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MICROMECHANICAL PYROLYTIC CARBON STRING RESONATORS

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The dynamic development in the field of micro- and nanofabrication resulted in the definition of a class of ultrasensitive micro- and nanomechanical sensors capable of detecting different physical variables [1]. These devices typically consist of simple micromechanical structures such as singly-clamped cantilever beams or doubly-clamped bridges. The principle of operation is generally based on the monitoring of the shift of the resonance frequency of the beams due to external stimuli. A figure of merit is a quality factor (Q). A high Q allows for precise resonance frequency detection. It has been shown that micro- and nanomechanical string resonators, which essentially are highly stressed bridges, exhibit exceptionally high Qs due to stress-induced damping dilution [2]. The damping dilution effect has resulted in Qs of several million in silicon nitride (SiN) resonators [3,4] and a few hundred in SU-8 resist resonators [5]. Pyrolytic carbon is an interesting newer material, which has been previously explored for the fabrication of micromechanical resonators mainly focusing on cantilevers [6] and bridges [7].

The goal of this work was to study micromechanical pyrolytic carbon resonators. This includes the design of a simple and reliable fabrication process and the subsequent characterization of the pyrolytic resonators. The developed fabrication method essentially consists only of three processing steps: 1) photolithography, 2) dry etching and 3) pyrolysis. Two different fabrication approaches called “dry etch – pyrolysis” and “pyrolysis – dry etch” were investigated, where the last two process steps were carried out in a variable order, (see Fig. 1(a)). It was decided to use two different photoresists, namely SU-8 2005 (negative) and AZ 5214e (positive). Fabricated resonators are shown in Fig. 1(b&c). The characterization of the resonators was conducted at room temperature and in high vacuum

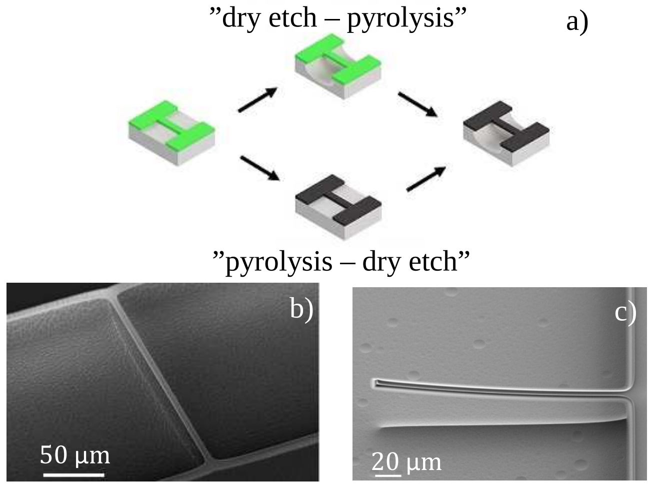

Fig. 1: a) Two fabrication procedures for pyrolyzed photoresist microresonators. In the schematic grey is the Si substrate, green is the photoresist and black is the carbon. b) SEM picture of AZ 5214e carbon string and c) SU-8 carbon cantilever

at a pressure below 10^{-5} mbar. The chips were glued directly onto a piezoelectric actuator. The resonance frequency of the out-of-plane vibration was read-out by an optical technique using laser Doppler vibrometer. The measured relations between resonance frequency, Q-factor and length of carbon resonators are presented in Fig. 2.

The resonance frequency values of the cantilevers are inversely proportional to resonator length squared, according to the Euler-Bernoulli beam theory. On the basis of these results the Young’s modulus values for pyrolytic carbon were calculated to be 71±9 GPa for the SU-8 and 113±12 GPa for the AZ 5214e precursor. The obtained values are much higher than for polymers with 4 GPa for SU-8 [5] but significantly lower than for silicon nitride resonators with 240 GPa [4]. Due to the amorphous internal structure of pyrolytic carbon with a high friction the fabricated cantilevers had moderate Q values of several hundred, which is better than 60 for SU-8 [5] and obviously less than 17000 reported for silicon nitride [4].

The resonance frequency of strings is inversely proportional to resonators length which is in agreement with theory. Also the ratio between higher resonance modes and fundamental mode was as expected for strings close to integer, with 2.017 for the second and 3.106 for the third mode. The resonance frequency data was used to determine the tensile stress in the string resonators to be 33±7 MPa. This value is slightly higher than for strings made of SU-8 with 20 MPa [5] but lower than for silicon nitride, where tensile stress can reach 200 MPa for low-stress and 900 MPa for high-stress strings [4]. The string's Q values had increased approximately linearly with length as predicted by the damping dilution model [2,4] with maximal values of up to 3000 for 525 µm long strings.

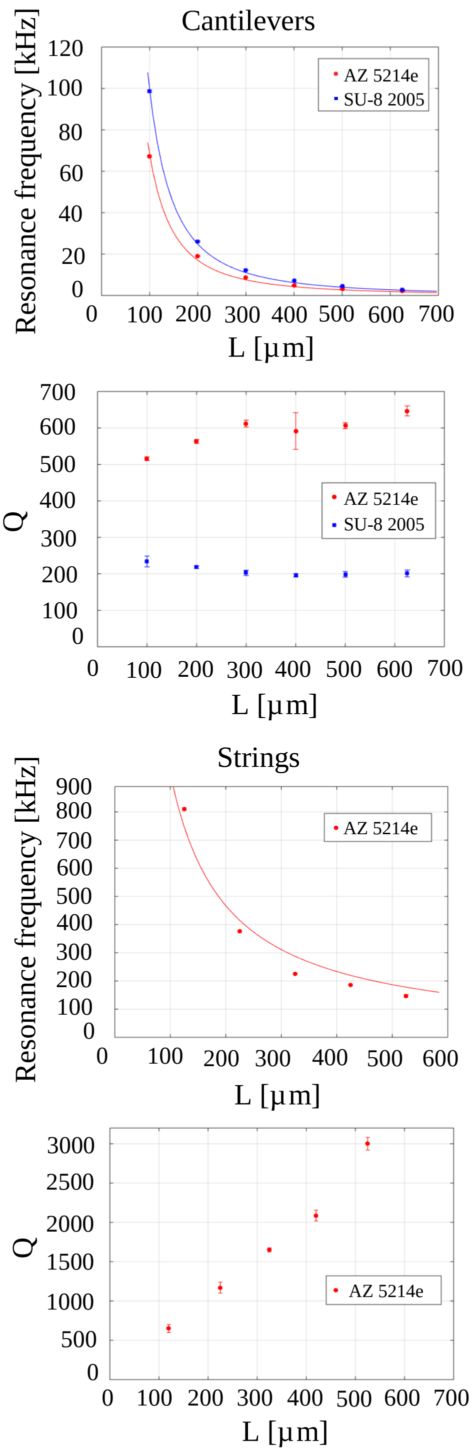

Fig. 2: Experimental results of fundamental mode resonance frequency and Q-factor values for carbon cantilevers (thickness of 550 nm for AZ 5214e and 1 µm for SU-8 resist precursor) and strings (thickness of 550 nm) with different lengths

Pyrolytic carbon is an interesting material for MEMS, allowing for a simple fabrication of micromechanical resonators with decent quality factor. The intrinsic conductivity of pyrolytic carbon [6] readily allows for an electrical integration in future designs.

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