A COMPARATIVE STUDY OF THE TRANSIENT LATERAL PHOTOVOLTAIC EFFECT IN THE HYBRID T/SiO_2/Si (T = Fe, Fe_3O_4, TiO_2) STRUCTURES

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Motivation

Lateral photovoltage in hybrid structures based on SiO_2/Si is generated due to the difference of the charge concentration arising as a result of nonuniformly irradiation and of subsequent asymmetric diffusion of the charge, the magnitude of the lateral photovoltage varying linearly with a change of the light spot position [1-3], that may be used, for example, in position-sensitive detectors (PSD) [3]. The operating characteristics of the PSD are the sensitivity of the lateral photoelectric effect (LPE) and LPE nonlinearity [2], as well as the rise time and fall time of the photovoltage signal at pulsed illumination [3].

Goal In our opinion, one of the directions in the LPE problem is the investigation of the transient characteristics of the photocurrent in hybrid structures with different conductivity of the top layer. This work presents a study of the transition LPE in hybrid structures T/SiO_2/Si (T = Fe, Fe_3O_4, TiO_2), in which Fe is a metal, Fe_3O_4 is a semimetal, and TiO_2 is a semiinsulator.

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Experiment

The samples were prepared on n- and p-type single-crystal Si(001) substrates. An ultrathin SiO_2 layer ~1.5 nm thick was formed on the Si substrate surface in nitric acid (68% HNO_3) at 121°C for 10 min at the final stage of wet cleaning. Fe and Fe_3O_4 films were formed by equipment Katun on an oxidized Si(001) surface by deposition of iron at a rate of 2.5 nm/min in a vacuum and oxygen atmosphere with P_{O_2}= 10^{-6} Torr, respectively [4,5]. TiO_2 films were formed by the sol-gel method [6] ex-situ on the oxidized silicon surface. The film thickness was measured by the spectral ellipsometry and the atomic force microscopy.

The LPE was done using He-Ne laser (0.3 mW, 633 nm) and Keithley 2000 multimeter. The TiO_2 surface was partially illuminated by He-Ne laser spot with a diameter of about 60 μm. The LPV measurements have been carried out using the aluminum evaporated electrodes. The electrode distance was 2 mm.

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Results and Discussion

For a comparative study, hybrid structures with the optimal thickness of the top layer were selected. The observed experimental values of the lateral photovoltage correspond to those calculated according to

$$LPV = K_1\left[e^{\beta|\varphi_t|} - 1\right]\left(|x_1| - |x_2|\right)$$

with the substitution of the built-in potential φ_i(Fe)=0.39 eV, φ_i(Fe_3O_4)=0.58 eV, φ_i(TiO_2)=0.62 eV obtained from the energy band diagrams constructed by us for the structures under study, taking into account the energy parameters of the system elements and the surface states at the SiO_2/Si interface. The lateral photovoltage polarity is determined by the substrate conductivity type, the choice of which is determined by the presence of a strong band-bending at the SiO_2/Si interface.

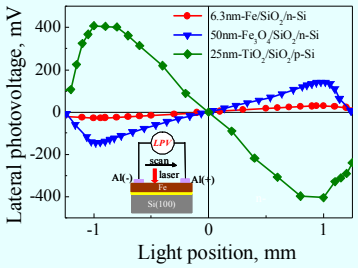
The time profiles of the photovoltage for the Fe/SiO_2/n-Si, Fe_3O_4/SiO_2/n-Si and TiO_2/SiO_2/p-Si structures reveal an increase of the top layer resistivity leads to both an increase of the photovoltage signal amplitude and a change of this signal shape. The latter is due to the design of the RC-filter at the near-contact region. Three versions of the equivalent circuit for three types of the top layer conductivity are suggested:

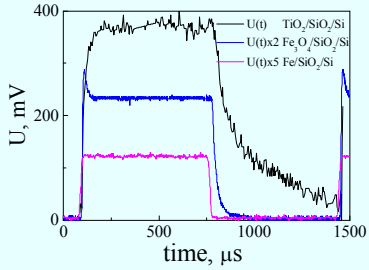
i For the Fe/SiO_2/n-Si structure, the transient characteristics is determined only by the RC-filter, which consists of the distributed characteristics of the silicon near-surface layer (C_{dep}, C_{ss}, R_{ss}) and the silicon oxide layer (C_{ox}), as well as parallel resistance (R_{tun}).

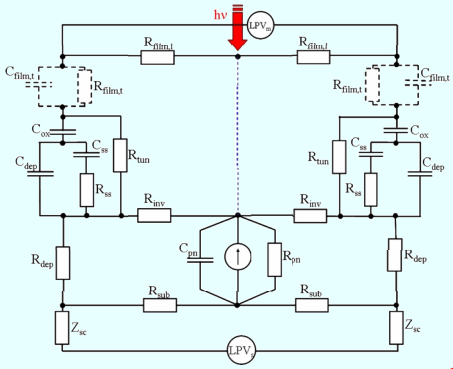
ii For the Fe_3O_4/SiO_2/n-Si structure, the active resistance of the film in the transverse direction ($R_{film,t}$) is successively added to the above mentioned RC-filter of the SiO_2/Si interface.

iii In the case of a TiO_2/SiO_2/p-Si heterostructure, an complementary RC-filter of the film ($(RC)_{film,t}$) is added to the RC-filter of the SiO_2/Si interface, which takes into account the impedance characteristics of the TiO_2 film.

Thus, the generality of studying the transition LPE in structures with different conductivity of the top layer can be achieved using the equivalent circuits of the hybrid structure.







Summary

It was found the slowing down of the photoresponse process in the Fe_3O_4/SiO_2/n-Si and TiO_2/SiO_2/p-Si structures is associated with a change of the RC characteristics of the electrical contact. From the point of view of transient LPE, the most promising candidates for LPE-based PSDs should be considered hybrid Fe_3O_4/SiO_2/n-Si structure with a semimetallic top layer, which have the high LPE sensitivity and the relatively fast photoresponse.