Poster

NANOMECHANICAL MASS SENSOR FOR SPATIALLY RESOLVED ULTRASENSITIVE MONITORING OF DEPOSITION RATES IN STENCIL LITHOGRAPHY

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Shadow masking (also known as nanostencil lithography, SL) is a well known technique to fabricate patterns on a surface. It is a versatile method that can be used in a variety of applications. There has been recently a strong interest regarding the use of shadow masks, mostly related to combinatorial materials science, organic based device fabrication, as well as rapid prototyping of nanoscale structures using dynamic or quasi dynamic stencil deposition [1]. From the study of almost all reported variants of SL, a series of intrinsic generic advantages emerges. Its main features are its 'cleanliness', its flexibility, its parallelism and its high resolution. This exclusive characteristic makes that ultra-clean surfaces with high purity deposits can be obtained. From that, mechanically fragile and chemically functionalized surfaces can be structured, due to the absence of cyclic process steps seen in lithography and the absence of etching processes. Its parallelism makes it much faster than charged particle techniques (FIB or eBL). Recently it has been demonstrated its implementation at full-wafer scale while providing 150 nm resolution [2].

Here, we report on a novel application for NEMS mass sensing, which allows in situ monitoring and characterization of material fluxes flowing through nano- or micro-apertures in vacuum deposition systems, enabling the development of a new generation of micro- and nano-SL systems for sequential multilevel patterning [3]. A dedicated sensor with spatial resolution is used to characterize the deposition rate (or flux) profile after the material has passed through the stencil membrane apertures. A mechanical mass sensor is developed based on a resonating mechanical structure whose resonance frequency shifts down when a small quantity of material is deposited on top of it. By tracking the change of resonance frequency, the mass deposition can be monitored in real time by computer. In particular, we use a CMOS integrated NEMS mass sensor. [4]

The NEMS mass sensor used here is an 18 μm long, 600 nm wide, 850 nm thick (nominal dimensions) resonant doubly clamped beam whose metallic structure is fabricated with the top metal layer of a commercial 0.35 μm CMOS technology (Figure 1). The electromechanical resonator is monolithically integrated with a CMOS oscillator circuit [5]. This sensor presents the following specific features: (i) a high mass resolution (around $3.4\text{x}10^{-11}\text{g}\cdot\text{cm}^{-2}\cdot\text{Hz}^{-1}$), which allows detecting deposition rates below 10 $\text{pm}\cdot\text{s}^{-1}$ for silver deposition; (ii) very good spatial resolution, in the range of hundreds of nanometers, due to the small dimensions of the sensor, which allows a position-dependent detection; (iii) device portability, because the sensor actuation and readout are completely electrical (CMOS integration), simplifying the detection set-up.

We have modeled the local material deposition rate in the sensor surface and compared the modeling results with the experimental measurements employing the sensor. We found that the material flux through confined apertures can be described by taking into account two geometrical effects: (i) The pattern widening effect, which causes the pattern on the sensor plane to be smaller than the aperture on the shadow mask, due the presence of a gap between stencil and, and because the source is not perfectly punctual; (ii) the penumbra effect, which obscures part of the whole source area, causing the maximum flux on the sensor plane to be smaller than the maximum flux provided by the source. The model was validated with experimental data obtained by displacing the stencil laterally in a given direction while monitoring the change of resonance frequency of the sensor (Figure 2).

Regarding future applications, we have evaluated the minimum squared aperture size (W_{ST_MIN}, defined as the width of a square aperture) that still would be sensed, using the geometrical model of the flux on the sensor plane passing through confined apertures. W_{ST_MIN} has been calculated as a function of the stencil–sensor gap G for a minimum detectable deposition rate by the sensor F_{MIN} of 0.01nm s^{-1} (value based on the previous experimental observations) and considering a constant stencil scanning speed of 3mm s^{-1}. In addition, as further miniaturization of the sensor will result in an increase in its mass sensitivity, W_{ST_MIN} is calculated for several sensor beam lengths, L_S (Figure 3). Our analysis suggests the possibility of detecting sub-100-nm apertures in future developments, which would require reducing the gap between stencil and sensor and reducing the sensor length.

References:

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Figures:

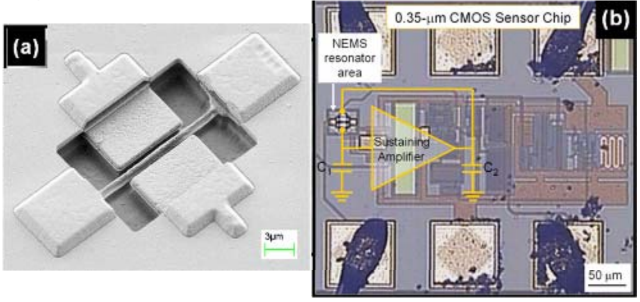

Figure 1. SEM image of the Nanomechanical resonator (left) and optical image showing the sensor + CMOS circuit

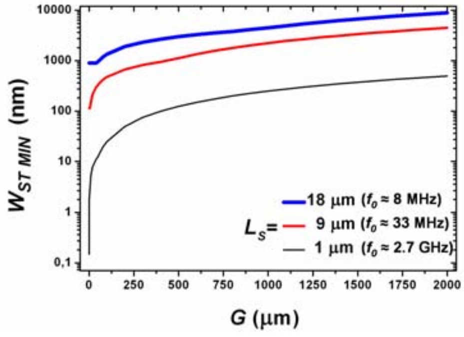

Figure 3. Evaluation of the minimum detectable stencil aperture $W_{ST\ MIN}$ as a function of the stencil-sensor gap G for a relative minimum detectable flux of 0.05 and a scan speed of 3 μm/s

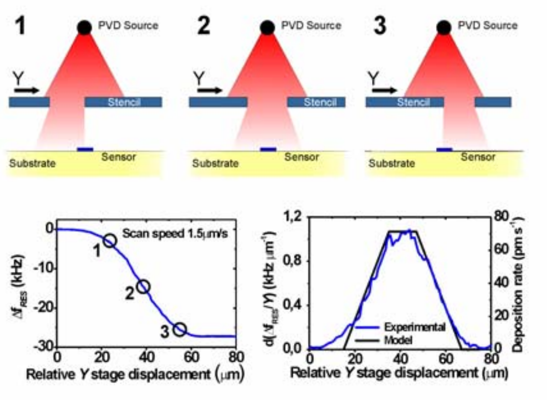

Figure 2. Experimental determination of the evaporation rate of an atom beam after passing through an stencil hole