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Fabrication and characterization of pyrolytic carbon string resonators

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Here, we present a novel simple process for the fabrication of pyrolytic carbon string resonators. More specifically, the goal of this work was to optimize the fabrication process to achieve good structural definition, high resonance frequencies and high quality factors. For this purpose, different approaches for preparation of the precursor template for pyrolysis were compared using AZ5214E positive resist, AZ5214E resist with image reversal and SU-8. From the results, we conclude that the optimized process for fabrication of string resonators is the one with AZ5214E positive resist with additional hard bake and a 2-step pyrolysis.

In microelectromechanical systems (MEMS), micromechanical resonators have a wide range of potential applications including resonant sensors for high-resolution mass and force sensing [1]. Basically, for MEMS resonators such as cantilevers, strings and membranes, the working principle is based on the frequency shift due to external stimuli such as changes in mass or temperature. A large bulk of research on optimized materials for micromechanical resonators such as SiN [2], SU-8 [3], and carbon-based materials [4-6] was performed. Among those materials, carbon-based materials such as silicon carbide, graphene, and carbon-nanotube (CNT) show promising mechanical properties [4-6]. However, a major drawback for these devices is expensive and complicated fabrication processes. Recently, pyrolytic carbon showed tunable electrical and mechanical properties due to the possibility to modify the pyrolysis parameters [7].

The fabrication process of the pyrolytic carbon string resonators is shown in Fig.1. The process is simple with spin-coating, photolithography, dry etching and pyrolysis. After lithography, the thickness of the AZ5214E and SU-8 device layers are 4µm and 6µm, respectively. After development, an additional hard-bake in 1 hour was introduced to make the structures more stable and avoid damage during the following etching process. The isotropic silicon dry etching step was optimized to improve the structural definition of the strings and maximize the fabrication yield. For pyrolysis, 1-step and 2-step pyrolysis processes were compared. In the 1-step process, the polymer strings are heated up to 900ºC with 10ºC/min ramping rate and in the final temperature is maintained for 90 minutes. In the 2-step process, at first, the strings are pre-conditioned 200ºC for 30 minutes followed by pyrolysis at 900ºC for 90 minutes with 10ºC/min ramping rate.

The results show that the resonance frequencies for the strings fabricated with the one-step process were lower than for the 2-step process. The pyrolytic carbon string resonators successfully fabricated with the two-step pyrolysis process are shown in Fig.2. Finally, those pyrolytic carbon strings were characterized at room temperature and high vacuum at a pressure below 10^{-5} mbar. The resonators were actuated by a piezoelectric crystal and the resonance frequencies were detected by optical readout. Figure 3 shows the resonance frequencies of pyrolytic carbon string resonators with different lengths. The quality factor of those pyrolytic carbon resonators is approximately 10,000. As we can see from Fig.3, the strings obtained with AZ5214E positive resist show the higher resonance frequency and more structure can be measured.

In conclusion, we demonstrate the optimized fabrication process for pyrolytic carbon string resonators using AZ5214E resist with 2-steps pyrolysis. In near future, those resonators will be improved and adapted for biomedical applications.

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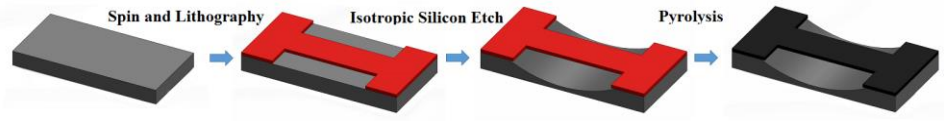

Figure 1. Fabrication process of pyrolytic carbon resonators.

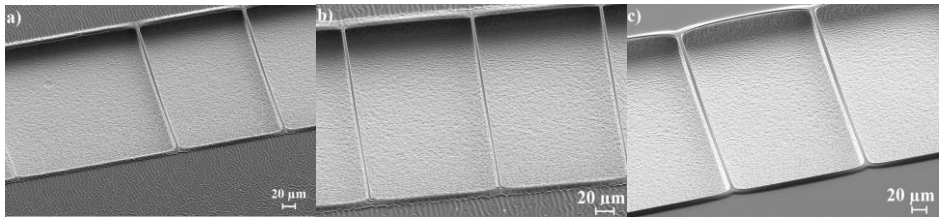

Figure 2. SEM images of pyrolytic carbon strings obtained with a) AZ5214E positive photoresist, b) AZ5214E photoresist with image reversal and c) SU-8 as precursors for pyrolysis.

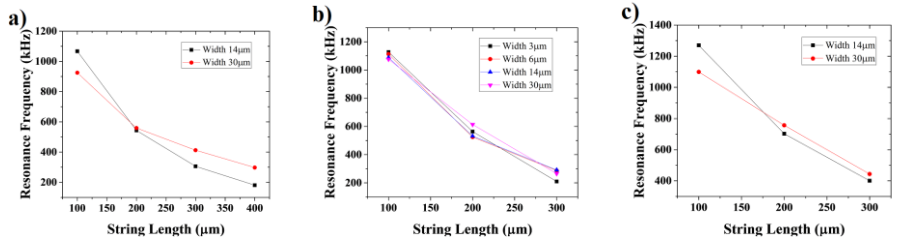

Figure 3. The resonance frequencies of pyrolytic carbon string resonators obtained with a) AZ5214E positive photoresist, b) AZ5214E photoresist with image reversal and c) SU-8 as precursors.