Materials Science-Poland, Vol. 26, No. 1, 2008

Submicron suspended structures based on A(III)B(V) epitaxial layers

M. KRAMKOWSKA*, A. SZYSZKA, B. ŚCIANA, I. ZUBEL

Faculty of Microsystem Electronics and Photonics, Wrocław University of Technology,
ul. Janiszewskiego 11/17, 50-370 Wroclaw, Poland

A technological process has been described for fabrication of suspended structures on GaAs substrate with AlGaAs/GaAs epitaxial multi-layers deposited by the AP MOVPE method. The patterns of beams and bridges with various dimensions were made by the photolithography method. The structures were fabricated by wet chemical etching in two systems of solutions based on phosphoric or citric acid with hydrogen peroxide. The former one enabled etching through the deposited epitaxial layers down to the GaAs substrate. The latter one allowed a selective etching of GaAs over AlGaAs. In effect, a beam made of AlGaAs layer was released and formed the suspended structure. As an etching mask, AZ 1813 positive photoresist was used. A series of rectangular beams with various planar dimensions and submicrometer thicknesses was fabricated. The elaborated process may be used for fabrication of suspended structures for various applications.

Key words: *GaAs; A(III)B(V) epitaxial layers; AP MOVPE; suspended beam*

1. Introduction

Properties of A(III)B(V) compounds such as high piezoresistive constant, low thermal conductivity, relatively high Seebeck coefficient, direct band gap, high electron mobility and high saturation velocity are interesting for various applications. By combining micromechanical properties with good optomechanical sensitivity, piezoelectricity and piezoresistivity, III–V micromachined devices offer new opportunities for micro-electro-mechanical-systems (MEMS) and micro-opto-electro-mechanical -systems (MOEMS) applications. Many examples of devices such as infrared thermopiles, pressure sensors, resonators, based on A(III)B(V) compounds have been reported [1–3].

Epitaxial layers of A(III)B(V) compounds grown by the MOVPE technique offer high flexibility and precision in micromachining. Wet chemical etching, commonly

*Corresponding author, e-mail: malgorzata.kramkowska@pwr.wroc.pl

used in production of 3D micro-mechanical structures formed from a substrate or a multilayer structure, employs two main features of the etching process. The former one is based on preferential etching, utilizing etch rate anisotropy and the fact that due to zinc blende crystal structure of the compounds, the etching of A(111) planes proceeds much slower than the all other ones. The latter approach uses the differences in etch rates of the layers with various chemical compositions, leading to so-called etching selectivity. The layer with a higher etch rate plays a role of sacrificial layer and is etched off whereas the second one forms a structural layer which is released during the process.

Suspended structures like beams, bridges or cantilevers play an important role in fabrication of various types of sensors and integrated optoelectronic devices based on A(III)B(V) compounds. The structures can be used as carriers for active devices or as sensing elements in various types of sensors. In the solutions, the suspended structures secure thermal isolation of active part of a circuit or form a mechanical part of various types of sensors subject to various enforcing factors. In this work, a procedure of obtaining such structures in laboratory conditions is described.

2. Experimental

Deposition of epitaxial layers. Epitaxial AlGaAs/GaAs heterostructures were grown by atmospheric pressure metal organic vapour phase epitaxy (AP MOVPE) in an AIX200 R&D horizontal reactor. The following epilayers were deposited on (100) - oriented semi-insulating (SI) GaAs substrate:

- undoped (UD) GaAs buffer (thickness 0.5 μm),
- undoped (UD) AlGaAs (thickness 1.05 μm),
- undoped (UD) GaAs "cap" (thickness 0.05 μm).

A schematic presentation of the AlGaAs/GaAs heterostructure is shown in Fig. 1.

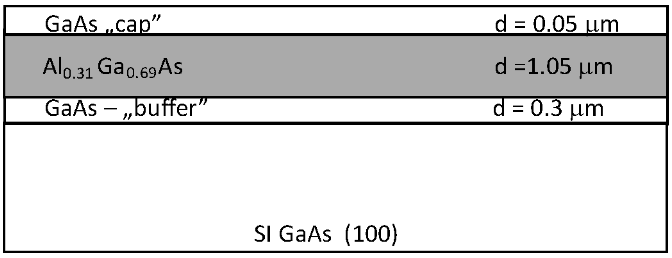

Fig. 1. Schematic presentation of AlGaAs/GaAs heterostructures

The growth process was carried out at 700 °C. Trimethylgallium (TMGa), trimethylaluminum (TMAl) and arsine (AsH_3, 10% mixture in H_2) were used as the growth precursors. High purity hydrogen was employed as a carrier gas. The aluminum content in AlGaAs epilayer was 31%. High resolution X-ray diffraction was used for estimation of the thicknesses of all epilayers and AlGaAs composition.

Etching solutions. Many etching systems for A(III)B(V) compounds have been described in the literature. Clawson [4] compiled literature reports describing etching of the compounds. The choice is, however, very difficult as many results are not reproducible between different laboratories. Actually, the etching procedures and the compositions of etching solutions should be individually elaborated for a particular purpose. In the work, etching systems based on phosphoric acid and citric acid have been tested. Solution of phosphoric acid enables non-selective etching of GaAs and AlGaAs epitaxial layers, necessary in the initial stage of suspended beams fabrication. The solutions based on citric acid maintain etch rate selectivity of GaAs layer over AlGaAs. However, the selectivity depends on the ratio of citric acid and hydrogen peroxide. Therefore, a series of experiments was carried out at room temperature in a wide range of solution compositions. For the preparation of etching solutions, 50% water solution of citric acid and 30% solution of hydrogen peroxide were used. The etching depth was measured by the interferometric method on the boundaries between etched and non-etched areas. At the ratio of $C_6H_8O_7:H_2O_2$ exceeding 2, the etch rate selectivity decreased dramatically; at the ratios below 2, the morphology of etched surfaces underwent deterioration. The compositions of selected solutions with corresponding etch rates and selectivities are presented in Table 1.

Table 1. Set of etching solutions and basic parameters of the etching process

Composition of etching solution	*V* [nm/min]		Selectivity
	GaAs	AlGaAs	
$C_6H_8O_7:H_2O_2$ 2:1	472	18.9	25
$H_3PO_4:H_2O_2:H_2O$ 8:1:1	800	800	none
$H_3PO_4:H_2O_2:H_2O$ 1:1:40	80	80	none

Design and fabrication of a suspended beam. The idea of fabrication of suspended beam structure is shown in Fig. 2. At the first stage of the fabrication process, holes in the GaAs/AlGaAs epitaxial layers are etched with phosphoric acid solution to expose GaAs substrate. At the second stage, citric acid based solution is used to release the AlGaAs structure. Since the second solution is selective with respect to AlGaAs, the vertical and lateral etching of underlying GaAs results in releasing of AlGaAs suspended beam structure.

As an etching mask, a positive photoresist AZ 1813 was used. The structures of beams, crosses and bridges with different widths and lengths were patterned by the photolithography method. A section of the mask pattern is shown in Fig. 3. The beam width was designed in three basic dimensions: 7, 16 and 24 μm.

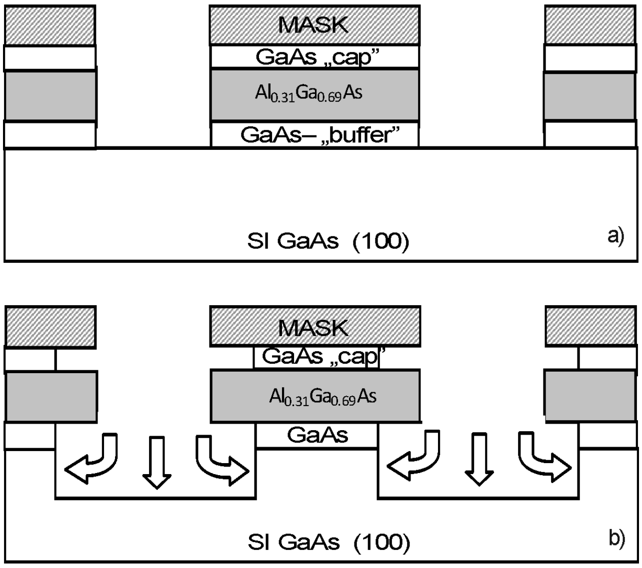

Fig. 2. Schematic presentation of two stages of fabrication of a suspended beam:
a) photolithography and nonselective etching of the heterostructure,
b) selective etching of GaAs substrate and releasing of AlGaAs layer

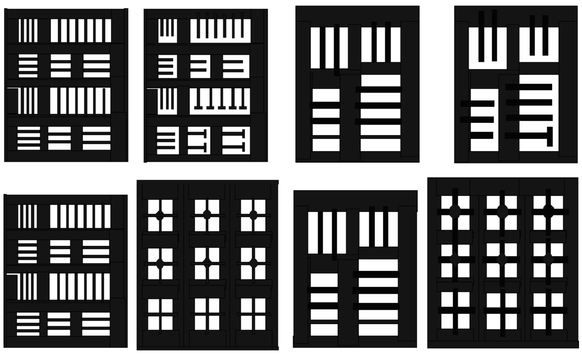

Fig. 3. A module of etching mask pattern with the structures for fabrication of suspended bridges, beams and masses

3. Results and discussion

SEM images of etched structures after the first stage of etching are shown in Fig. 4. The etching was carried out in phosphoric acid solutions (Table 1). No significant differences in the etching results obtained in "fast" and "slow" etching solutions were observed. In both cases SI GaAs surface was exposed. Depending on the composition of the etching solution, the duration of etching process was 15 or 1.5 min, respectively.

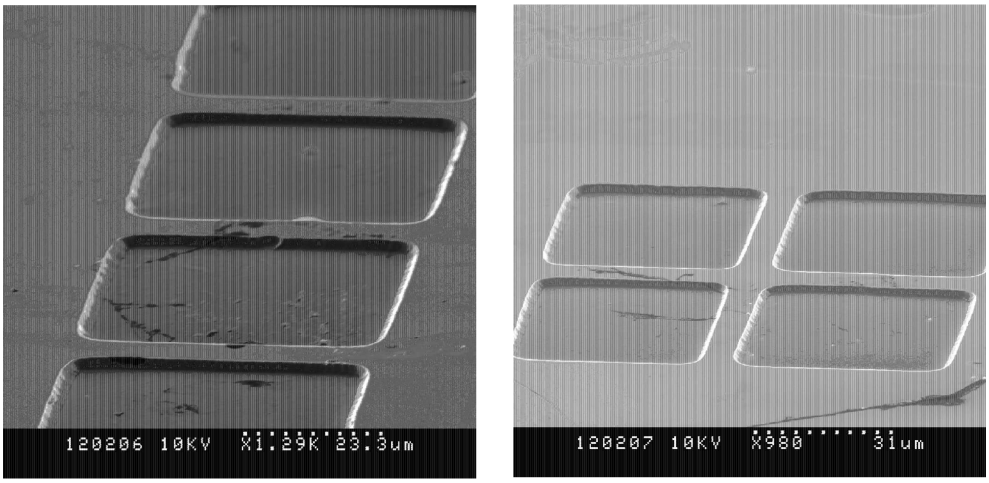

Fig. 4. SEM images of etched structures after the first stage
of fabrication process (etching in phosphoric acid)

In the second stage, the structures were etched in citric acid solution assuring etching selectivity of AlGaAs over GaAs. SEM images of released beam structures with the width of 7 μm are shown in Fig. 5. The AlGaAs layer provided almost perfect etch stop to the etching solution, withstooding a prolonged etching process even after collapsing of the photoresist mask.

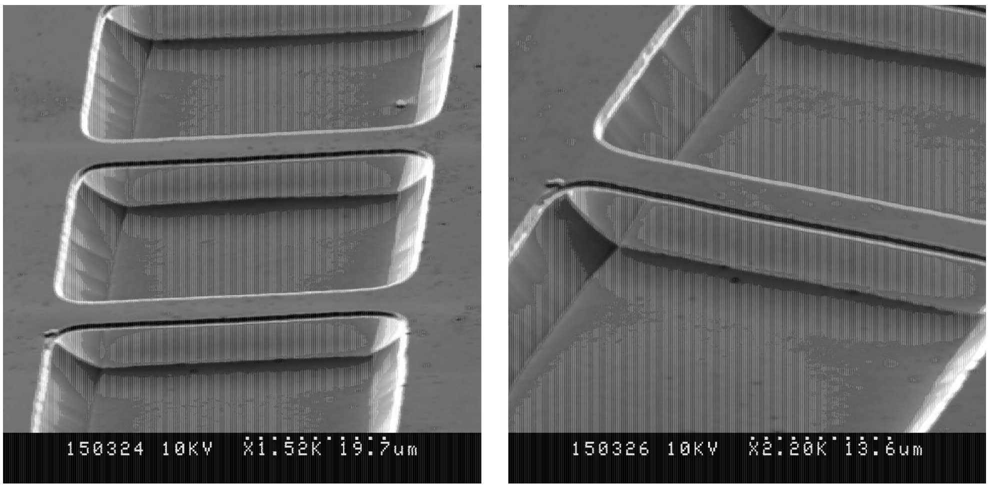

Fig. 5. SEM images of released AlGaAs structures

The release of beams was possible only in one crystallographic direction. The structures containing crossed beams were linked with the substrate even after a prolonged etching time (Fig. 6).

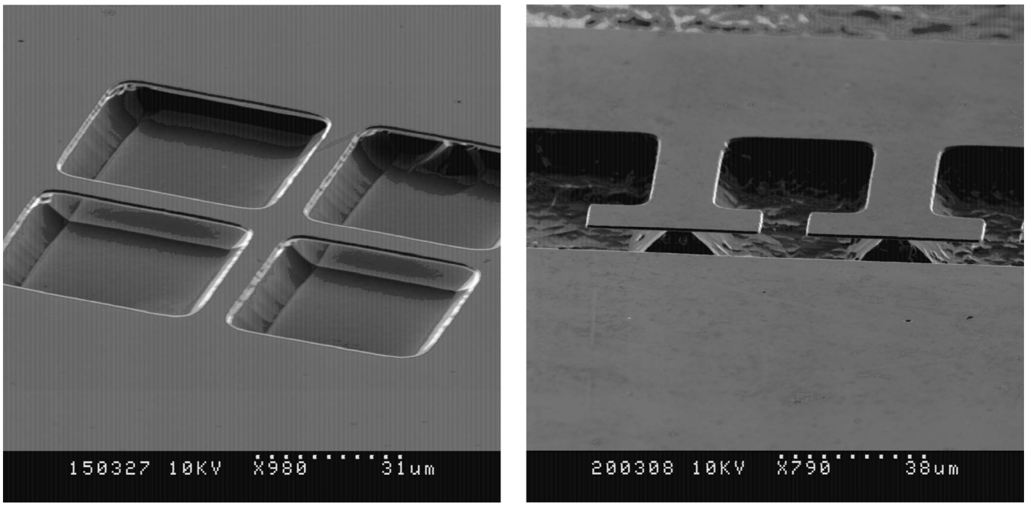

Fig. 6. SEM images of cross structures with released and not released beams

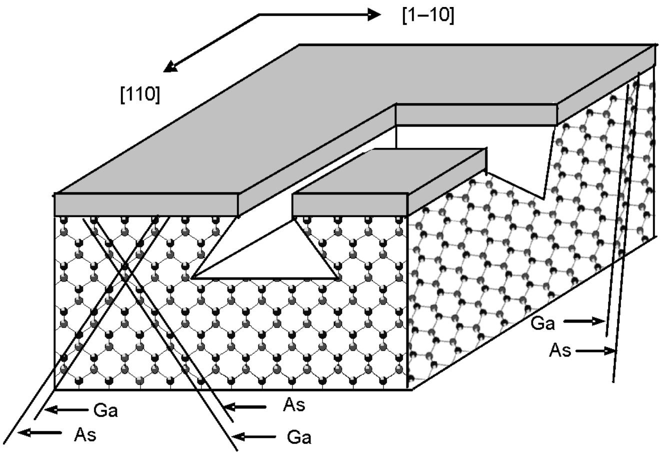

Fig. 7. Schematic presentation explaining different shapes of grooves etched in GaAs in [110] and [1–10] crystallographic directions

The process of etching of monocrystalline GaAs in majority of acid solutions is strongly affected by the etch rate anisotropy. The fact stems from the crystal structure of GaAs which causes that different crystallographic planes are etched with different etch rates. The planes with the lowest etch rates form a lateral profile of etched concave structures. Usually, these are (111) planes, which are the most densely populated.

In GaAs, the (111) planes can be either Ga or As terminated. The (111) planes of A-type – terminated by Ga atoms, are characterized by the lowest etch rates. In (001) oriented GaAs wafers, the planes are situated in two crystallographic directions: [110] and [1–10]. In these two directions, the (111) A-type planes are inclined either at obtuse or acute angles with respect to the wafer surface. It makes that concave structures etched in (001) wafers may form holes with either triangular or trapezoidal cross-sections (Fig. 7).

Only the structures with (111) planes of A-type, inclined at acute angles toward the substrate have a chance to be released in an anisotropic etching process. Therefore, an appropriate mask pattern layout is of crucial importance in the fabrication process. To obtain released crossed structures, the etching solution with isotropic character, assuring also selectivity of etching of GaAs over AlGaAs, should be employed. Work on the development of such etching formulas is in progress.

Acknowledgements

This work has been supported by a statutory grant no R02 018 02 granted by Polish Ministry of Science and Information Society Technologies.

References

[1] LECLERCQ J.L., RIBAS R.P., KARAM J.M., VIKTOROVITCH P., Microelectron. J., 29 (1995), 613.
[2] LATINSKY P., BURIAN E., DRZIK M., HASCIK S., MOZOLOVA Z., KUZMIK J., J. Micromech. Microeng., 10 (2000), 293.
[3] IWATA N., WAKAYAMA T., YAMADA S., Sens. Actuat. A, 111 (2004), 26.
[4] CLAWSON A.R., Mat. Sci. Eng., 31 (2001) 1.

Received 28 April 2007
Revised 16 February 2008