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SEMICONDUCTOR STRUCTURES, INTERFACES, AND SURFACES

Investigation of a Change in the Chemical Composition of the Surface of $Cd_xHg_{1-x}Te$ Samples as a Result of Treatment by N_2O and H_2 Gases Activated in a High-Frequency Discharge

V. V. Vasil’ev, T. I. Zakhar’yash, V. G. Kesler*, I. O. Parm, and A. P. Solov’ev
Institute of Semiconductor Physics, Siberian Division, Russian Academy of Sciences,
pr. Akademika Lavrent’eva 13, Novosibirsk, 630090 Russia
** e-mail: kesler@isp.nsc.ru*

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Abstract—A change in the chemical composition of the $Cd_xHg_{1-x}Te$ surface as a result of its treatment by atomic beams of oxygen and hydrogen was investigated. The beams were obtained by the electron impact in a high-frequency plasma of N_2O and H_2 gases. The consecutive action of beams of atomic oxygen and hydrogen was shown to result in the removal of carbon-containing compounds, a layer of native oxide, and tellurium in its elemental state from the surface of samples. © *2001 MAIK “Nauka/Interperiodica”.*

A large number of methods are used nowadays for passivating the surface of compounds based on cadmium, mercury, and tellurium (CMT), with the subsequent formation of insulating protective films. Of wide usage are the methods of vacuum deposition of zinc-sulfide layers, the molecular-beam epitaxy (MBE) and MOC-hydrate epitaxy of cadmium telluride, and the pyrolytic and plasma-chemical deposition of silicon-dioxide and silicon-nitride layers [1–3].

An actual surface of II–VI semiconductors is always covered by a layer of the native oxide 1–3 nm thick, formed as a result of the interaction of a substrate with oxidizing components of an etchant and atmospheric oxygen. The chemical composition of this oxide depends substantially on the method of chemical treatment of the semiconductor and the relationship between components of the etchant and the solutions used for rinsing the surface. In the process of the synthesis of an insulator, the chemical composition of the native oxide can also undergo considerable chemical transformations, which ultimately exerts an adverse effect on the parameters of photoelectronic devices.

The idea of obtaining structures on the II–VI semiconductors with an oxygenfree interface, i.e., with a complete removal of the native oxide, and the subsequent synthesis of the insulating layer, has been actively discussed [4]. Treatment of a semiconductor by atomic hydrogen obtained by the method of thermal decomposition of H_2 at a heated tungsten filament was suggested [4]. According to [4], under these conditions (a substrate temperature is T = 80°C), the following reducing reactions can proceed:

$$CdTeO_3 + 6H \longrightarrow CdTe + 3H_2O\uparrow,$$

$$TeO_2 + 4H \longrightarrow Te + 2H_2O\uparrow,$$

$$Te + 2H \longrightarrow TeH_2\uparrow,$$

$$HgTe + 2H \longrightarrow Hg\uparrow + TeH_2\uparrow.$$

In this case, mercury in the elemental state is thermally desorbed from the surface of a semiconductor. According to the model suggested, the removal of oxide and elemental phases from a CMT surface is theoretically attainable. At the same time, cleaning the substrate surface of carbon-containing contaminations (residues of organic solvents after rinsing, etc.) is impossible by atomic hydrogen from the standpoint of the chemical thermodynamics [5]. The carbon-containing particles are removed from the surface by activated oxygen [for example, by means of a high-frequency (HF) discharge]. As a gas reactant in such processes, nitrogen oxide with a low dissociation energy of its molecules (E = 1.7 eV) can be used. In our opinion, the combination of treatments of a surface by atomic beams of oxygen (carbon-containing contaminations are removed) and hydrogen (the native-oxide layer is reduced and elemental phases are removed) is promising for the technology of improving the insulator–CMT interface.

In our study, we investigated the influence of atomic beams of hydrogen and oxygen on a CMT surface. The beams were obtained by electron impact in the high-frequency (f = 13.56 MHz) plasma. The usage of a two-chamber reactor in our technological setup with a special separation of the substrate and the HF-discharge zones precluded the impact of ions and electrons of the plasma upon the surface of CMT samples [6]. This

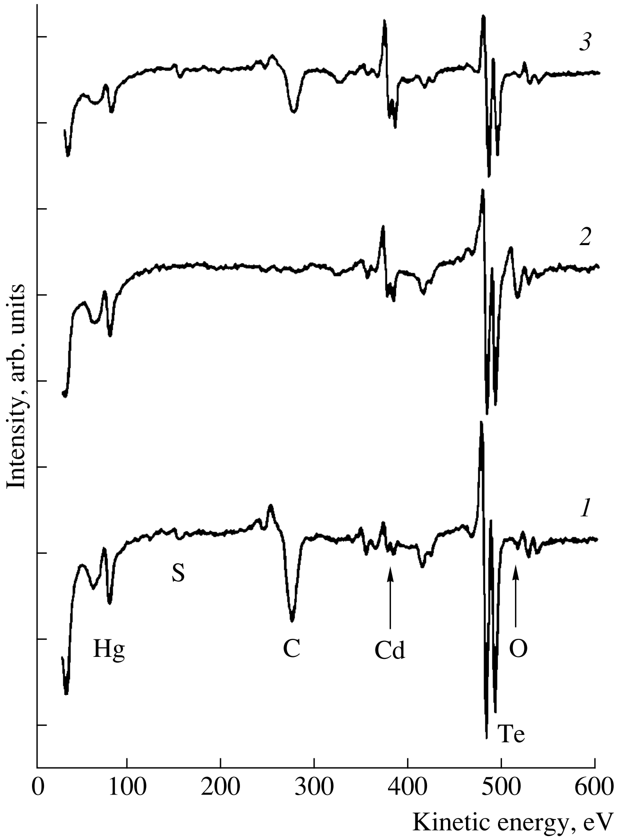

Fig. 1. The Auger spectra of the surface of a $Cd_{0.22}Hg_{0.78}Te$ sample: (*1*) initial surface; (*2*) surface after the treatment by a beam of atomic oxygen, and (*3*) surface after the treatment by a beam of atomic hydrogen.

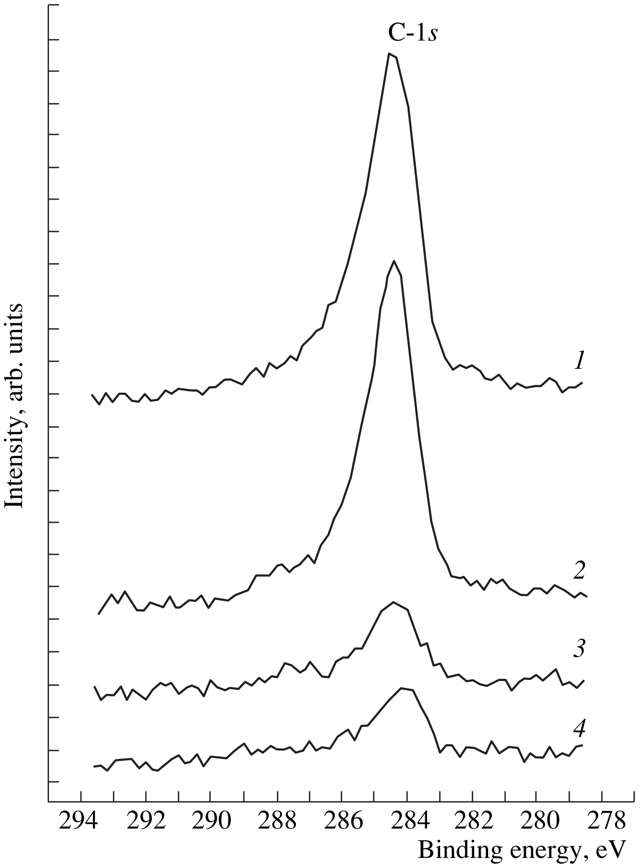

Fig. 2. X-ray photoelectron spectra C-1*s* of the surface of a $Cd_{0.22}Hg_{0.78}Te$ sample: (*1*) initial surface, (*2*) surface after the treatment by a beam of atomic hydrogen (sample 3), (*3*) surface after the treatment by a beam of atomic oxygen (sample 2), and (*4*) surface after the combined treatment.

setup also made it possible to deposit an insulating layer immediately after atomic-beam treatment, without removing the sample from the reactor.

Preliminary electrical investigations of the MIS structures manufactured on the basis of CMT show that electrical parameters depend strongly on the conditions existing during treatment of the semiconductor surface (the nature of a gas reactant, a substrate temperature, the duration of exposure to activated gas, etc.). With the purpose of clarifying the causes of significant modification of MIS-structure parameters, we investigated the chemical composition of the surface of substrates.

The analysis was carried out by Auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS). These methods are exclusively sensitive to the upper monolayers of the sample and are mutually complementary; their combination makes it possible to determine both the elemental composition of the surface under investigation and the chemical state of atoms. The AES spectra of the sample surface were obtained using an OPC-2 Riber analyzer with a relative energy resolution $\Delta E/E = 0.2\%$. For obtaining the spectrum of secondary electrons, they were excited by an electron beam with an energy of 3 keV. The electron-beam diameter amounted to 5 μm, and the beam current was 100 nA. The XPS spectra were obtained using a MAC-2 Riber analyzer of the two-stage cylindrical-mirror type. For exciting the X-ray radiation, we used a Mg-anode source with a Mg-line energy of 1253.6 eV. The X-ray-beam diameter amounted to 5 mm, the source power was 300 W, and the energy resolution of the analyzer amounted to 0.5 eV and was constant within the entire energy range measured.

The objects of investigation were p-$Cd_xHg_{1-x}Te$ ($x = 0.22$) bulk samples subjected to the mechanochemical polishing (a damaged layer was removed up to a depth of 100 μm), the dynamic chemical polishing in a brom–ethanol etchant (a damaged layer of 10 μm was removed), and a rinsing in three portions of acetone and in deionized water. The treatment in gases activated by a high-frequency discharge was performed at a substrate temperature equal to 80°C. In this paper, we display the results of investigating a chemical composition for four CMT samples:

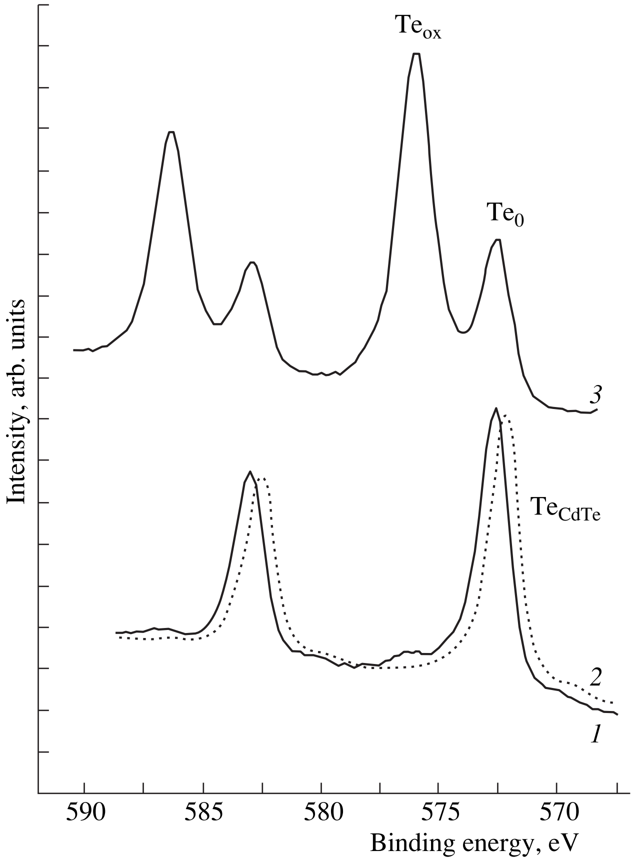

Fig. 3. X-ray photoelectron Te-3*d* spectra from the surface of a $Cd_{0.22}Hg_{0.78}Te$ sample: (*1*) initial surface, (*2*) surface after the treatment by a beam of atomic hydrogen (sample 3), and (*3*) surface after the treatment by a beam of atomic oxygen (sample 2).

sample 1 is the initial sample after the chemical preparation and rinsing;

sample 2 is the sample treated in nitrogen oxide activated by the HF discharge (t = 30 s);

sample 3 is the sample treated in hydrogen activated by the HF discharge (t = 30 s); and

sample 4 is the sample subjected consecutively to the same treatments as samples 2 and 3 for 60 s.

For investigating the chemical composition of the surface, all the samples were transported from the reactor to the setup through atmospheric air with an identical exposure to air for each sample. On the initial surfaces of the samples 1–4, the peaks of elements Te, Cd, Hg, O, and C were observed. No other elements were detected within several atomic percent. The carbon concentration on the surface of samples 2 and 4 is much lower than that on the surface of samples 1 and 3 (Figs. 1, 2), which substantiates the conclusions [5] that it is impossible to clean the substrate surface of carbon-containing contaminations exclusively by means of atomic hydrogen. It is necessary to emphasize that the use of combined treatment (sample 4) makes it possible to fix the effect of cleaning the surface of carbon-containing contaminations.

The energy position of the photoelectron peak of tellurium (Te-3$d_{5/2}$) (Fig. 3) observed in the XPS spectra of the samples under investigation bears important information. For example, for sample 2, we observe a pronounced splitting into two peaks, with binding energies of 576.1 and 572.8 eV corresponding to oxidized and elemental (metallic) states of tellurium [4]. Assuming that the peak with lower binding energy is the substrate signal weakened by a thin oxide film, it is possible to calculate a thickness of the oxide film, which amounts to ~1.6 nm in our case. A similar calculation for the initial sample 1 yields a value of ~0.2 nm, and tellurium under a thin oxide layer is also observed in the metallic state. On the surface of the sample 3, treated by atomic hydrogen, and sample 4, subjected to combined treatment, there is no oxide film, and tellurium resides in the CdHgTe compound with a binding energy of 572.3 eV.

Thus, the proposed combined treatment of the CMT-sample surface by atomic beams of O and H produced using the high-frequency discharge leads to an efficient removal of carbon atoms, the surface oxide film, and also of tellurium in the elemental state. The method proposed for treating the surface of CMT substrates can be efficiently used in the technology of fabrication of CMT-based structures.

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