Electrochemical micro machining using short pulses

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Silicon micro machining is a delicate step to build actuators and MEMS [1]. The technique utilizes in combination a succession of lithography steps and etching procedures (anisotropic chemical etching, isotropic etching or reactive ion etching). The technique is essentially 2D and building 3D structures requires a great deal of imagination. Standard micro-machining of metals is much less developed and does not work very well since the dissolution is isotropic [2].

Three dimensional structures were realized using electrochemical machining. In a recent publication, highly resistive (>1000 Ω.cm) n-type silicon was machined in *dc* mode and in the electropolishing regime [3]. This elegant technique, which still requires a masking step, allows to perform high aspect ratio features which lateral dimensions are limited by the thickness of space charge layer (few µm).

Pulsed electrochemical micro-machining of conductive substrates is a new concept which was recently developed in by Schuster [4]. The technique is entirely maskless and may be compared to 3D machining like with milling cutter. The method may be applied to metals and semiconductors.

The principle of the technique may be understood from Fig. 1 (left). The tool and workpiece electrode potentials are controlled with a bipotentiostat. The pulse of potential is applied between them. As a result, the double layer (DL) capacitance is charged and a current flows if the time constant of the charging process is *shorter* than the pulse duration. If this is not the case no reaction occurs. Hence by controlling the the pulse width one also controls the spatial extension of the electrochemical reaction. In the case of a metal workpiece, the relevant time constant is $\tau \sim \rho d C_H$, with ρ the resistivity of the electrolyte, d the distance between two points on each of the electrodes et C_H the DL capacitance. With classical values of parameter (ρ = 30 Ω.cm, C_H = 10 μF/cm^2), a pulse duration *T* = 30 ns, confines the reaction within d ~ 1 µm. This prediction is experimentally verified in the case of copper dissolution. The 3D structure in Fig.1 (right, top) was machined with a submicrometer precision in 0.01 1M $HClO_4$ + 0.1 M $CuSO_4$ with a 10 µm Pt cylinder as tool and 50 ns pulses.

Figure 1 (right, bottom) is an example of hole made in p-Si in 1% HF with a 50 µm Pt cylinder as tool and 200 ns pulses. The resolution is much poorer than with Cu because we had to make a compromise to enter the electropolishing regime and obtain a sufficiently fast dissolution rate. Both conditions were indeed conflicting parameters. In addition, to reach a sufficient vertical dissolution rate. The resistivity of the material ($\rho_{Si} \sim \rho$) and the small space charge capacitance $C_{SC} << C_H$ made that the pulse largely dropped inside the substrate and not at the electrode-solution interface.

We will show at the conference how both the resolution and the speed of machining could be improved.

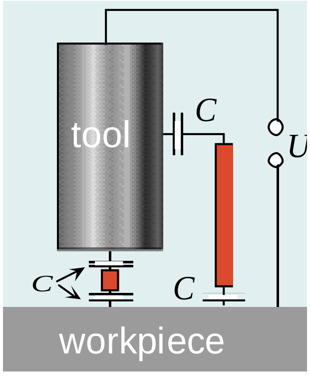

Fig. 1 : Principle of pulsed electrochemical micro machining

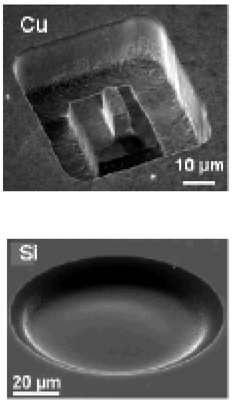

Fig. 2 : application to Cu in $HClO_4$(top) and highly doped in dilute HF Si (bottom)

References :

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