Investigation of mechanical modes coupling in silicon nitride drum resonators at room temperature

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Silicon nitride (SiN) micro electromechanical system (MEMS) is one of the good candidates for sensing and signal processing because of its high-quality factor and mechanical properties \cite{1}. Here, we present our recent work in studying mechanical modes coupling by using SiN based MEMS. The MEMS used in our experiment is a SiN drum covered with an Al thin layer, capacitively coupled to a suspended Al top gate \cite{2}. It is fabricated by a standard top-down nanofabrication process. The ultra-clean fabrication process allows to have a high-quality factor, $Q_c \sim 10^4$ at the room temperature. We use microwave reflectometry to detect the mechanical modes $\Omega_{n,m}$ of the drum resonator by using an ac signal to excite its mechanical motion. The suffixes $n,m$ refer to azimuthal and radial modes, respectively. For a drum with a diameter of ~ 30 µm, three mechanical modes $\Omega_{0,1} \sim 11$ MHz, $\Omega_{1,1} \sim 19$ MHz and $\Omega_{0,2} \sim 27$ MHz have been observed.

In order to understand the mode coupling in this MEMS, we choose $\Omega_{0,2}$ as the phonon cavity and use side-band pumping technique to pump the phonon cavity at the frequency, $\omega_p = \Omega_{0,2} + \Omega_{0,1}$ (blue side-band) or $\omega_p = \Omega_{0,2} - \Omega_{0,1}$ (red side-band) and use a very small RF signal to probe the cavity \cite{3,4}. Because of the nonlinearity induced mode-mode coupling, a splitting phenomenon in mode $\Omega_{0,2}$ has been observed as shown in Figure 1. Similar to the optical damping effect in optomechanics, the damping rate of the first mode $\Omega_{0,1}$ increases with increasing the pumping power when the phonon cavity is pumped at the red side-band and decreases when the cavity is pumped at the blue side band. Besides, we also investigate capacitive coupling between the mode $\Omega_0 \sim 3$ MHz (Q ~300) coming from the suspended Al top gate and the mechanical modes from the SiN drum, exhibiting a different kind of coupling mechanism. In brief, our high-Q drum resonator with large capacitive coupling scheme allows to study mechanical modes coupling which could serve for both classical and quantum engineering.

Figure 1: (Left) Phonon cavity’s response under blue sideband pumping ($\Omega_{0,2} + \Omega_{0,1}$), $\delta \Omega_{0,2}$ is the detuning from the resonant frequency $\Omega_{0,2}$ and $\delta \omega_p$ is the detuning from the pump frequency, $\omega_p = \Omega_{0,2} + \Omega_{0,1}$. (Right) The profile of the splitting phenomenon taken from the horizontal line (dashed blue) on the left figure.

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