Laterally Coupled BST/Sapphire High Overtone Bulk Acoustic Resonators Exhibiting DC Tunable Comb Filter Response with High $Q.f$ Product

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***Summary* — In this paper, the use of laterally coupled barium strontium titanate (BST) based high overtone bulk acoustic resonators (HBAR) for RF comb filter applications is investigated. $Ba_{0.5}Sr_{0.5}TiO_3$ (BST) being in its paraelectric phase, the DC dependence nature is exploited for studying capability of tuning the 2-port device and exploring the enhancements such categories of devices has to offer. The individual resonators having the capability of exhibiting high *Q* multimode across a wide frequency spectrum, the 2-port device does provide multiple filter passband which are periodically spaced in the measured frequency range of 300 MHz to 10 GHz. The effect, DC biasing has on the filter response is studied and is found that the biasing conditions significantly enhances the *Q* and the bandwidth (BW) of the filter. *Q.f* product in the range of 4×10^{13} Hz (with BW around 65 kHz) with DC tunabilty is reported for one of the filter modes.**

Keywords— Higher overtone, comb filter, tunability, narrow bandwidth, high Q factor.

I. Introduction

HBARs find applications in material characterizations, microwave source and RF filters [1]. Recent developments points towards the use of HBARs as phonon sources in hybrid quantumacoustodynamic (QAD) circuits due to its capability of exhibiting extremely high Qs in cryo-temperature [2]. Works on HBARs have focused on exploring new high Q (low acoustic loss) materials as the substrate, optimization of electrodes, acoustic impedance matching of the material stack for optimal acoustic wave transfer and utilization of new transducer materials enhancing the overall resonator performance [3].

Spectrum sensing schemes which scan and identify the usage of the RF spectrum require MEMS resonators which can give a comb filter/spike train filter response with multiple passbands which are periodic in nature exhibiting high *Q*. For such requirements, the use of multiple single passband MEMS filters are not considered rather the use of LOBARs and HBARs which demonstrate multiple trains of equally spaced resonant modes across a wideband of frequency is preferred [3]-[5].

In this work, laterally coupled BST based HBARs is explored as for RF comb filter application. The HBARs are coupled acoustically instead of being configured in a typical ladder filter topology (electrical coupling). As a result, the device complexity reduces both in design and fabrication (as

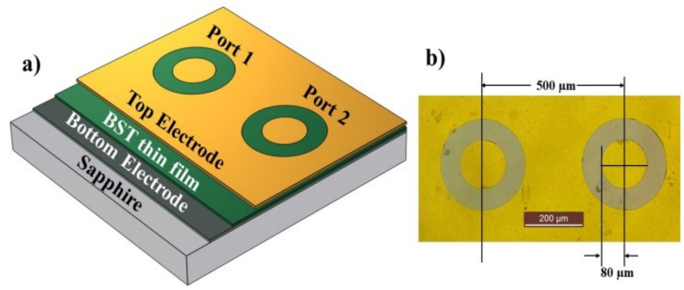

Fig. 1: a) Schematic of the 2-port laterally coupled HBARs b) OM image of the top electrodes.

shown in Fig. 1). The use BST thin film allows for certain degree of reconfigurability in the filter response when compared with existing HBARs/LOBARs based RF comb filters which utilizes piezoelectric thin films. The BST based comb filter reported here shows DC controllability for multiple passbands occurring in the frequency spectra.

II. Experimental Results and Discussions

Fig. 1 shows the schematic of the device. Fig. 2 demonstrates that the 2-port HBARs which are acoustically coupled exhibits multiple filter responses. From the figure, it is clear that multiple filter passbands (~ 350) occur over a wide frequency spectrum with individual modes/passbands having a spacing (FSR) of 11 MHz which is determined by the thickness and

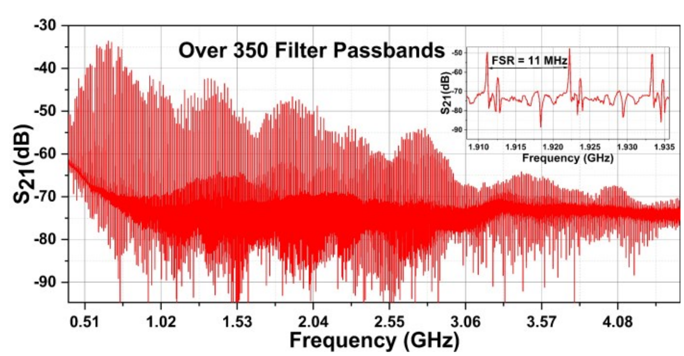

Fig. 2: Frequency response of the 2-Port laterally coupled HBARs.

acoustic velocity of the substrate being used. The spike train/comb filter response of the device proves that the multimode property of the HBAR can be harnessed to achieve smaller footprint and robust filters. 2-port measurements results are plotted in Fig. 3 where it is shown that without a DC bias applied, no passbands appear in the spectrum and the filter response are excited only upon application of either a positive or a negative DC bias. An interesting observation which needs further investigation are the excitation of higher frequency modes (C band) upon application of a negative bias voltage.

The coupled resonators show switchability due to the use of BST (induced piezoelectricity) [1]. Four filter passband responses at different narrowband windows are shown in Fig. 4. This plot confirms that the two separate HBARs are acoustically (in the lateral direction) coupled and exhibit a filter response. To explore the DC bias dependence nature of the device, varying DC voltages are applied across the transducer stack and its effect on one of the filter passbands at around 1.62 GHz is studied.

Fig. 5, shows the S_{21} response of one of the filter passbands with application of varying bias voltages from - 40 V to + 40 V. From this plot, it is observed that a) upon increasing the bias voltage from + 10 V to + 40 V, the center frequency (f_c) of the filter shifts towards the right (frequency increases) and b) upon decreasing the bias voltage from - 10 V to - 40 V, f_c of the filter tends shifts towards the left (frequency decreases). The case discussed here are when similar bias voltage is given for both

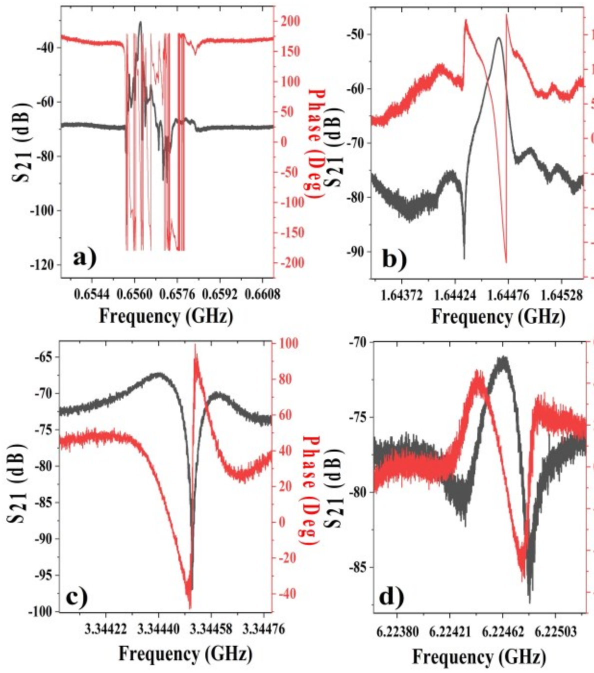

Fig. 4: Filter passbands at a) 656 MHz b) 1.64 GHz c) 3.34 GHz and d) 6.22 GHz.

ports during measurement. For the case when one port is fixed at a + 40 V biasing and the biasing in other port is varied from –

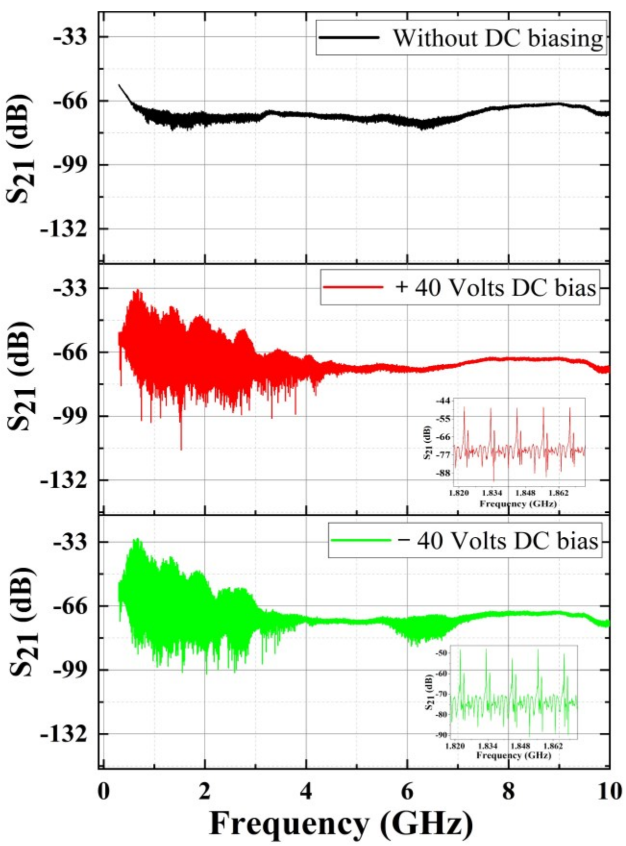

Fig. 3: Frequency spectra with and without DC bias.

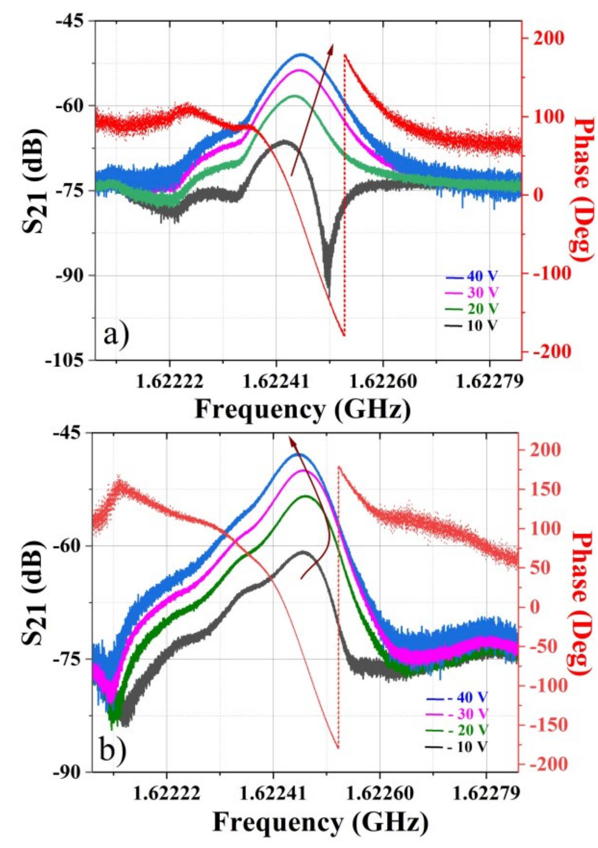

Fig. 5: DC bias dependence of the filter passband

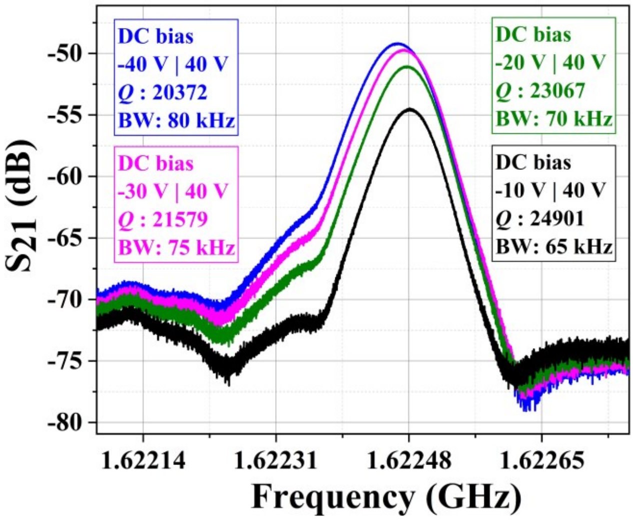

Fig. 6: Filter passbands performance with varying negative bias and fixed positive bias (unterminated filter response).

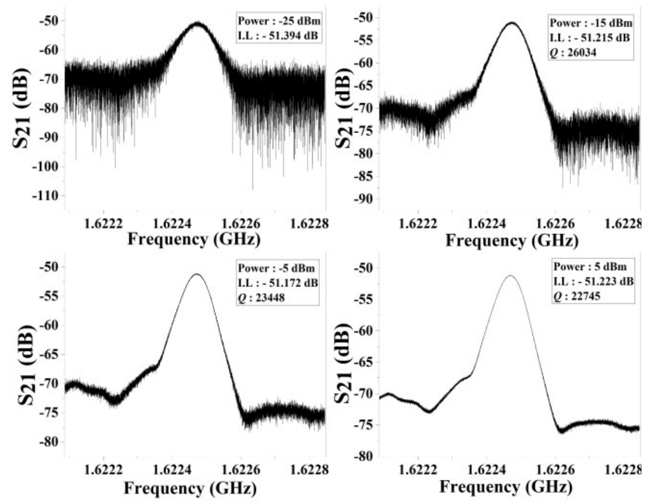

Fig. 7: Filter passbands performance with varying powers (unterminated filter response).

10 V to - 40 V, the filter performance in terms of B.W and Q factor is shown in Fig. 6. Here, it is observed that certain combination of DC biasing in the two individual HBARs can make significant improvement in filter performance and provide a scope for tuning the f_c. The power handling capability of the same passband is shown in Fig. 7 and no degradation in its response is evident. Even though heavily loaded by the substrate, such resonators can provide an easy way of band tuning capability for comb filtering applications which would be difficult for filters utilizing piezoelectric materials.

III. Conclusions

A reconfigurable DC bias dependent ferroelectric thin film based laterally coupled HBAR exhibiting comb filter response over a broad microwave frequency is demonstrated successfully in this work. The tuning capabilities and the Q controllability is also demonstrated with one of the filter passbands.

Acknowledgment

This work was supported by the Indian Institute of Science (IE/REDA-21-0065) and IoE, IISc. The authors would like to thank University of Hyderabad (SOP and CFN) for providing the thin films for device fabrication, and the fabrication (NNFC) and characterization (MNCF) facilities at the Centre for Nano Science and Engineering, Indian Institute of Science.

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