl alcohol vapor (b), and air + 0.4% CO (c).