Novel method for identification of intrinsic vibration modes in piezoelectric crystals

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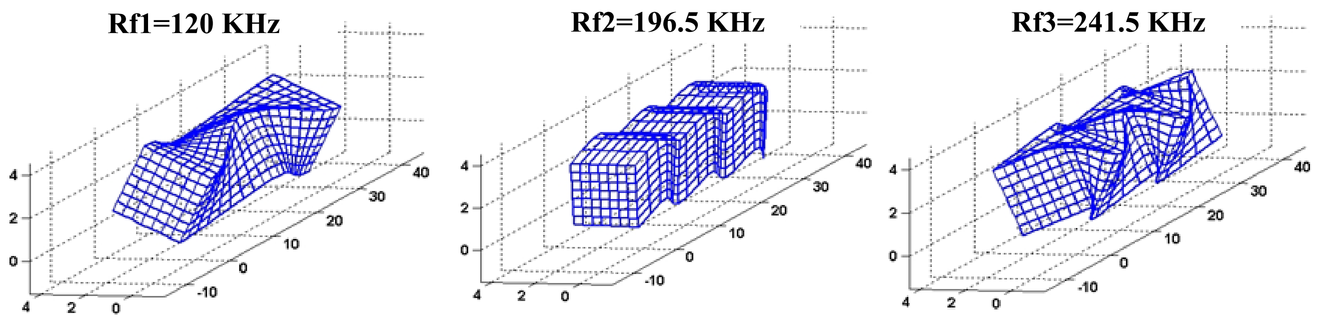
Variety of practical applications of dielectric piezoelectric crystals in scientific experiments as well as in everyday life can be compared with that of semiconductor crystals. Moreover novel surprising applications of piezoelectric crystals in nonlinear optics have only recently been established [1, 2]. With respect to development of theoretical models that can explain behavior of the crystal in certain experimental conditions the considerable retardation is the case in relation to semiconductor physics and semiconductor devices. One of the most important property of piezoelectric crystals that is exploited consists in explicit response (piezoelectric resonance at certain frequencies Rf_n, n-mode index) to the applied radiofrequency electric field. However microscopic model of this unique phenomenon is not developed so far. Moreover there is no macroscopic model that can describe dependence on frequency of line forms of experimentally observed piezoelectric resonances. Discrepancy of line form amplitudes and widths experimentally measured in certain crystal can substantially vary. Great amazement arise the fact that quantity of resonances calculated from model approximation doesn't correspond to the quantity of measured ones [3]. Number of resonances obtained from theory can exceed that of experimentally measured by more than a factor of ten. Problem of large quantity of calculated modes and its identification becomes more complicate because one experimentally measure mode can be at the same time attributed to several calculated modes that are close in frequency. In practice because of unavoidable experimental errors it is impossible to identify reliably the experimental mode with calculated one. In case of mode identification mismatches the calculation of physical parameters of the crystal using experimentally measured piezoelectric resonance frequencies becomes impracticable. For authentic determination of the elastic and piezoelectric constants, which amount depends on the crystal symmetry, the number of identified modes should be several times higher than that of nonzero elastic and piezoelectric constants.

In present paper we introduce novel method for identification for resonance modes in piezoelectric crystal. This method is based on recently proposed theoretical model of piezoelectric resonance frequencies dependence on temperature $Rf_n(T)$. Calcualtion of Rf_n is based on Lagrange-Hamilton variation principle. Lagrangian for piezoelectric crystal includes not only potential energy of deformed crystal together with kinetic energy of vibrating points but also the energy term related to piezoelectric properties. For calculating the dependence of piezoelectric resonance frequencies on temperature we used crystal temperature dependent tensors: elastic, piezoelectric and dielectric. For mathematical solving the components of the sample points mechanical displacement as well as electrical potential should be expanded in some set of basis functions. As a result, the Lagrangian is dependent on the expansion coefficients and equations for the eigenmodes are obtained by Lagrangian differentiation in the components. Below calculation results of three intrinsic vibration modes are shown. Calculations were performed for quartz crystal 3×3×30 mm^3 cut along crystallographic axes



Comparison of temperature dependencies of the measured and calculated resonance frequencies reveals reliable method for identification of vast majority of the experimentally measured resonance modes. It should be emphasized that amplitudes of the experimentally measured piezoelectric resonances strongly differ from each other and mathematical criteria for theoretical analysis of intrinsic vibration mode amplitudes aren't devised so far.

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