1P1-8

Discovery of avoided crossing of mechanical resonances during temperature change in piezoelectric materials

圧電体における温度変化による力学的共振擬交差現象の発見

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1. Introduction

Avoided crossing is the phenomenon, which could appear in two coupled harmonic oscillators; their eigen frequencies repel each other even when their energies become nearly the same, and they cannot get crossed. For example, the mass-spring systems shown in Fig.1 reflects this phenomenon.[1] We assume that k_A shows negative temperature dependency and k_B shows positive temperature dependency, and the coupling spring constant ε is much smaller than k_A and k_B (k_A, $k_B \gg \varepsilon$). Without the spring ε, the resonant frequencies cross each other when temperature is changed as shown in Fig.1(b). With the spring ε, however, the frequencies fail to intersect, but the vibration modes of the two resonator systems switch each other at the avoided crossing point. The larger the spring constant ε, the wider the gap frequency at the avoided crossing. Therefore, the gap width indicates the strength of the interaction between two systems. In addition, Landau-Zener effect[2], which indicates degrees of nonabiabaticity between two systems, is a typical example of the avoided-crossing phenomenon. Thus, avoided crossing implies that a system interacts with other systems.

We reveal that temperature change causes avoided crossing in mechanical resonant frequencies. This indicates that interaction works between mechanical resonant modes.

Resonant frequencies of rectangular parallelepiped materials are calculated from dimensions, mass density and elastic moduli within linear theory of elasticity[3,4]. Temperature dependence of resonant frequency is thus obtained by calculating resonant frequency for each temperature using thermal expansion coefficient and experimental data of temperature dependencies of elastic moduli[5]. We find that the temperature change of resonant frequency calculated in this method can reproduce avoided crossing between modes in the same vibration group, but fail to reproduce it between modes in different vibration groups. Hence, we consider that avoided crossing between resonant modes in different vibrational groups relates to a coupling phenomenon which cannot be explained with the linear elasticity theory. Then, we measured temperature dependence of resonant frequency of the piezoelectric crystals by changing the excitation power for making the resonances.

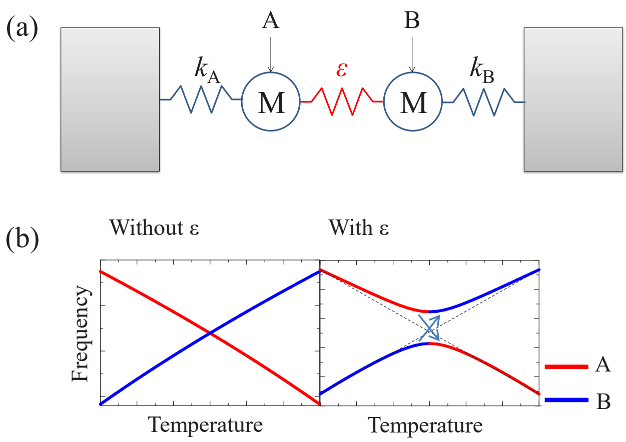


Fig.1 (a)Mass-spring system which causes avoided crossing. (b) Temperature behaviors of the two resonant frequencies.

2. Sample

The sample used in this study is α-TeO_2 crystal, which is a tetragonal material and reported to exhibit unique properties, including a negative Poisson's ratio[6]. The sample measures 7.4×8.3×9.3 mm^3, and each side is parallel to the crystallographic *a*, *b* and *c* axis.

3. Experiment

We put the sample in a cryostat and refrigerate it in vacuum by flowing Liquid-He inside the heat exchanger. To measure resonant frequencies, we used the antenna transmission acoustic resonance (ATAR) method[7], where vibrations of piezoelectric materials are excited by emerging oscillating electric field between two antennas, and they are detected by the other antenna through piezoelectric effect. We changed the resonance amplitude of the sample by changing the voltage applied to excitation antenna.

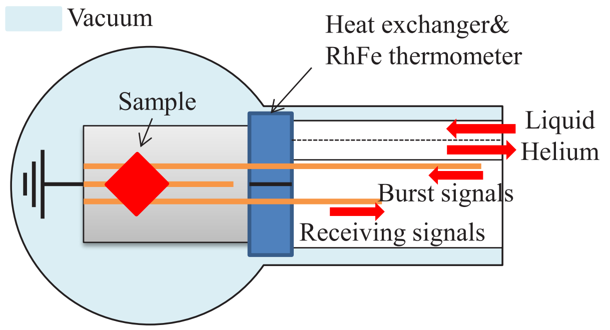
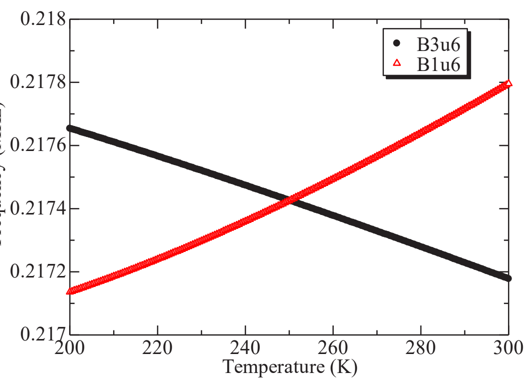


Fig.2 Schematic illustration of the ATAR experiment system.

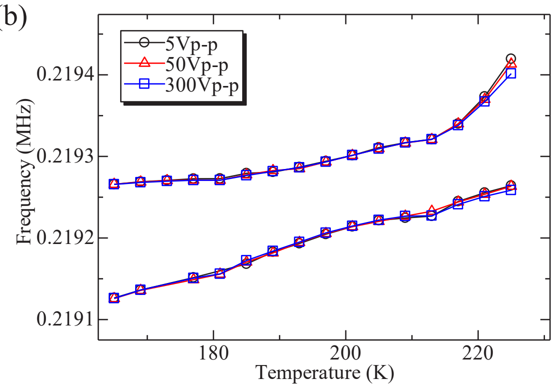
4. Results

We measured a pair of resonant frequencies which cross each other in the theoretical calculation of the temperature dependency as shown in Fig.3(a). On the other hand, their temperature behavior in experiment is obviously different from the calculation result, showing avoided crossing. We measured resonant frequencies while changing the magnitude of voltage to 5, 50 and 300 Vp-p, but no notable difference was found among their temperature behaviors. This result suggests that nonlinear elasticity fails to explain the avoided crossing, and there is unknown mode coupling mechanism inside this material.

(a)



(b)



(c)

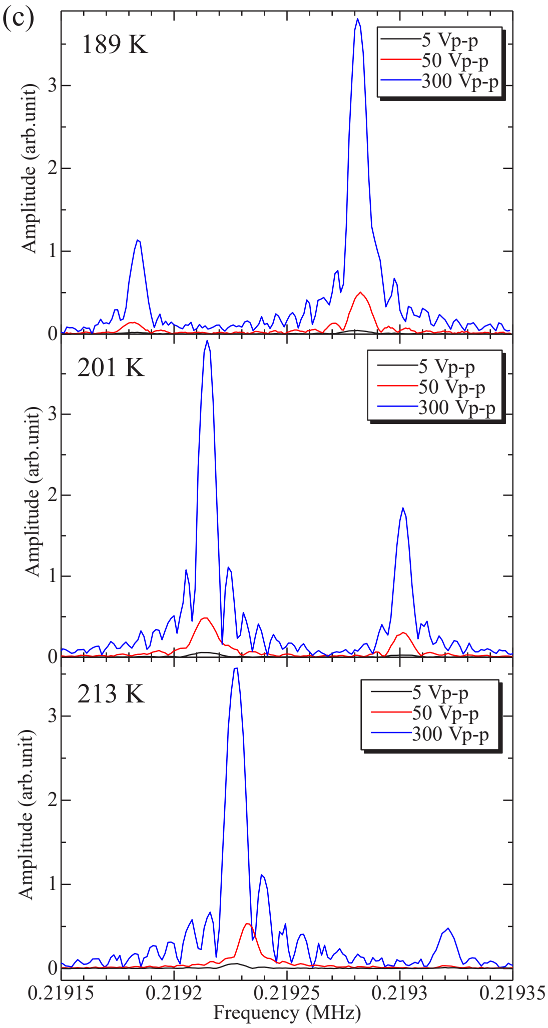


Fig.3 (a)Theoretical calculation and (b) experimental results of temperature dependency of resonant frequency. (c)Frequency spectra of the measuring results.

5. References

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