Effects of Cobalt-60 Irradiation on the Performance of AlN-Transduced Microelectromechanical Resonators

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This work presents the effects of gamma radiation on piezoelectrically transduced bulk acoustic wave (BAW) resonators. Two AlN-transduced rectangular flat plate resonators are designed, with and without a silicon dioxide (SiO_2) thin film, and are commercially fabricated *(Figure 1*). The devices are mounted to a custom printed circuit board (PCB) and exposed to 1 Mrad(Si) using The Ohio State University's (OSU) Cobalt-60 (Co-60) Underwater Irradiator (*Figure 2*). During irradiation, scattering (S-) parameters are measured in-situ. Measured resonant frequency (f_r), motional resistance (R_m), quality factor (Q), and electromechanical coupling factor (k_{eff}^2) are extracted. The results are used to validate a theoretical model that describes device reaction to the effects of atomic displacement damage and charge generation/trapping. Furthermore, this work demonstrates a new method of permanent frequency trimming of MEMS resonators by up to 30% of their bandwidth without modifying quality factor or motional resistance.

Figure 3 presents the frequency response of the two designs operating at the 1st width extensional mode (WEM) while under irradiation. Insertion loss and Q remain stable throughout the exposure. f_r exhibits a small but significant trimming during irradiation. The change to f_r is described by a decaying exponential equation. This frequency shift is due to high energy Compton electrons causing sufficient dislocation damage to alter the effective elastic modulus of the device. Raman spectra of pre- and post- irradiated Si are collected to assess the change in crystallinity. Defect density remains sufficiently small such that there is no detectable change in crystallinity, but sufficient defects are introduced to change the resonant frequency.

The frequency shift is much smaller than the precision obtainable by many commercial MEMS fabrication processes and it remains stable at room temperature. Furthermore, the other resonator performance parameters; Q, R_m, and k_{eff}^2; remain stable throughout the gamma irradiation. This presents two implications. First, the resiliency of these devices in an ionizing radiation environment has been determined. Secondly, this experiment demonstrates the first use of gamma radiation to permanently trim the f_r of a resonator by up to 30% of its bandwidth without altering the device's other performance parameters.

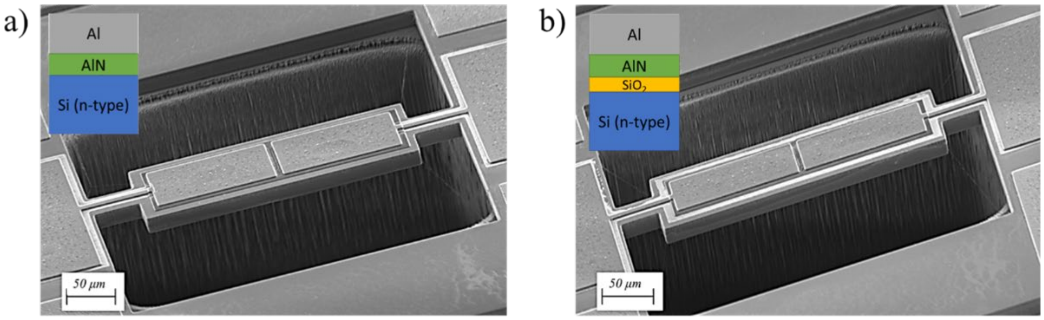

Figure 1: Scanning electron micrographs of the fabricated (a) AlN-on-Si and (b) AlN-on-SiO_2 rectangular thin plate resonators.

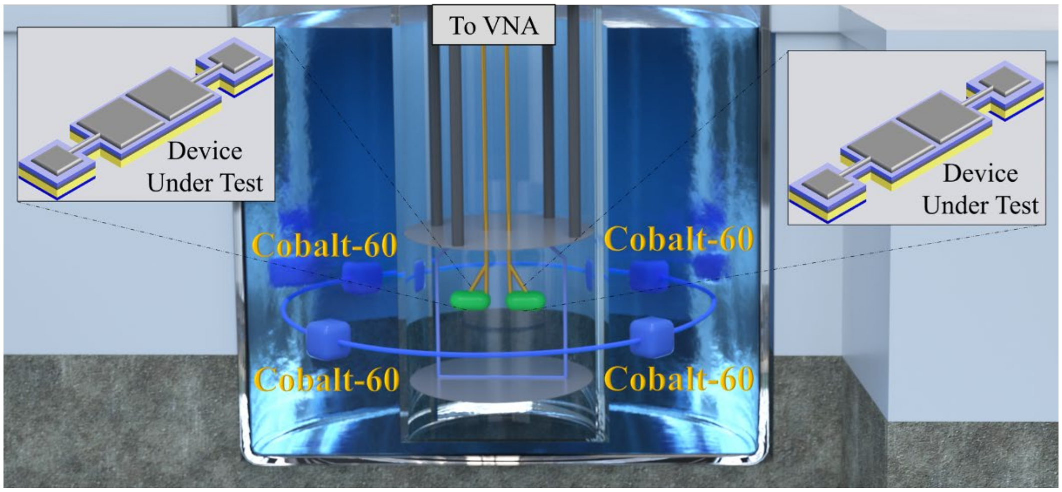

Figure 2: Diagram of OSU's Co-60 Underwater Irradiator (not to scale). The pool is roughly 16 feet deep. The underwater irradiator supported the simultaneous irradiation of two resonators via a dry access tube. RF cables lead out of the dry tube to VNAs that continuously record S-parameters.

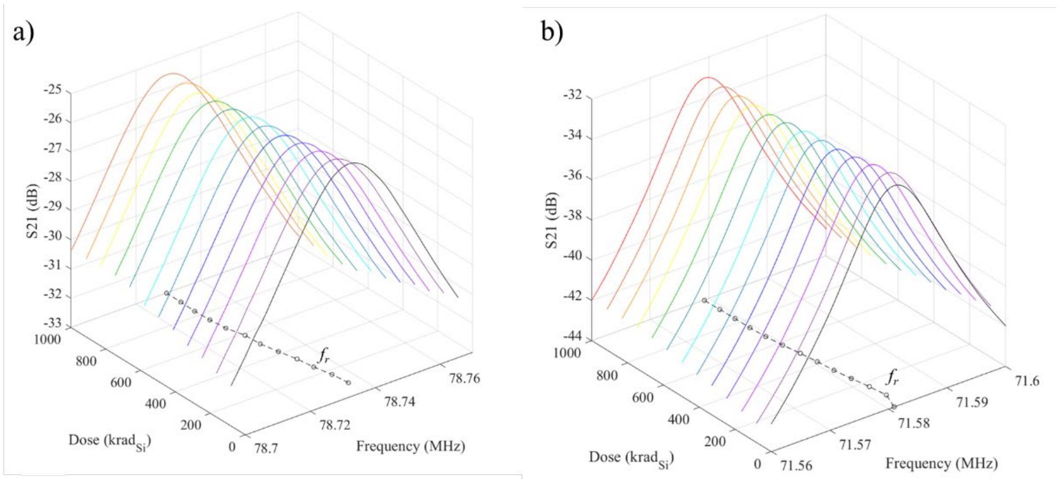

Figure 3: Measured frequency response for an irradiated resonator (a) with no oxide thin film and (b) with a 0.2 µm oxide layer. The rate of frequency trimming is halved when the oxide layer is added.