AUTOMATIC GENERATION OF WAGON-WHEEL SHAPE PATTERN FOR 2D ANISOTROPIC ETCHING SIMULATION

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ABSTRACT

This paper presents the automatic generation of 'wagon-wheel' shape pattern that extends Etch Simulation Tools [8]. Such a kind of structure is quite useful for anisotropic etching characterization and simulation in front-side bulk micromachining technique since the etched region obtained corresponds to the 2D polar diagram of the etchant used. The main objective of this extension in the existing Java 2D etching simulator is to help users to construct complex area shapes for MEMS purpose, in this case the 'wagon-wheel' pattern. The generator allows the definition of certain shape dimensions, as well as the addition of extra patterns in the final layout. Etching simulation is carried out over the proposed structure.

1. INTRODUCTION

Micro-Electro-Mechanical Systems - MEMS represent nowadays an emergent and promising area with an increasing interest of research and industrial communities. The construction of mechanical structures with electronic circuits on a single chip represents the main obstacle in obtaining monolithic smart machines and sensors. Among microelectronics compatible micromachining approaches, the front-side bulk technique proved to be very efficient in terms of costs and process facilities since a straightforward post-process wet etching is enough to suspend mechanical structures, after electronics construction [1][2].

In the front-side bulk micromachining approach, the etching procedure for mechanical structure construction is commonly realized by using wet chemical solutions in order to obtain a significant underetching effect. In fact, the lateral etching, or underetching, is the main responsible for the structure releasing, whereas the etched region depth is sometimes not so critical.

The etching rates for each crystallographic direction are represented in a three dimensional (3D) etching rate polar diagram through the normal vector of such crystallographic planes present in the etched region walls, which represents the plane displacement directions [3]. However, the extraction or generation of this 3D etching rate diagram is not a simple task.

In the particular case of the front-side bulk micromachining, a two-dimensional (2D) etching simulation considering the top view, showing the interface of the etched region with the surface, as illustrated Fig 1, is generally enough to predict the edge displacements of the 'open areas', which are openings in the surface layers for etching attack.

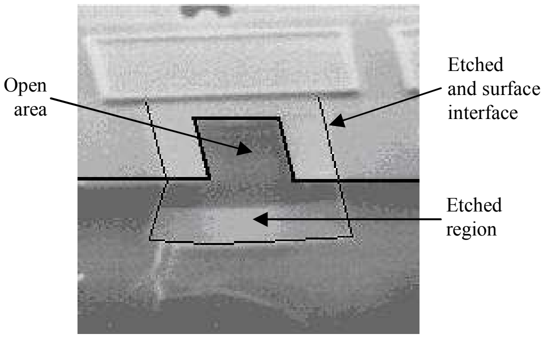


Figure 1 – Bulk etched region (cut view) and the 'open area' (surface pattern).

In this work, the existing MEMS simulator – E.T. tool [8], has been extended to include an automatic generator of the 'wagon-wheel' shape pattern, with parameterized dimensions. This kind of structure is very useful to verify the etch rates of an etchant in a certain material, considering a 2D top view of the released structure**.**

2. ETCHING PREDICTION

Although isotropic etching solutions could be used to such micromachining technique, as occur in GaAs technology [4][5], usually anisotropic wet chemical solutions such as KOH, EDP and TMAH are the most suitable in MEMS silicon-based processes [3][6][7]. The anisotropic behavior of these solutions is observed through the accentuated bulk material etching in some crystallographic directions and the etch stop planes occurrence in others.

The underetched region is observed on the top view of a micromachined chip by using an optical microscope, as shown in Fig. 2. In the discussed micromachining approach, this top view is enough to verify the complete suspension of surface layers, with few exceptions [4].

Thus, it is important to know the direction and the displacement rate of the 'surface' edges from the etched region in order to predict the final etched shape after a certain period, demonstrated in Fig. 3.

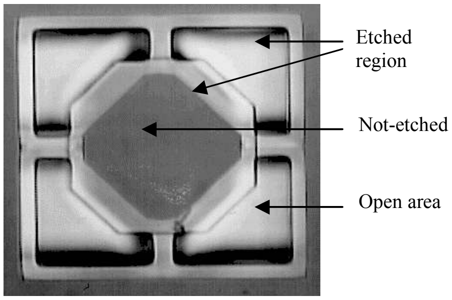
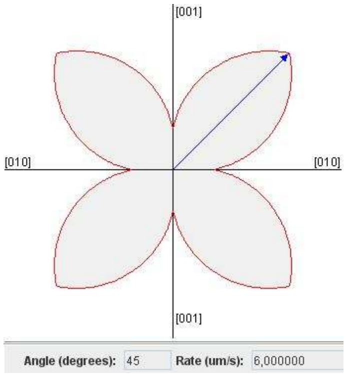


Figure 2 – Top view of 'open areas' and the underneath etched regions (shadow).



Angle (degrees): 45 Rate (um/s): 6,000000

Figure 3 – Example of etch rate polar diagram.

To build such 2D surface etch rate polar diagram it is not necessary to dispose the etch rate for all angles or directions; the complete diagram can be generated from some available values or more accurately from the minimum and maximum etch rate values. To do this the following procedure can be applied [4]:

a) the minimum and maximum etch rates are known (Fig. 4a);
b) the etch rate values are inverted to build the slowness diagram (Fig. 4b);
c) the equations of the straight lines connecting two slowness values are inverted to construct the etch rate diagram (Fig. 4c).

3. 2D ETCHING SIMULATION

In the front-side bulk micromachining technique the underetching or lateral etching is the main responsible for the structure releasing, and in most of the cases the information about the interface between the etched region and the surface layers is enough to verify and guarantee the mechanical suspension. As previously discussed, this interface, called here surface etched shape, is easily observed by using an optical microscope.

The etching simulator, presented in [8], aims to predict the surface etched shape from the original 'open areas' used to allow the bulk etch attack. To do this, a geometric method has been largely discussed in the literature [7,9-11]. It consists in displacing the crystallographic planes corresponding to the etched region walls towards the external side of this region, in the normal direction of the such crystallographic plane, and to the distance given by the etch rate polar diagram after a specific period.

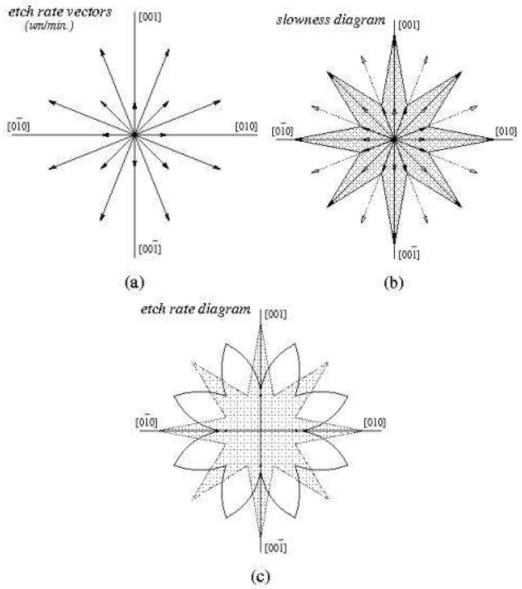


Figure 4 - Generation of etch rate polar plot from available minimum and maximum values.

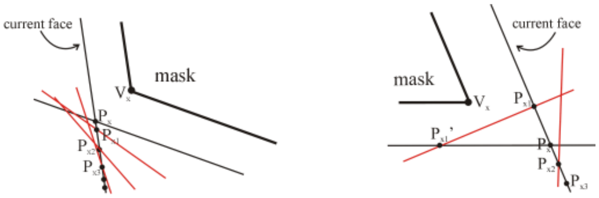
The geometric method can be directly applied to a 2D surface analysis evaluating the displacement of the 'open area' edges, from the etched region top view. First of all, the etched shape vertices must be extracted to obtain the line equations of the edges. These equations determine the corresponding normal vectors for each edge.

The next step is to determine the external side of the polygon area in order to obtain the displacement direction of the edges and the corresponding etch rate vector module.

To do this, a line normal to the specific edge is drawn passing through the medium point of this edge. The intersections of such line with the polygon edges are obtained and the middle point between two intersections are analyzed. If this point is outside of the polygon so the displacement direction is toward to it, otherwise the edge will displace to the opposite direction.

After that, the edges are moved towards the right direction, using the distance calculated from the respective etch rate and the time step period, as illustrated in Fig. 5.

Special attention must be taken in the polygon vertices or corners because they are responsible not only for appearing and disappearing of etched shape edges, according to their concavity, but also for the higher or lower rate values. New etched shape edges appear in concave corners since intermediate rate values, present between the corresponding edge etch rates, are lower than the last ones (see Fig. 5b). This situation may also occur in convex corners for higher intermediate rates. Edge disappearances are observed in the opposite cases.



(a) Vector with points of interest: [empty]
New envelope contains: [P_x]

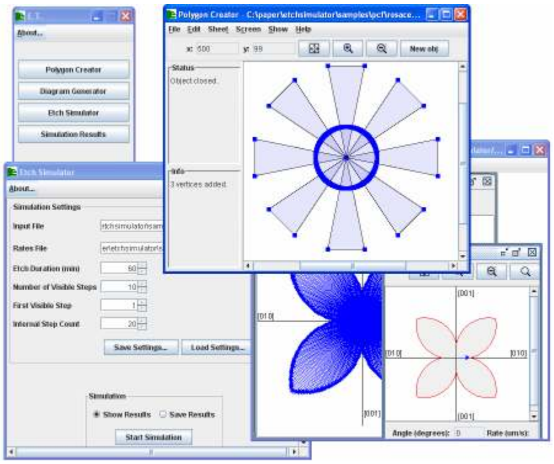
(b) Vector with points of interest: [P_{x1}]
New envelope contains: [P_{x1}',P_{x1}]

Figure 5 – Etched shape corner evaluation.

4. AUTOMATIC PATTERN GENERATION

The existing 2D etching simulator has been implemented using Java platform, in order to allow its portability to different operating systems [8]. The tool interface and windows are illustrated in Fig, 6.

In the etching simulation tool, the user has to draw the open area shape to be simulated. Other parameters, like the final time, the simulation time step and the visualization time step, can also be determined by the user. The simulator provides also a module where it can combine the polar diagram and etch mask generated to visualize step by step the etching effect.



x: 500 y: 99

Status
Object closed.

Info
3 vertices added.

Simulation Settings
Input File: etchsimulator\sam
Rates File: er\etchsimulator\s
Etch Duration (min): 60
Number of Visible Steps: 10
First Visible Step: 1
Internal Step Count: 20

Simulation
● Show Results ○ Save Results

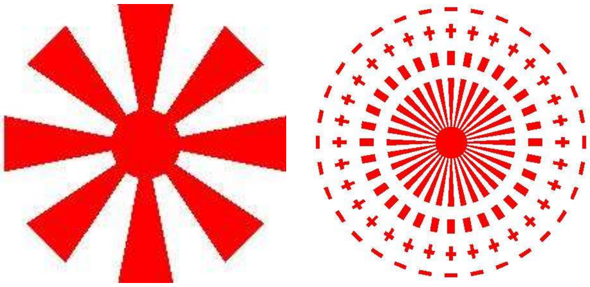
Angle (degrees): 0 Rate (um/s):

Figure 6 – E.T. tool: a 2D etching simulator for front side-bulk micromachining.

The creation of a complex area shape, even using the option available in the tool, is an arduous task that demands patience.

To avoid this handcraft task, a 'wagon-wheel' shape automatic generator was added in the tool, with the option to choose the generation the basic structure, as seen in Fig. 7a, and also with extra external shapes, as illustrated in Fig. 7b. Moreover, it is possible to enter with the number of points or 'arms' in the pattern.

The etching simulation of a structure with 64 points was carried out, and the result is shown in Fig. 8.



(a) (b)

Figure 7 – 'Wagon-wheel' patterns.

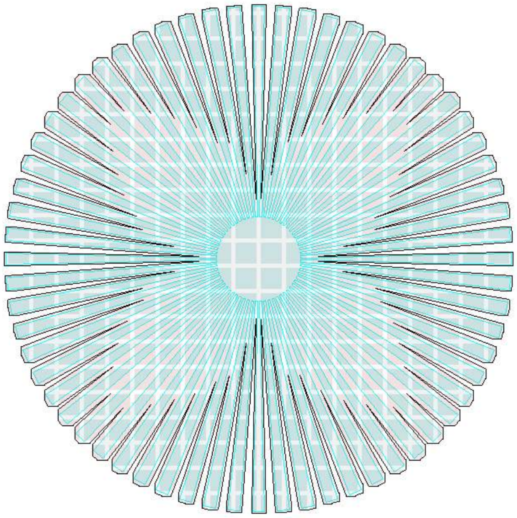


Figure 8 – 'Wagon-wheel' etching simulation result.

5. CONCLUSION

The automatic generator of 'wagon-wheel' pattern represents an important extension of the E.T. tool [8], a Java-based 2D etching simulator for front-side bulk micromachining technology. Generators for other specific patterns are in development.

6. REFERENCES

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