HIGH-Q MICROMECHANICAL RESONATORS IN CH$_4$-REACTANT-OPTIMIZED HIGH ACOUSTIC VELOCITY CVD POLYDIAMOND

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ABSTRACT

Vibrating micromechanical resonators with Q’s greater than 30,000 have been demonstrated in CVD polydiamond material with an acoustic velocity of 14,252 m/s—the highest to date among surface-micromachinable materials for micromechanical resonators—achieved via exhaustive modifications to a CVD polydiamond deposition recipe that identify low CH$_4$ reactant concentration as the key to attaining high acoustic velocity. As a result of these modifications, folded-beam comb-transduced micromechanical resonators made in CVD polydiamond have now been measured with resonance frequencies 1.77X higher than that of identical polysilicon counterparts, 1.20X higher than achievable by SiC (another high acoustic velocity material contender [1]), and 1.53X higher than a previous attempt at using CVD polydiamond as a resonator structural material [2].

Keywords: wireless communications, RF MEMS, diamond, resonator

I. INTRODUCTION

Spurred by increasing interest in RF communication applications of MEMS technology [3], the frequencies of vibrating micromechanical resonators have seen dramatic increases in recent years, through which frequencies in the hundreds of MHz have now been demonstrated [4][5]. Among strategies for further extending frequencies past 1 GHz, the use of alternative structural materials with higher acoustic velocities than polysilicon, such as silicon carbide [1][4], have been particularly successful. Of the presently available set of thin-film-depositable materials, diamond potentially offers the largest acoustic velocity, with single crystal values on the order of 18,076 m/s [6], which is 2.24X higher than that of polysilicon and 1.50X higher than that of silicon carbide. Unfortunately, however, recent attempts to use CVD polydiamond as the structural material for micromechanical resonators have thus far yielded an acoustic velocity on the order of only 9,320 m/s, far lower than potentially achievable [2].

This paper reports for the first time micromechanical resonators in CVD polydiamond material with an acoustic velocity of 14,252 m/s, achieved via exhaustive changes made to the CVD polydiamond deposition recipe that identify low CH$_4$ reactant concentration as the key to high acoustic velocity. As a result of these changes, folded-beam comb-transduced micromechanical resonators made in CVD polydiamond are now demonstrated with resonance frequencies 1.77X higher than that of identical polysilicon counterparts, and with similar Q’s.

II. CVD POLYDIAMOND RECIPE VARIATIONS

The fabrication process that achieves CVD polydiamond devices with the final cross-section of Fig. 1 is similar to that of [2], except that doped LPCVD polysilicon (rather than metal) is used as the interconnect layer, and a 920°C LPCVD oxide (HTO) is utilized as the sacrificial layer (rather than PECVD oxide). These adjustments were made mainly to allow a wider variance in diamond deposition and etch recipes during the search for the right recipe.

As in [2], CVD polydiamond was deposited by first establishing a seed layer of diamond with a sufficient nucleation density, then depositing and in situ boron doping the diamond material via a microwave PECVD process, still using 2.45 GHz microwaves, but this time changing the substrate temperature and the concentrations of the CH$_4$ and B$_2$H$_6$ reactants, in search of an optimum recipe that yields high acoustic velocity while retaining high-Q, low stress, and low surface roughness. Table I presents a listing of four representative recipe variations.

III. EXPERIMENTAL RESULTS

Figure 2 presents the wide-view SEM of a fabricated TypeD folded-beam, comb-transduced CVD polydiamond micromechanical resonator.

Fig. 1: Final cross-section of a CVD polydiamond micromechanical device in the process technology used for this work.

Fig. 2: SEM of a fabricated TypeD folded-beam, comb-transduced CVD polydiamond micromechanical resonator.

From Table I the main difference between these two devices is in the CH$_4$ concentrations used during CVD diamond deposition, which was much smaller (0.33%) for the higher frequency TypeD device than for the TypeC device (0.9%). This, together with the observation that lower deposition rates attained with low CH$_4$ reactant concentrations lead to smaller deposits of non-diamond carbon

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since the boundary areas where non-diamond carbon, voids, and defects present in the final film. In addition, since larger grain sizes generally increases with film thickness, a higher $E$ is expected for thicker films, as verified in Table I. Since acoustic velocity goes as $\sqrt{E/\rho}$, thicker films with fewer voids and defects should also exhibit higher acoustic velocity.

A mechanism where film quality plays a significant role in setting $E$ is clearly supported by Fig. 5, which presents close-in SEM shots of TypeC and TypeD devices, showing a substantially smoother, porosity-free surface for the better performing TypeD device. The surface roughness seen for the TypeD device is, in fact, comparable to that attainable in previous polysilicon counterparts [10]. On the other hand, pores and voids are clearly visible in the TypeC material, and these then likely contribute to a smaller Young’s modulus. As evidence of the degrading impact of non-diamond carbon in the final film, the TypeA recipe lacks a plasma pretreatment step [2], and thus, suffers from poor nucleation and carbonization over the substrate before deposition, leading to the lowest acoustic velocity of all recipes in Table I.

In summary, in order to maximize the acoustic velocity of CVD diamond material, the CH$_4$ reactant concentration should be reduced during deposition, and the temperature increased to maintain a reasonable deposition rate, as was done for the TypeD device en route to the highest reported acoustic velocity so far in a surface-micromachinable material for micromechanical resonators.

### IV. CONCLUSIONS

CVD polydiamond with an acoustic velocity as high as 14,252 m/s has been achieved via a low CH$_4$-concentration deposition recipe and used to demonstrate micromechanical resonators with $Q$’s greater than 30,000 and frequencies substantially higher than those of equivalently sized devices in any other material to date. These results now establish CVD polydiamond as one of the strongest contenders among high acoustic velocity materials potentially capable of extending vibrating micromechanical resonance frequencies past 1 GHz for RF communication applications [3].

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**References.**