MEMS Resonator Tuning using Focused Ion Beam Platinum Deposition


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ABSTRACT

This paper presents a novel post-fabrication tuning method which changes the resonant frequency of micromechanical beam resonators using Focused Ion Beam (FIB) deposition and removal of platinum. Tuning was achieved by depositing platinum on a 13×5μm surface area at the tips of cantilever and the middle sections of bridge resonators in thicknesses ranging from 0.3 to 3.1μm. Measurements on both types of resonator structures showed a maximum frequency change of -12% for 2.4 and 3.1μm thick deposition. A decrease was observed in the quality (Q) factor due to the damping effect of the platinum material and the increased surface roughness of the resonator. After deposition, the change in resonant frequency was re-adjusted by precise milling of the deposited platinum.

Keywords: resonators, frequency tuning, focused ion beam

1 INTRODUCTION

Characteristics such as high-Q factors, good temperature stability and favourable aging properties make micromechanical resonators attractive components for RF filter [1] applications. In order for these frequency-selective devices to deliver optimum performance, a precise resonant frequency is often required. This is not always possible, since fabrication tolerances, stresses and defects result in a resonant frequency which is different from the designed value [2]. In this situation a frequency tuning method can be used to adjust the resonant frequency. Other researchers have achieved this by changing the stiffness, using localized filament annealing [3]; or by altering the mass of the resonator employing either a localized Chemical Vapour Deposition process [2] or a laser [4]. However, when high temperatures are employed for frequency tuning, stress is generated in the material and results in deformation of the resonator structure. Additionally, laser deposition processes are often limited to the minimum laser spot size (10μm) which is critical when resonator sizes become smaller. Most of the tuning methods are not able to re-adjust the frequency after tuning. This can be problematic as the resonant frequency changes over time due to stress release in the device material after packaging [5]. In this paper, a new frequency tuning method is demonstrated which uses FIB induced platinum deposition onto silicon carbide beam resonators. A FIB system has been employed before to change the resonant frequency by altering the resonator stiffness [6]. However, this paper uses the system to alter the resonator mass. The tuning process presented has the advantage of precise material deposition at room temperature and allows the frequency shift to be re-adjusted through removal of the previously deposited platinum.

2 FIB TUNING PROCESS

A FIB system uses a beam of gallium ions to physically sputter material from the sample surface or to deposit different materials such as platinum. In the deposition mode, an organometallic precursor gas (trimethyl platinum) is decomposed under a high energy (30kV) gallium ion beam leaving platinum on the surface of the resonators (Fig. 1).

![Figure 1: Focused ion beam platinum deposition.](image)

2.1 SIMULATION

In order to evaluate FIB platinum deposition for resonator tuning, structures were first simulated using a Finite Element (FE) model, which predicted the change in resonant frequency due to the deposited material. The structures modelled were 200μm×15μm×2μm 3C silicon carbide cantilever and bridge resonators which included an undercut shown in the attachment region in Fig. 1 [7]. The software employed for the FE-analysis was Coventorware 2001.3. The physical material properties used for the simulations are summarised in Table 1.

An ideal rectangular cross section and a uniform resonator thickness were assumed during the simulations.
Table 1: Material properties of 3C SiC [7], [9], [10] and platinum [11].

In order to evaluate the mass tuning effect, a platinum layer with a fixed 13×5μm surface area and a range of thicknesses from 0.3 to 3.1μm was placed on the tips of cantilevers and the middle sections of bridges. Fig. 2 presents the simulated frequency change due to the platinum deposited on the silicon carbide resonators. There is a linear decrease in frequency with increasing material thickness. The simulated maximum frequency change was -23% for the cantilevers and -19% for the bridges with 2.4μm and 3.1μm deposited platinum, respectively.

Figure 2: Simulated frequency change of silicon carbide cantilever and bridge resonators versus deposited platinum thickness.

3 EXPERIMENTAL RESULTS

A FEI FIB 200 workstation was employed to deposit platinum onto silicon carbide cantilever and bridge resonators. For optimum control over the tuning process, a platinum deposition rate of 120nm×min⁻¹ was experimentally determined for a beam current of 150pA. Platinum was deposited on a 13×5μm surface area of the resonators in thicknesses ranging between 0.3 and 3.1μm. Fig. 3 shows deposited platinum on a silicon carbide cantilever and bridge resonator.

The tuning process was characterised using the optical ‘workstation’ shown in Fig. 4 [8]. The resonator samples were attached to a piezoelectric disc and inertially actuated in a vacuum.

Their resonant peaks were detected using a laser vibrometer and the deposited platinum thicknesses measured by a surface profiler. The change in resonant frequency was obtained by measuring the fundamental resonant frequency of each resonator before and after the deposition process. The measured change in resonant frequency as a function of platinum thickness is presented in Fig. 5.

It can be observed that the resonant frequency of the cantilevers decreases with thickness in a linear fashion as predicted by the simulation and in the literature for laser deposition [4]. Bridges show a deviation from a lin-
Figure 5: Measured resonant frequency change of silicon carbide cantilever and bridge resonators as a function of deposited platinum thickness.

The decrease in frequency change. It is believed that this is due to slightly off-centered platinum position and temperature variations between measurements before and after deposition. The maximum measured change in resonant frequency was found to be -12% for both cantilevers and bridges with a platinum thickness of 2.4μm and 3.1μm, respectively.

The simulation results differ markedly from the measurement data by up to 92%, because properties of pure platinum and a specified value for the silicon carbide thickness were assumed for the FE-analysis. In order to calibrate the simulations with the measurement data, the thickness of the silicon carbide was determined using an ellipsometer (SOPRA SE-5). Measurements gave a material thickness of 2.5μm instead of the 2μm assumed for the previous FE-simulation. After the resonator thickness was known, the value of bulk platinum density was changed during the simulation from ρ₁ = 21500kg×m⁻³ to ρ₂ = 13400kg×m⁻³. Fig. 6 presents the re-simulated frequency change using the modified silicon carbide thickness and platinum density.

Figure 6: Re-simulated frequency change of silicon carbide cantilever and bridge resonators versus deposited platinum thickness.

Using these parameters, the maximum frequency change was -13% for the cantilevers and -11% for the bridges which brings the simulation and measurement results into close agreement. The small discrepancy is probably due to the assumed ideal rectangular cross section of the resonators and temperature variations between measurements. Fig. 7 shows an example of the normalised amplitude of a cantilever resonator as a function of frequency before and after platinum deposition. A clear decrease can be observed in the resonator’s quality factor (Q) after the deposition process. In this case, 0.3μm of platinum has been deposited onto the resonator.

Figure 7: Normalised amplitude as a function of frequency for a silicon carbide cantilever before and after platinum deposition.

The decrease in Q can be caused by: 1) the increased resonator surface roughness [12] due to the ion bombardment during FIB operation and 2) the damping effect of the deposited platinum film. It is believed that a lower beam current for sample imaging will reduce the surface roughness and retain a higher Q. However further investigations are required. In order to demonstrate the ability to re-adjust the change in resonant frequency, 375nm of platinum was removed from a cantilever and 600nm from a bridge resonator. For the platinum removal, a beam current of 350pA was used. The resonant frequency decreases after FIB platinum deposition (FIB step 1) and increases after platinum removal (FIB step 2) as shown in Fig. 8.

The resonant frequency of the bridge after milling is
slightly higher than before deposition. This is because a small amount of silicon carbide was removed during milling. The cantilever has a lower resonant frequency than before deposition, because not all platinum was removed from the resonator.

4 CONCLUSIONS

A novel post-fabrication frequency tuning method for micromechanical resonators using FIB platinum deposition and removal has been demonstrated in this paper. The resonant frequency was decreased by platinum deposition on a 13×5μm surface areas of cantilever and bridge resonators with thicknesses ranging from 0.3 to 3.1μm. There is a slight difference in the maximum frequency change obtained from the simulations and the measurements. Modelling can only serve as a guide to predict the frequency tuning of resonators. For accurate tuning control, it is therefore necessary to monitor the change in resonant frequency during the tuning process. The Q-factor of the resonators decreases after deposition probably due to the increased surface roughness caused by the gallium ion beam and damping of the platinum material. In addition, the resonant frequency was re-adjusted by removal of some or all of the platinum from the resonators. FIB can deposit smaller amounts of platinum than other published methods [4]. Therefore, this method has major attractions for changing the resonant frequency of small (high frequency) resonators. Furthermore, the method offers the flexibility of being able to remove platinum after deposition to compensate for changes in the tuned resonant frequency over time. Hence, FIB induced platinum deposition provides a precise and re-adjustable tuning process.

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