http://dx.doi.org/10.5755/j01.eee.18.8.2610 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 18, NO. 8, 2012

The Specificity of Solid-phase Interaction of Aluminium with Silicon Carbide in the Manufacture of Diffusion-welded Contacts to Semiconductor Devices

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***Abstract*— This paper presents the characteristics of solid-phase interaction of aluminium with silicon carbide in the process of creating a diffusion welding of contacts to semiconductor devices. It is shown that the solid-phase etching of silicon carbide has an isotropic polishing effect. Proved that not involved in dissolution carbon atoms precipitate as an amorphous thin layer. Are given the differences of the diffusion welded aluminum interaction between a semiconductor silicon carbide and silicon.**

***Index Terms*—Contacts to semiconductors, diffusion welding, silicon carbide, solid-phase-interaction.**

I. INTRODUCTION

In our earlier published work [1] was considered the concept of three-stage solid-phase interaction in the case of diffusion welding (DW) of semiconductor silicon and aluminium. Its essence lies in the fact that the processes of solid state bonding for such dissimilar materials like metal and semiconductor can be subdivided into 3 stages:

- Intimate closing of materials (creation of physical contact);
- Contact area activation (generation of active centres);
- Development of bulk interaction.

The last stage completes the process of forming a permanent, close-set connection between the metal and semiconductor surfaces. At the same time, the third stage is a complex process, followed by a chain of physical processes, including solid-phase diffusion, dissolution, formation of two-component or multicomponent chemical compounds, etc. These processes are due both to energy conditions and to the properties of materials going to be welded. For example, during diffusion welding of aluminium with a silicon substrate at elevated temperature, silicon atoms diffuse actively and dissolve in the surface layer of aluminium forming a solid solution. That is, is the so-called solid-phase etching of silicon by aluminium. And if after DW we remove the aluminium foil by hydrochloric acid etching, we find on the pre-polished silicon surface (111) characteristic triangular etch pits (Fig. 1).

The depth of etch pits formed in the range from 100 nm to 400 nm.

At the same time, in earlier studies on DW applied to semiconductor SiC [2] it was found that after removal of Al from SiC surface by etching in hydrochloric acid no typical marks of surface interaction could be found. The local pits of solid state etching, typical for diffusion welding of Si, have not been found on the SiC surface.

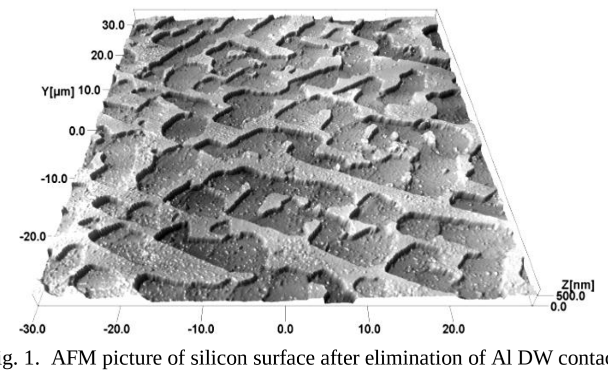


Fig. 1. AFM picture of silicon surface after elimination of Al DW contact.

It was also suggested, since the process occurs at a temperature below the melting point of aluminium (below 650 °C), carbon has extremely low solubility in solid aluminium. Even in liquid aluminium solubility of carbon is ~0.1 at %, and the solubility of carbon in solid aluminium does not exceed one-hundredth of an atomic percent [3]. The solubility of silicon in solid aluminium at a temperature close to the eutectic temperature (577 ºC) is > 1.65 at % [4]. Apparently, only the silicon atoms of silicon carbide take part in the process of solid state solving in Al leaving behind

Manuscript received February 20, 2012; accepted May 22, 2012.
The present research work was supported by the European Union through the European Regional Development Fund, Nations Support Program for the ICT in Higher Education "Tiger University", the Estonian Ministry of Education and Research (the target oriented project SF0142737s06), the Estonian Science Foundation (the research grant G8592), and the Foundation Archimedes through the Centre of Excellence CEBE (TK05U01).

unreacted carbon atoms. Such separate solving destroys the crystal surface and is equal to the process of isotropic etching, after which the surface remains smooth and polished. Besides that, it would be expected the precipitation of carbon at interface during cooling after DW.

To confirm the stated assumption, below are described the results of two indirect and direct experiments. The results of these investigations should be important in developing predictive models of interfacial structure.

II. Experiments and Results

A. Investigating of the surface topography by AFM microscopy

For the experiment was used the chip of 4H-SiC substrate, 350 µm thickness, 5x5 mm^2 area, with polished surfaces, prepared for epitaxy.

The topography of the sample was investigated in the soft tapping mode by Atomic Force Microscope (AFM) Veeco NanoScope IIIa with cantilever MikroMasch NSC15/AlBs.

First, the sample was scanned in initial state and then, the sample was scanned again after diffusion welding and subsequent etching removal of the 30 µm aluminium foil from the surface. All together there were traced about 20 scan lines. The typical pictures of the surface topography before and after DW are shown in Fig. 2.

As is evident from Fig. 2 the height irregularities in plan and profile changed after the interaction of the silicon carbide with aluminium foil during diffusion welding. The peaks regularity caused by mechanical polishing disappears and the surface becomes smoother. It is the effect that was expected to see, but the change of the surface roughness is only indirect evidence of interaction of Al and SiC. If this is true, then we should expect the precipitation of unreacted carbon at interface after DW. To detect the precipitated carbon the next step of the experiment was taken.

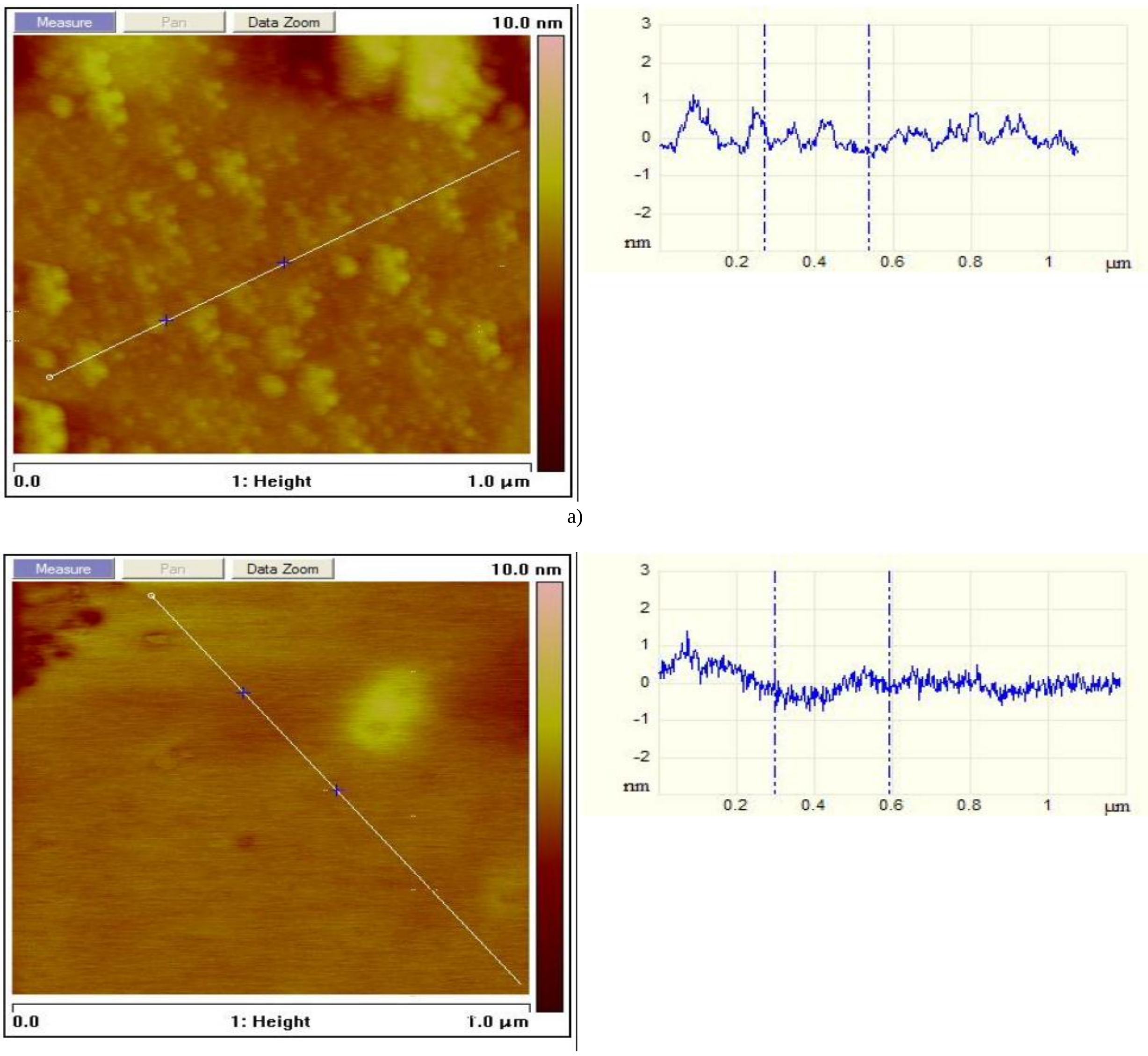
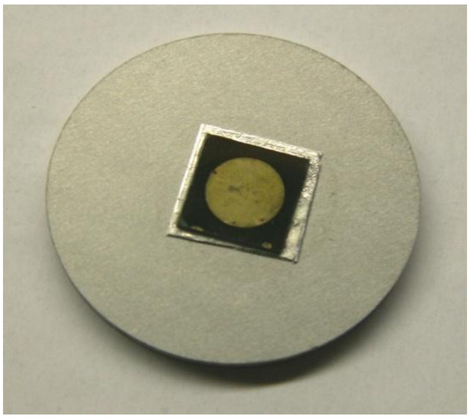


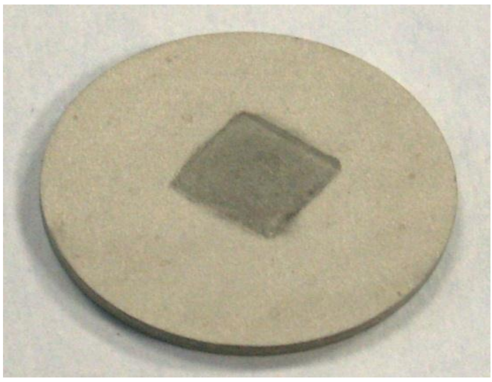
Fig. 2. AFM images and cross-sectional profiles before (a) and after diffusion welding (b).

III. THE SEM SCANNING OF THE SURFACE

For an investigation SEM model ZEISS EVO MA-15 and energy Dispersive X-ray microanalysis (EDS) analyser Oxford Instruments INCA Energy system have been used. The SiC chip of 5x5 mm2 was welded by 100 µm aluminum foil to the ground tungsten electrode. Then, after etching in hot hydrochloric acid the SiC chip was separated from the tungsten. Thus, on the surface of the tungsten under side lighting can be seen the place, where the chip was welded (Fig. 3).



a)



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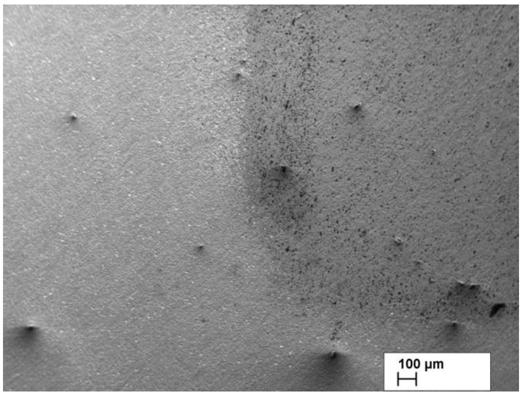

c)

Fig. 3. The view of the welded chip (a), tungsten electrode after etching (b) and tungsten electrode surface under the great magnification (c) (secondary electron image).

Spectral analysis has not revealed the presence of carbon on the surface of silicon carbide, as might be expected in view of the polished surface. Spectrum taken from ground surfaces of tungsten is shown in Fig. 3.

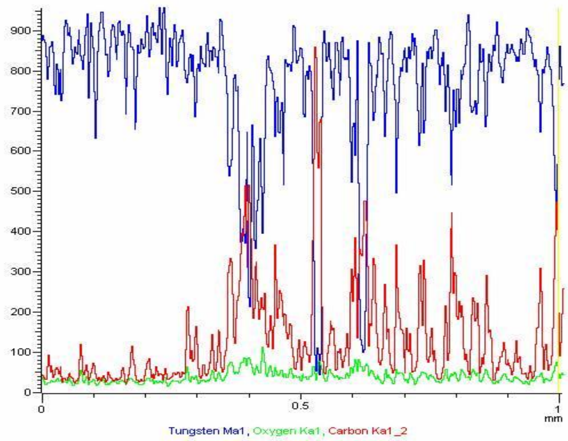

Fig. 4. The spectral distribution of elements on the surface of tungsten in welding area.

As seen from Fig. 4 presence of the precipitated carbon in welding place is not in doubt.

IV. DISCUSSION AND SUMMARY

Diffusion-welded contacts to semiconductor devices, and especially contact in Schottky diodes, are of particular importance and are the device forming element. In addition to general physical principles of the formation of DW connection should always take into account the individual nature of the interaction of the contacting materials. The results presented in this paper clearly demonstrate this. Thus, the interaction of aluminium with silicon solid-phase is accompanied by anisotropic solid-phase etching. The result is that on a pre-polished surface are formed the etch pits of depth up to 400nm, which is, apparently, characterizes the depth of the bulk interaction. In the case of silicon carbide solid-phase etching is looks like isotropic. The surface of the semiconductor is undergoing to additional polishing effect. As a result, regular peaks and cavities left by the pre-chemical-mechanical polishing smoothed from a 1nm to 0,5 nm. However, in this case, the decrease of surface roughness to 0,5 nm cannot be considered as the depth of the interaction of aluminium with silicon carbide, as this is not an indicator of total dissolved silicon in aluminium. The amount of silicon diffused into the aluminium contact corresponds to the percent solubility of silicon in aluminium at welding temperature. During the cooling after the formation of contact the solid solution of silicon in aluminium is becoming oversaturated. The excess silicon atoms precipitate. In the case of the semiconductor silicon atoms crystallize in line with the crystallographic orientation of the maternal matrix. This is the process of solid-state epitaxy. During the diffusion welding of aluminium with silicon carbide the solid-phase epitaxy is not possible, since the original crystalline matrix is destroyed in the process of selective diffusion of silicon atoms in aluminium. The silicon atoms falling out of the solid solution are grouped on the surface of silicon carbide in the form of microcrystal lines mixed with the residual carbon atoms, forming a thin amorphous layer. It is the pattern that was fixed in the electron-microscopic study of the contact region of aluminium and silicon carbide after diffusion welding in our work [5]. However, specific structural features of the sub contact region require deeper investigation.

V. CONCLUSIONS

The results presented in this paper clearly demonstrate that the interaction of the metal with the semiconductor material during the process of diffusion welding is individual. Thus, the interaction of aluminium with silicon crystals is accompanied by anisotropic solid-phase etching, followed by solid-phase epitaxy in the cooling. In the case of silicon carbide solid-phase etching is looks like isotropic, followed by precipitation of carbon on the contacting surfaces.

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