電気信号による駆動とセンシングを一体化した単結晶ダイヤモンドMEMS

On-chip Single Crystal Diamond MEMS with Electrical Actuation and Sensing

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Single-crystal diamond (SCD) yields the best material properties for NEMS/MEMS among the semiconductors owning to its outstanding mechanical strength, thermal conductivity, electronic properties, and chemical inertness. At the first stage, we had been making efforts to develop the high quality (Q) factor diamond resonators. We succeeded in the batch fabrication of single crystal diamond (SCD) MEMS/NEMS resonators on diamond by using the ion-beam induced phase transition method (IPT) in diamond.[1,2] We realized that the Q-factor of the IPT SCD resonator was strongly degraded by the ion-implantation induced damaged layer.[3] Therefore, we improved the Q-factor by growing a thick SCD layer and etching the defective layer to reduce the energy loss by the damaged layer at the bottom of the resonator.[4] Ultimately, we achieved the SCD resonators on diamond with ultrahigh Q-factors over one million.[5]

As the next step, to fulfill the functionalities of SCD NEMS/MEMS, all-electrical on-chip transducers with all-electrical sensing and actuation are necessary to provide electrical interfaces with integrated circuits. An ideal on-chip SCD NEMS/MEMS with both actuation and sensing parts integrated should provide low actuation voltage, high sensitivity, little energy dissipation imposed by either sensing or actuation, high-frequency (> MHz) operation, and high-temperature reliability. Unfortunately, present on-chip NEMS/MEMS transduction schemes exhibit various drawbacks and are difficult to be applied to SCD. One conventional method is the self-sensing and actuation achieved by the integration of a piezoelectric thin film on the resonator. The problems of this method are the large energy dissipation of the NEMS/MEMS resonator, low-frequency limitation, and low-temperature operation. For the capacitive actuation or readout, the NEMS/NEMS resonators have to be conductive or semiconductive, which exhibit high energy dissipation. In addition, due to the weak electrostatic force, a high direct current bias (>50V) is adopted and the readout spectra are always asymmetrical.

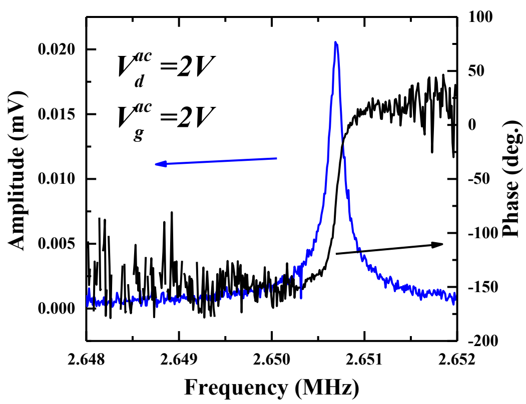

Fig. 1 On-chip electrical actuation and sensing of the resonance of the SCD cantilever with an rf amplitude of 2V applied to the S-D electrodes (V_d^{ac}) and 2 V to the gate electrode.

In the present work, we describe the on-chip SCD NEMS/MEMS by proposing a universal signal transduction scheme called self-sensing enhancing actuation (SEA) with electrically integrated actuation and sensing.[6] Figure 1 shows the resonance frequency and phase of a diamond MEMS cantilever achieved by the SEA. In the SEA scheme, the sensing part enhances the actuation force, and in turn, its own sensitivity. The on-chip SCD NEMS/MEMS shows the features of self-sensing, low-voltage actuation (mV), little energy dissipation, and high-frequency (> MHz) and high-temperature operation (873 K).

References

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