Primary Current Distribution Model for Electrochemical Etching of Silicon Through a Circular Opening

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Abstract

INTRODUCTION
Anodization of silicon is an electrochemical process performed in fluoride-containing electrolytes, which can be used to generate porous silicon or perform electropolishing. The process was demonstrated as a flexible structuring technique to etch forms of various shapes [1, 2]. However, the process depends on many parameters, such as electrolyte concentration, silicon substrate doping and type, charge flow distribution, etc. [3], therefore it is challenging to transfer the process to industry scale. Modelling of the process, for example with COMSOL Multiphysics®, can help bringing the process to a wider acceptance in industry. In the presented work, etch form development observed in the anodization process through an insulating masking layer with a circular opening is modeled and compared to experiments. The work is the further development, systematic analysis and corrections of the previously presented results [4, 5].
In electrochemical dissolution processes, amount of dissolved material and the dissolution rate can be calculated from the Faraday's law of electrolysis with known current density, dissolution valence, and density and molar mass of the material. Thus, the etch rate is directly proportional to the local current density on the etch front. In case of silicon anodization, with increase of current density, the process switches from divalent (pore formation) to tetravalent (electropolishing). Additionally, the porosity of the generated porous silicon layer changes with increase of current density from, e.g., 70 % for p-type silicon of resistivity in the range 10-20 Ohm cm, to 100 % in electropolishing regime, and must be also considered in the model.

USE OF COMSOL MULTIPHYSICS
In the present work, primary current distribution model for the process was developed with the electrodeposition physics interface. Current dependent porosity and dissolution valence functions have been defined for the model (s. Figure 1). The model was solved for varied diameter of opening in the frontside insulating masking layer and varied constant applied current.

RESULTS
The resulting etch form development for diameter of the frontside opening of 400 micrometers and applied current of 1.257 mA corresponding to the initial current density of 1 A/cm2 is shown in Figure 2. The resulting etch forms were characterized with curvature measured at the bottom of the etch forms and anisotropy factor (s. Figure 3). The structure depth, at which the shape

switched from convex (negative curvature) to concave (positive curvature) was called threshold depth. Dependence of the threshold depth on the opening diameter for different values of the applied current is shown in Figure 4.

CONCLUSION

The simulations showed the transformation of the etch forms from convex to concave shape as was observed in the experiments. Also similar to the experiments, strong dependence of the threshold depth on the opening diameter was obtained. However, the threshold depth values obtained from the model were at least twice bigger than those from the experiment. These and further results are shown and discussed in the paper. The study was performed in frames of the PhD work of A. Ivanov.

Reference

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3. V Lehmann, Electrochemistry of Silicon. Weinheim and FRG: Wiley-VCH Verlag GmbH; 2002.
4. A Ivanov, U Mescheder, Dynamic Simulation of Electrochemical Etching of Silicon with COMSOL. In Proceedings COMSOL Conference 2012, October 10-12, 2012, Milan (Italy). 2012:7 pages.
5. A Ivanov et al., Finite-Elements Simulation of Etch Front Propagation in Silicon Electropolishing Process. ECS Transactions 2014, 58:15–24.

Figures used in the abstract

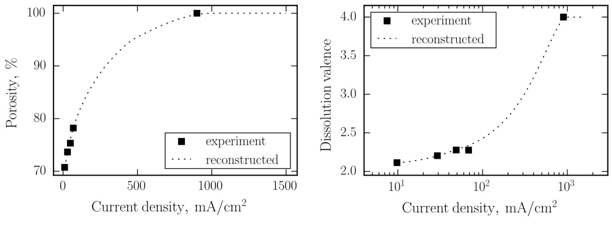

Figure 1: Functions of porosity and dissolution valence used for the model, constructed based on experimental results

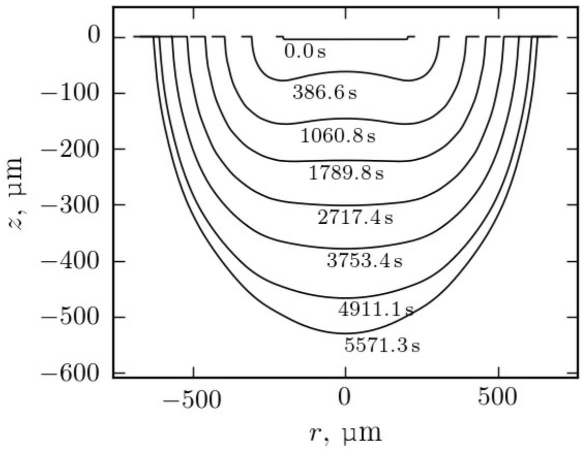

Figure 2: Simulated etch form development for the model with opening diameter of 400 micrometers and applied current of 1.257 mA

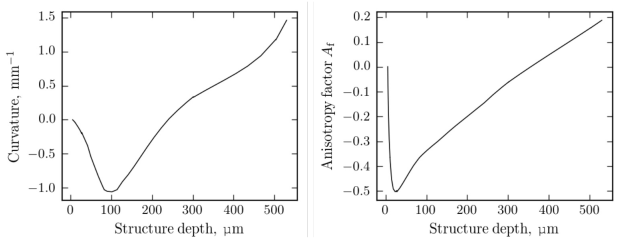

Figure 3: Curvature and anisotropy factor vs. structure depth observed in the model for opening diameter of 400 micrometers and applied current of 1.257 mA

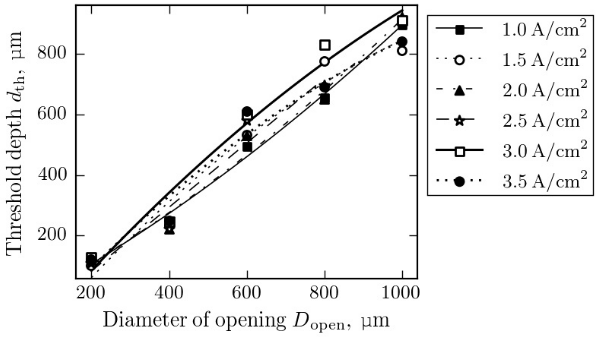

Figure 4: Threshold depth vs. diameter of opening evaluated for the model; the datasets are for varied initial current density calculated from the applied current and area of the opening.