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Suppression of Unwanted B-mode of SC-cut Quartz Resonator
水晶 SC-cut 振動子の不要 B-mode の抑制

Morio Onoe[1†], Takeru Mutoh[2], and Takashi Yamaguchi[2]
([1]Professor Emeritus, University of Tokyo, [2]Nihon Denpa Kogyo Co. Ltd.)

尾上守夫 [1†]，武藤猛 [2]，山口貴士 [2]（[1]東京大學名誉教授， [2]日本電波工業株式会社）

1. Introduction

In OCXO applications, SC-cut quartz resonators are widely used, because of its better performances in temperature-frequency stability, drive level sensibility, stress-frequency stability, G sensitivity, frequency overshoot in start up and aging in comparison with popular AT-cut quartz resonators. Since the cut is double rotated, however, all three modes of vibration, quasi-longitudinal (A-mode), fast quasi-shear mode (B-mode) and slow quasi-shear mode (C-mode), are piezoelectrically excited by the same electrodes on major surfaces. Whereas AT-cut is singly rotated and hence only C-mode is excited. B-mode in SC-cut has a strong activity comparable to the activity of the main C-mode at the resonant frequency which is closely located to the resonant frequency of the main C-mode (circa 10 per cent higher). Since a conventional oscillator circuit has littel frequency selectivity, an addition of a filter is often required to avoid a wrong oscillation at the frequency of the unwanted B-mode. This hinders miniaturization of OCXO and spoils the stability. Hence it is desirable to find some means to suppress B-mode within a resonator itself.

Recently there have been a number of studies presented by Lepetaev et al., based on vector or space sharing of piezoelectrically induced surface charges on plural electrodes.[1-6] It has been effective in relatively thick resonators such as plano-convex 3rd overtone 10MHz resontors with the thickness of 0.54 mm at the center. The modes of vibration are mainly determined by the trapped energy effect, which will be explained later, due to the geometrical shape of the substrate itself. There are many inharmonic modes due to a large size of the substrate. Electrodes serve merely to collect induced charge and its shapes and positions have little effect on the distribution of induced charge. Hence an aim of design is to find shapes and positions of electrodes to effectively collect surface charge induced by the main C-mode and cancel out charges of opposite polarity induced by unwanted B-mode.

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e-mail: m.onoe@ieee.org, tmutou@ndk.com and tayamagu@ndk.com

Recent demands for OCXO in higher frequency range require the use of thinner substrate with the thickness less than 0.1 mm. Then modes of vibration are mainly determined by the trapped energy effect due to the mass-loading effect of electrodes and are localized under electrodes. Hence the distribution of induced charge varies with shapes and positions of electrodes. This makes difficult the use of traditional approach, which first determine the distribution pattern of induced charge and then seek the optimum shapes and positions of electrodes.

This paper presents a new approach in the opposite direction. There exists one and only one trapped-energy mode within the guard band of frequency, when the size of electrode is smaller than a threshold called Bechmann number. The vibration energy is trapped under the electrode and spureads outside as exponentially decaying evanescent wave. Such a resonator is called dot resonator after Curran. Another dot resonator is placed on the same substrate. If the distance between both dot resonators is far apart, both electrodes can be used as independent resonators with the same (degenerated) resonant frequency and the same volume and polarity of induced surface charge. (This situation is similar to Uni-Wafer by Curran et al.) Then leads to both resonators are cross connected. The resultant resonator shows no piezoelectric response, because the sum of collected induced charge is canceled out.

Reduction of the distance between both electrodes causes an elastic coupling even through evanescent wave. It breaks the degeneration between two resonators yielding two resonant frequencies instead of one. At the lower resonant frequency, the polarity of induced charge is the same and hence no response is obtained at the cross-connected electrical terminal. This mode is called symmetric mode. Whereas, at the higher resonant frequency, the polarity of induced charge is opposite and piezoelectric response is obtained at the cross-connected terminal. This mode is called anti-symmetric mode.

The new approach utilizes the third rotation of electrode pattern in the plane of the substrate, which retains most of favorable features of SC-cut.

The target is to seek a rotation angle to suppress B-mode.

2. Trapped-Energy Modes

A brief review of trapped-energy modes will be in order before further proceeding.

In 1961, Bechmann experimentally found in high frequency AT-cut quartz resonators that spurious modes around the main C-mode rapidly diminish when the ratio of the diameter of a circular electrode and the thickness of the substrate is smaller than a threshold, which is now often called Bechmann number (revised later to include mass loading effect of electrode).[7] Also in 1961, Curran et al. experimentally found that a number of small electrodes placed on a ceramic substrate can be used as independent resonators without mutual interference to realize a ladder type filter, which was named Uni-Wafer filter.[8]

Both findings could not be explained by traditional view that the mode of vibration is determined by the whole substrate and electrodes merely serve to collect induced charge.

An explanation for these findings was given by Schockley et.al., which is based on the dispersion of elastic guided wave, including cut-off phenomena.[9,10] Their interest was limited to symmetric modes, however, little attention was paid on anti-symmetric modes. One of the authors (M.O.) showed that proper uses of both symmetric and anti-symmetric modes yields true lattice type filters. The coupling between dot resonators was also discussed, which became a basis of modern monolithic filters (MCF) and the present study, too.[11]

3. B-mode suppression by in-plane rotation

Resonant frequency and motional capacitance of C-mode and B-mode in a pair of dot resonators are calculated by FEM(ANSYS) as functions of in plane rotation angle. Good suppression of B-mode is available around rotation angle of 90 degree in both square and circular dot resonators.

Fig. 1 shows a typical performance of a pair of 0.5 x 0.5 mm square with 0.1 mm gap at angle of 86 degree.

Since vibration energy of B-mode leaks out in the surroundings, further improvement of the suppression of B-mode due to propagation loss is expected.

Impedance level can be lowered a parallel connection of plural resonator pairs placed far apart in the same plane.

4. Conclusion

Good suppression of B-mode in SC-cut is obtained in cross connected and coupled dot resonators vibrating in anti-symmetric mode at the third rotation angle of circa 90 degree.

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Fig. 1 Details at rotation angle of 86 degree.

Mode	C-Mode	B-Mode
Freq. (kHz)	20409.54	22298.14
C1 (fF)	0.221	0.033
Displacement at surface Displacement in cross-section