KOH-Etching of the Curved Electrode of an In-plane Moving Edge Actuator

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Fig. 1: Concept of the moving edge actuator

Fig. 1 shows the concept of the electrostatic moving edge actuator. The in-plane curved electrode is made by anisotropic KOH etch technique. This etchant generates vertical sidewalls along the <100>-mask edges so that a thin beam (width: wafer thickness) for the in-plane bending can be produced. In addition nearly vertical sidewalls are also generated along mask edges deviating about ± 4° from the <100>-orientation. An indication that vertical sidewalls occur is the equality of etch rates for their upper and lower edges (fig. 2). Therefore a vertical structure can be etched having a curved contour.

The mask of the curved electrode is realized by using a modified triangular structure. The hypotenuse is replaced by segments of a polygon. The design problem consists in finding the mask polygon from which the resulting course of vertical sidewalls fits equation (1).

\[ y = d_{\text{max}} \left( \frac{x}{L} \right)^n \]  
\( d_{\text{max}} \): maximum possible deflection,  
\( L \): length of curved electrode  

(1)

At first the curve of equation (1) is approximated by a polygon with an angle increment of \( \Delta \alpha = 0.1^\circ \). The mask is constructed by the displacement of the segments of the polygon by the distances of underetching corresponding to their direction = 45°-\( \Delta \alpha \) and to the etching time. The underetch rates of KOH 30% 80°C are known for all directions of mask edges in steps of \( \Delta \alpha = 3^\circ \) (file of etchant of simulator SIMODE). By a parabolic interpolation between 41° and 49° we can use \( v(45 \pm \Delta \alpha) = (0.00555 \Delta \alpha^2 + 1.0775) \mu m/min \) to calculate the rates in steps of \( \Delta \alpha = 0.1^\circ \) (equation (2) fits the rates of fig. 2 in region c).

Fig. 2: Etch rates as functions of the angle \( \alpha \) between the direction of the mask edge and the flat of a \{100\}-wafer.

a: sidewalls with inclination of about 55°;
b: sidewalls consisting of two facettes;
c: nearly vertical sidewalls

An example of the measured contours of the realized curved counter electrode is shown in fig. 3. The best fits were found with the exponents \( n = 2.25 \) and \( n = 3.48 \) which exceed a little the target values of \( n = 2 \) and \( n = 3 \), respectively. This indicates the realizibility of sidewalls with a defined curved course. The deviations arise from the inaccuracy of the etch rates.

Fig. 3: Measured contours of curved electrodes

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