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Optimization of Process Parameters of Deep Plasmachemical Etching Silicon for MEMS Elements

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Abstracts

The investigation of deep silicon etching process using methods of planning multifactorial experiments was performed. It is established that in an etcher AMS 200 pressure increasing simultaneously with bias power decreasing causes an increasing selectivity of silicon to a photoresistive mask and a SiO_2 mask. By gradient motion the recipe of deep silicon etching with selectivity 300 for a photoresistive mask and 1150 for silicon dioxide mask is certain. It is discovered that heterogeneity of silicon etching depth in trenches with different width (ARDE effect) decreases with increasing duration of passivation stage comparing to etching stage. By gradient motion conditions to lower heterogeneity of etching are found. Results of the fulfilled researches have been utilized during manufacturing the sensitive elements of real MEMS structures.

Keywords: MEMS, Plasmachemical, Etching, Silicon, Process

INTRODUCTION

Deep etching process of silicon is one of the basic and responsible step in technology of manufacturing of many sensitive elements (SE) structures MEMS [1]. It is also one of the most complex step, because of necessity to perform simultaneously the several, sometimes difficultly compatible conditions. Deep etching process should provide correct reproduction of geometrical structure of SE, quite high etching rate, high selectivity to a mask. At the same time it is necessary to provide also the good quality (roughness) both lateral surfaces of a structure and its bottom. In some cases decreasing or elimination of ARDE (aspect ratio difference of etching) effect is necessary etc

DESCRIPTION OF PROCESS

Processes of deep plasmachemical etching were performed using the etcher AMS 200 (Alcatel, France). This facility has high density plasma reactor (ICP type) and designed for deep silicon etching. So-called Bosch-process, which consists of periodic alternation of short passivation- (gas C_4F_8) and etching- (gas SF_6) stages, was used. Typical value of selectivity which Alcatel company shows by delivery of the equipment is quite high and equals to about 75 to a photoresistive mask (PRM). But some practical applications require increasing this number. In particular, for etching trenches which are deeper than 100 microns, the above-stated value of selectivity to a photoresistive mask are not enough. For etching on depth 200 μ and more (thinning process) it is necessary to use a metal or silicon dioxide mask This circumstance complicates the technological process, considerably increasing number of steps. Therefore optimization of selectivity Si/PRM and Si/SiO_2 has been performed in the present work. Also the opportunity to decrease the ARDE effect has been investigated.

STATISTICAL METHODS OF PLANNING AND ANALYSIS OF THE EXPERIMENT

Presence of several parameters which influence on the process result, makes more difficult a way of searching the optimum (or close to optimum) etching result. A logical solution of this problem is using the statistical methods of planning and analysis of the experiment [2]. Such methods allow us to reduce the number of experiments which are necessary for optimization of technological process.

Four input process parameters, which are presumable capable to influence on the optimized parameters were taken into account, namely: X1- passivation/etching stage duration ratio; X2- electrode temperature; X3- reactor pressure; X4-bias power on substrate holder. The plan of experiment representing one half from full four-factors experiment was designed. Variation of factors at two levels +1 and-1 has been made.

After experimental data processing the following regression equation for three optimized parameters have been received:

$$Y1=58,1+14,3X3 - 5,8X4 \qquad (1)$$

$$Y2=194,5+52X3 - 21,7X4 \qquad (2)$$

$$Y3=15,4 - 4,7X1+1,8X2+1,8X4 - 2,2X1X2 \qquad (3)$$

It follows from comparison of the regression equations (1) and (2), that for both kinds of protective mask (PRM and silicon dioxide) selectivity increases with pressure (X3) increasing and decreases with bias power (X4) increasing. Note, pressure influences especially strongly. Heterogeneity of silicon etching depth in trenches with different width (Y3) is influenced most considerably by passivation/etching stage duration ratio (X1). Y3 decreases with increasing factor X1.

The regression equations (1) and (2) for selectivity Y1 and Y2 are linear, and the equation (3) for heterogeneity of etching Y3 is close to linear. Hence, they can be used for parameters optimization by means of gradient motion on the response surface.

SELECTIVITY OF PROCESS

By means of gradient motion the recipe for deep silicon etching with selectivity 300 for PRM and 1150 for SiO_2 mask is found. Also by movement along a gradient the conditions at which heterogeneity of etching is essentially lowered are determined.

On fig.1 selectivity dependences on step number of gradient motion are presented for PRM and SiO_2 mask. Experimental values of selectivity are received for initial point, 5-th, 10-th and 15-th steps of gradient motion. Calculated values represent extrapolation of regression equations.

Apparently on fig.1, selectivity of silicon to PRM has increased from 50 up to 300, and to silicon dioxide –from 200 up to 1150.

The main reason of selectivity increasing is, probably, decreasing energy of ions bombarding a substrate. As a result etching rate of a mask (both PRM and SiO_2) decreases. Silicon etching rate practically does not depend on ion energy.

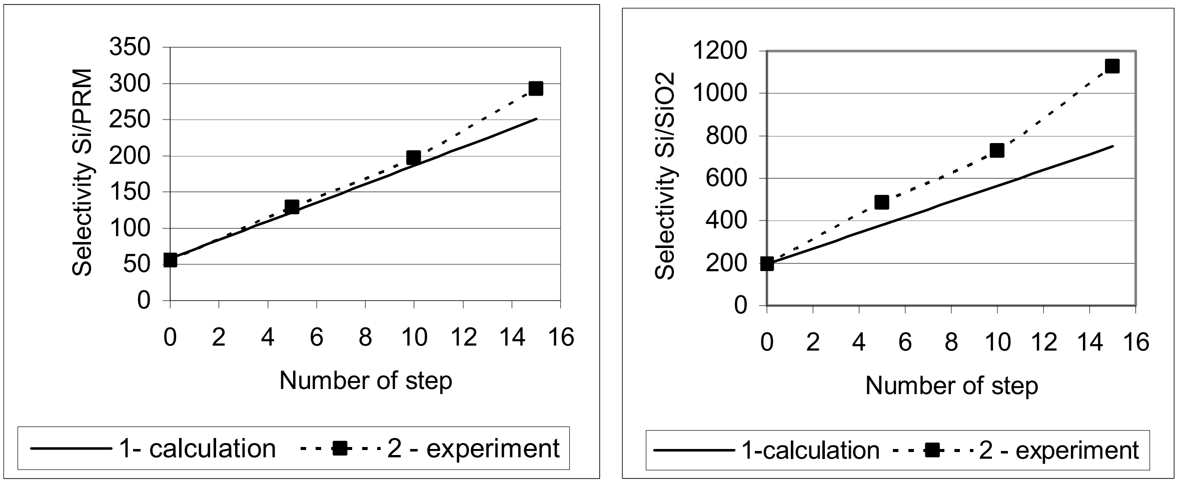

Fig.1. Selectivity dependences on step number of gradient motion for PRM and SiO_2 mask.
1- extrapolation of regression equations, 2- experiment.

Heterogeneity of silicon etching depth in trenches with different width is lowered from ~20 % up to ~4 % by gradient motion.

Results of the fulfilled researches have been utilized during manufacturing the sensitive elements of micromechanical accelerometer and gyroscope (see fig.2).

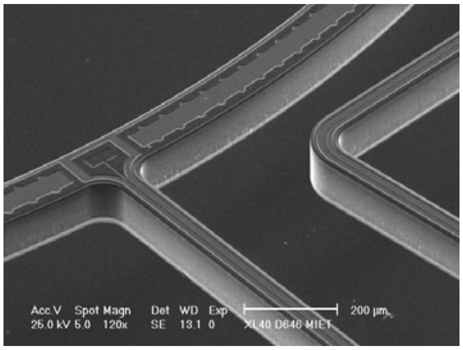

Fig.2. A fragment of a micromechanical ring type gyroscope.

The fragment of a micromechanical ring type gyroscope is presented in fig.2. Etching was executed on depth 200 microns using a photoresistive mask.

CONCLUSION

Dependences of performances of deep silicon etching on different process parameters were investigated. Method of planning multifactorial experiments was utilized to find the optimal recipes, which provide a high selectivity to a mask and decreasing ARDE. Results of the fulfilled researches have been utilized during manufacturing the sensitive elements of real MEMS structures.

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