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HBV deep mesa etching in InGaAs/InAlAs/AlAs heterostructures on InP substrate

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The chemical composition of newly developed anisotropic etching solution and several experimental results obtained with heterostructure barrier varactor (HBV) deep mesa formation are presented. The novel solution enables the deep etching of the InGaAs/InAlAs/AlAs heterostructure over InP substrate, up to 5 μm in the [100] crystal direction. It ensures etch-stop at the InP substrate and gives almost perfect surface quality, with mesa profiles meeting device design requirements. The etching solution is a mixture of two components: A (H_2SO_4:H_2O_2:H_2O = 1:1:8) and B ($C_6H_8O_7$:H_2O = 1:1), in the proportion B:(H_2O_2 content in A) =1:1.

Key words: *heterostructure; anisotropic; wet etching; mesa*

1. Introduction

In recent years, new varactor structures (Heterostructure Barrier Varactor, HBV) [1] with characteristics with even symmetry have been proposed. The importance of optoelectronic and other high-speed devices on InP bases is recognized today in modern technology. Nevertheless, there are critical technological steps in the processing of such devices that have not been optimally solved. In this publication, we present the HBV diode technology, especially the fragment related to mesa etching in InGaAs/InAlAs/AlAs heterostructures deposited with the MBE method on (100) InP substrates. The technology of HBV structure fabrication, which consists of two mesa formation steps – a big and a small one – is shown in Fig. 1.

The technological flow chart starts with the deposition of a 300 nm thick PECVD dielectric. After the first photolithography and mesa shape patterning in the dielectric layers, a 4.5 μm thick heterostructure is anisotropically etched in the newly developed

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solution. Dielectric layers, still remaining at the top of the first mesa, are used again in a second lithography step to define the second mesa shapes. Etching the second mesa is performed with a standard $H_2SO_4:H_2O_2:H_2O$ = 1:8:40 solution. It is very important that the InP substrate is not affected by this solution. The technological sequence is completed by the photolithography and lift-off technique of a metal sandwich, which forms electrical paths, contacts, and bonding pads.

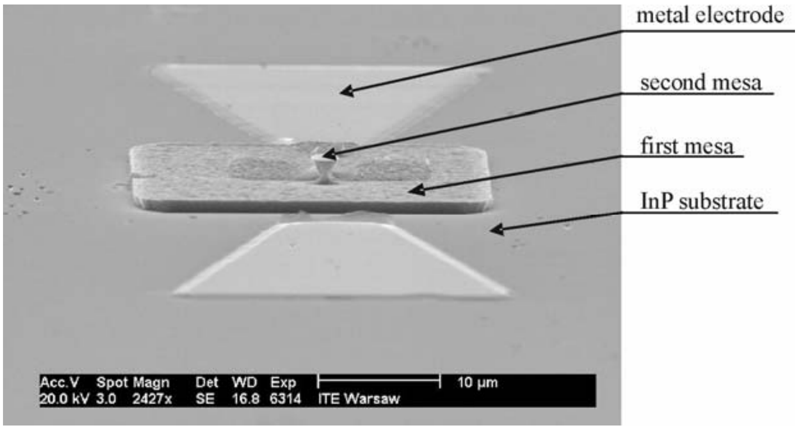

Fig. 1. Top view of the chip after the first metal level step

The main problem with the technology presented in this paper is a deep (ca. 4.5 μm) etching of the first mesa. According to the design requirements of the HBV diode, two mesa mask edges parallel to the $[01\bar{1}]$ crystal orientation should give a soft transition after the etching step which ensures the continuity of the metal paths. The other two mesa sidewalls, oriented along the $[0\bar{1}\bar{1}]$ crystal direction, should form sharp edges for the self-aligned cut-off of the metal paths. A negative angle between the crystal plane (100) of the substrate surface and the mesa sidewall crystal plane (332) is highly advantageous.

The solution presented in this work makes the deep etching of InGaAs /InAlAs/AlAs heterostructures on InP substrates possible up to 5 μm in the [100] crystal direction. It enables the etching zone to stop at the InP substrate and gives the almost perfect surface quality of the samples, with the mesa profiles meeting the design requirements of the device.

2. Experimental

Experiments were focused on the development of deep mesa etching technology (first mesa indicated in Fig. 1) in InGaAs/InAlAs/AlAs heterostructures, according to the requirements presented in Fig. 2. On the basis of published data [2, 3], three mixtures were selected. They selectively etch InGaAs and InAlAs against the InP substrate with the etching rate of several μm/min. These mixtures were prepared using sulphuric, citric, and phosphoric acids in the following proportions:

$$H_2SO_4:H_2O_2:H_2O=1:8:40,\ C_6H_8O_7:H_2O_2=2:1,\ H_3PO_4:H_2O_2:H_2O=1:1:50.$$

3. Results

SEM microphotographs of mesas etched in InGaAs/InAlAs/AlAs heterostructures over (100) InP substrates using the above mixtures are shown in Figs. 3–7.

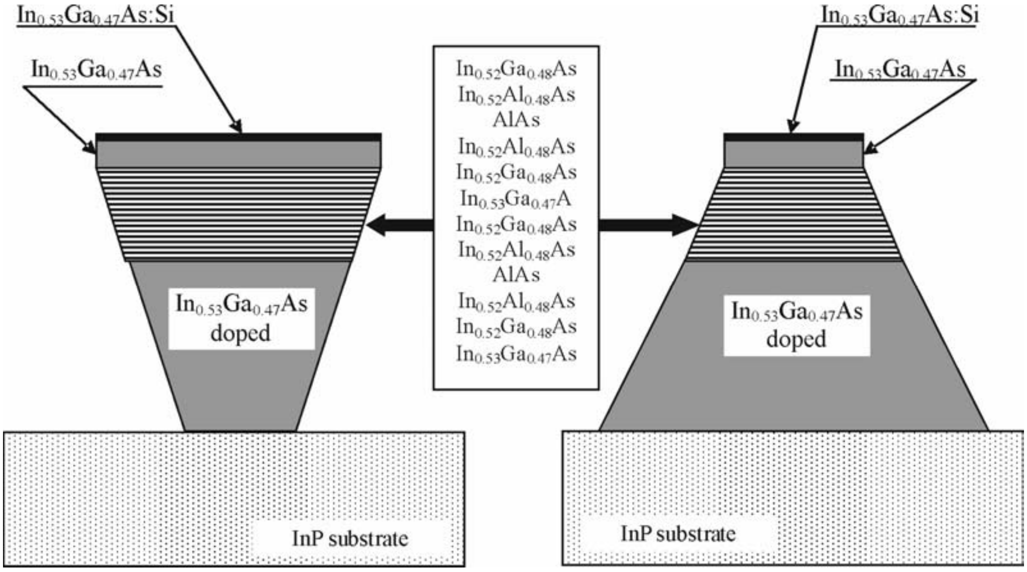

Fig. 2. Scheme of the two cross-sections of the required mesa profile (in the [01$\bar{1}$] and [0$\bar{1}\bar{1}$] crystal directions, not in scale)

Experiments performed with the etching solution $H_2SO_4:H_2O_2:H_2O$ = 1:8:40 gave the sample profiles as shown in Figs. 3, 4. Good results were obtained with shallow mesa etching only. Unfortunately, it was impossible to reach a sufficient etch depth, good (100) surface quality, and proper mesa profile. Longer etch times gave deformed dovetail profiles.

Other experiments were done applying citric acid with hydrogen peroxide mixtures. Figures 5, 6 show two sample profiles, obtained after etching with $C_6H_8O_7:H_2O_2$ = 2:1. It was expected, based on the published data, that after 480 sec the etch zone would reach the depth of at least 3 μm. The depth of only 1.05 μm was obtained. A longer etching time (1200 sec) caused forming of triple-stepped mesa profiles about 2 μm deep disqualifying this mixture.

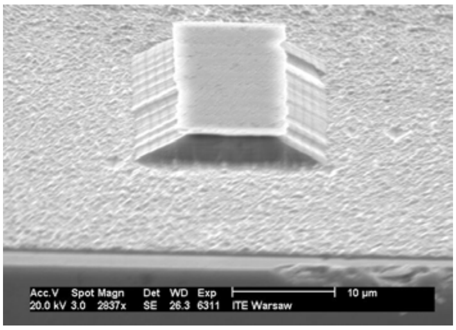

Fig. 3. Top view of the sample etched in H_2SO_4:H_2O_2:H_2O = 1:8:40, time 180 sec, etch depth 3.5 µm, poor (100) surface quality

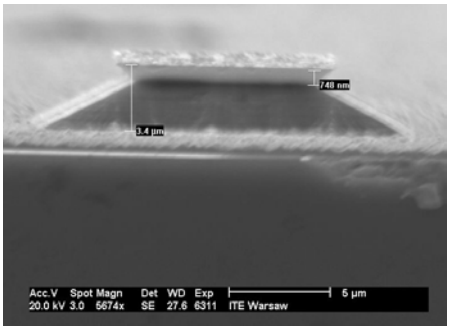

Fig. 4. Profile view of the sample etched in H_2SO_4:H_2O_2:H_2O = 1:8:40, time 240 sec, etch depth 3.4 µm, dovetail effect

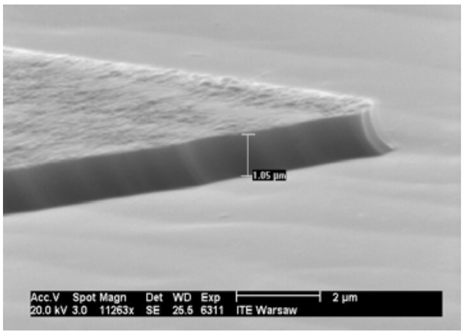

Fig. 5. Top view of the sample etched in $C_6H_8O_7$:H_2O_2 = 2:1, time 480 sec, etch depth 1.05 µm

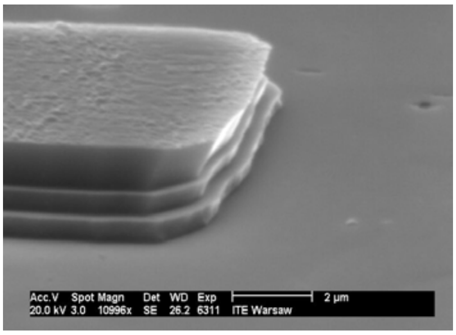

Fig. 6. Top view of the sample etched in $C_6H_8O_7$:H_2O_2 = 2:1, time 1200 sec, undesired three-step mesa profile

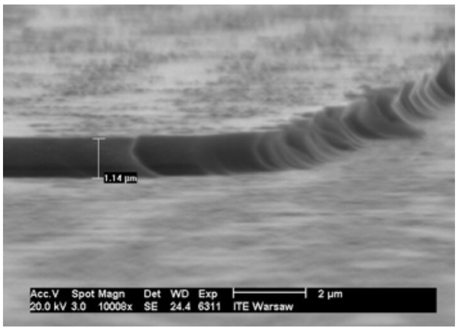

Fig. 7. H_3PO_4:H_2O_2:H_2O = 1:1:50, time 900 sec, etch depth 1.14 µm, uneven mesa edge

Phosphoric acid was also taken into consideration and tested, with the composition H_3PO_4:H_2O_2:H_2O = 1:1:50. After 900 sec, the etch depth was only 1.14 µm, and the masking edge and surface quality were not satisfactory.

The results presented suggest that heterostructures consisting of several very thin layers (individual layer thickness from 3 nm to 40 nm) of InGaAs and InAlAs are etched with significantly lower rates than the solids presented in literature. The mixture proposed in this publication, designed for HBV diode etching, consists of sulphuric and citric acid, mixed together with hydrogen peroxide and water [4]. Its chemical composition is as follows: component A = H_2SO_4:H_2O_2:H_2O = 1:1:8, component B = $C_6H_8O_7$:H_2O = 1:1, mixed in the following proportion *k* (in volume), prepared just before use, at room temperature, where:

$$k = \frac{V_B}{V_{\mathrm{H_2O_2\,in\,A}}} = 1 \tag{1}$$

This newly proposed anisotropic etching solution matches all technological requirements of the device. The samples were etched at room temperature. The chemical reaction was of the redox type. Sulphuric acid and hydrogen peroxide act as the oxidizing agents of the sample surface, forming the oxide layer. Citric acid and water

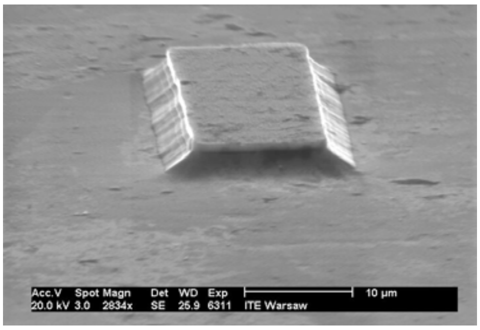

Fig. 8. Proper mesa shape, obtained with the newly developed solution. Two sidewalls (left and right) have soft slopes and the two other (upper and lower) have abrupt edges with negative angle of inclination; a residual dielectric layers still covers the mesa surface and reveals moderate lateral undercuts of the mask edges

dissolve this layer and discover semiconductor new surfaces for chemical oxidation. It is well known that even small changes in the etchant chemical composition influence the etch rate. The etch rate depends on the etchant and semiconductor chemical activity, as well as on the transport mechanism from/to the sample interface of the substrates and products. Diffusion is dependent on the stirring or agitation of the etching solution. The etchant composition proposed and optimum process parameters (temperature, agitation, liquid volume) give the required anisotropy of the mesa profile with respect to the crystal lattice orientation. Finally, good results obtained with the newly developed solution are shown in Fig. 8 and were confirmed by a number of other experiments not presented here.

4. Conclusions

An anisotropic etching solution that enables deep etching in heterostructures, with almost perfect surface quality, anisotropy effect, and etch-stop at the InP interface, was developed for the HBV (Heterostructure Barrier Varactor) mesa formation technology. An etchant composed of H_2SO_4, $C_6H_8O_7$, H_2O_2, and H_2O fulfils the device design and technological requirements, which is confirmed by several SEM microphotographs of the etched samples.

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