# Chiral phonons in helical single crystal Te by circularly polarized Raman spectroscopy

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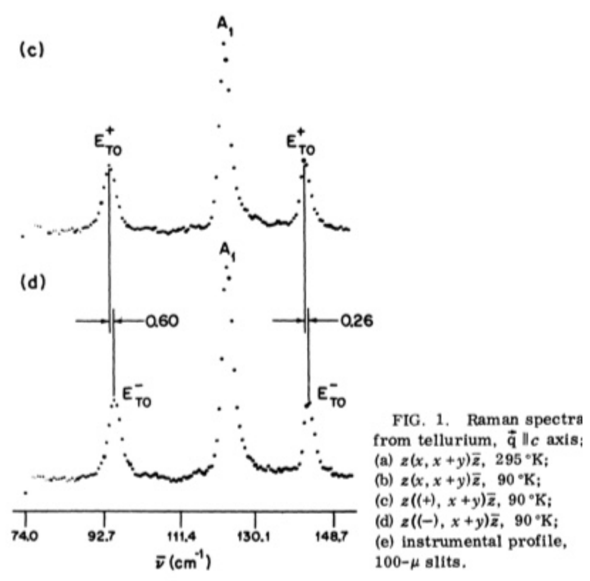
## Introduction

**Objective**

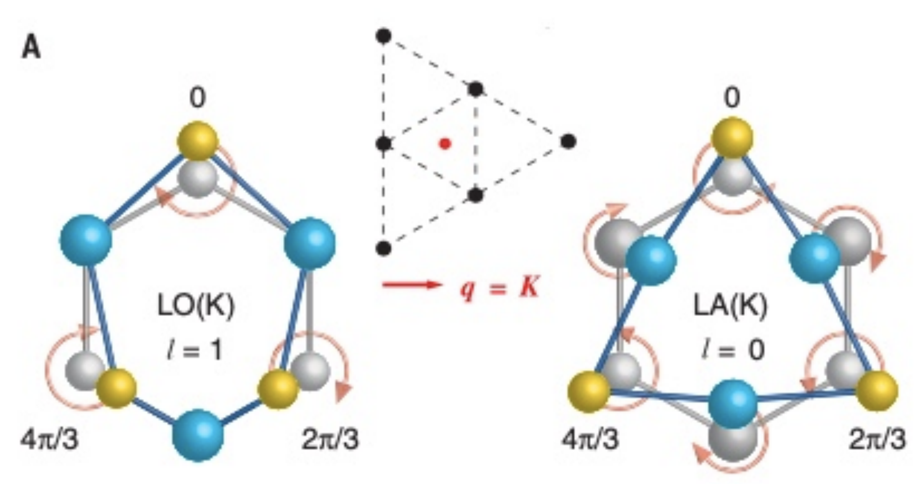
・Determination of handedness of helical single crystal Te by chiral phonon.

**Background**



*E*-mode phonon splitting in α-quartz

A. S. Pine et al. Phys. Rev. **188**, 1489 (1969).




Chiral phonon in $WSe_2$

H. Zhu et al. Science **359**, 579 (2018).

**Chiral phonon**

Phonons which have finite angular momentum and pseudoangular momentum (PAM)

## Material and Method

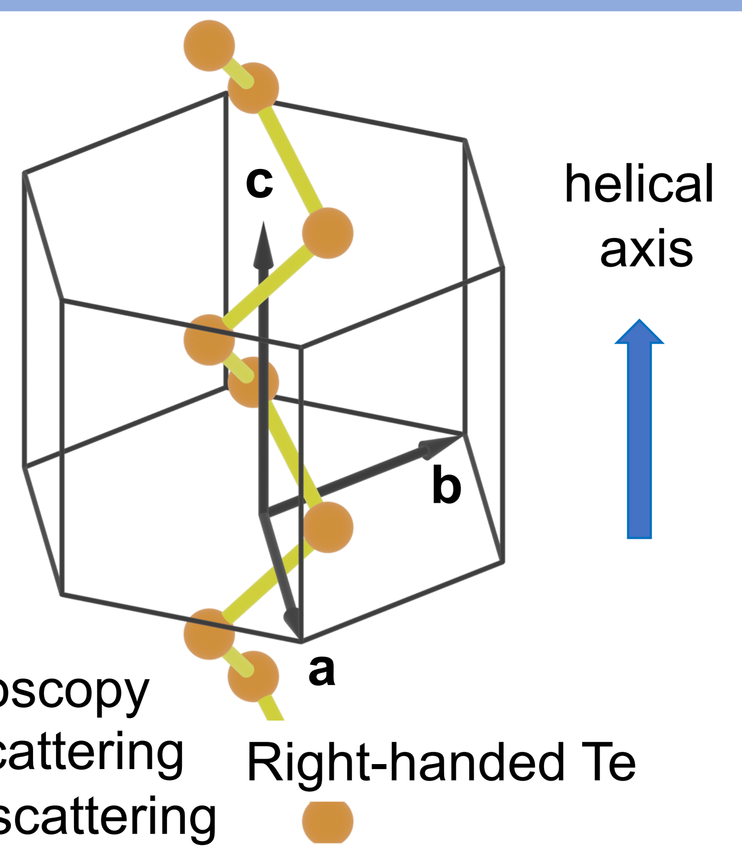
**Material**

Te (Tellurium)

・lack of inversion symmetry and mirror symmetry

・two enantiomeric structures ($P3_121$, Right-handed and $P3_221$, Left-handed)

・helical axis ($3_1$, Right-handed, $3_2$, left-handed)



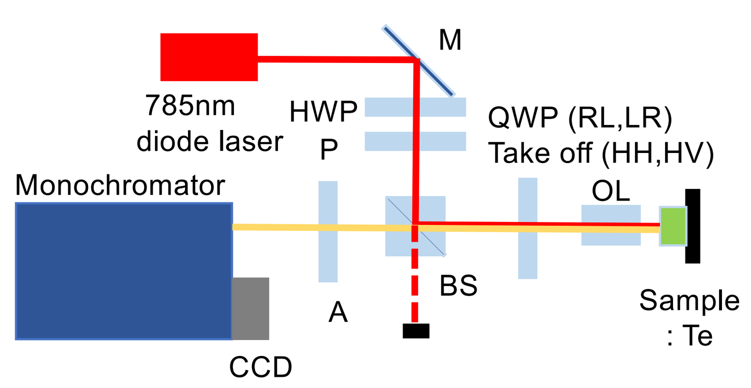

Right-handed Te

**Method**

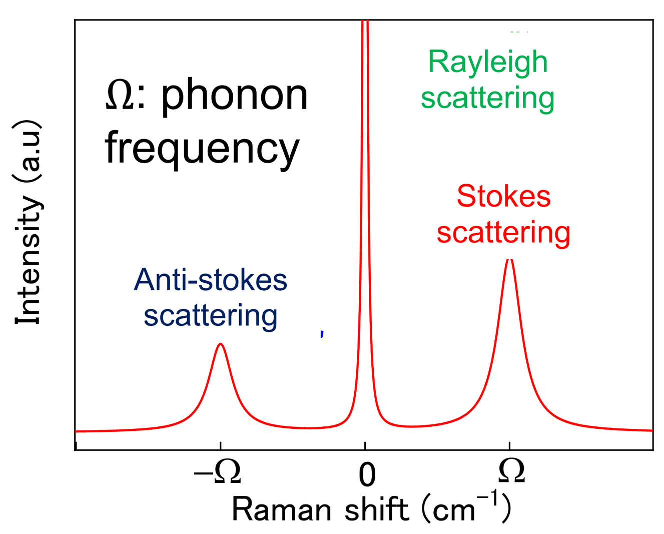
1. Circularly polarized Raman spectroscopy

・Inelastic circularly polarized light scattering

・photon frequency change through scattering corresponds phonon frequency




Experimental schematic




Raman spectrum

2. PAM calculation

・PAM originates from phase change by discrete helical rotational symmetry operation.

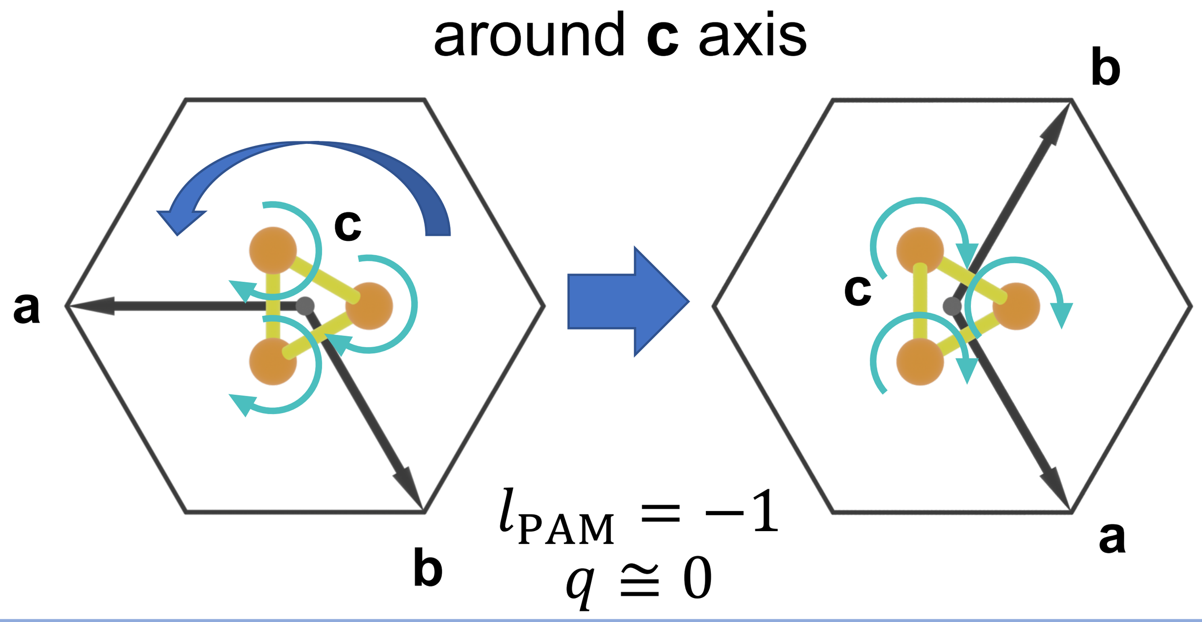
$$\left[C_3\middle|\frac{1}{3}\right]u = \exp\left[-i\left(\frac{2\pi}{3}l_{\mathrm{PAM}} + \frac{q\cdot c}{3}\right)\right]u$$

$\left[C_3\middle|\frac{1}{3}\right]$ : three fold helical rotation, $l_{\mathrm{PAM}}$ : pseudoangular momentum,

$q$ : wave number of phonon,

$u$ : eigenvector of dynamical matrix

Three fold helical rotation around **c** axis



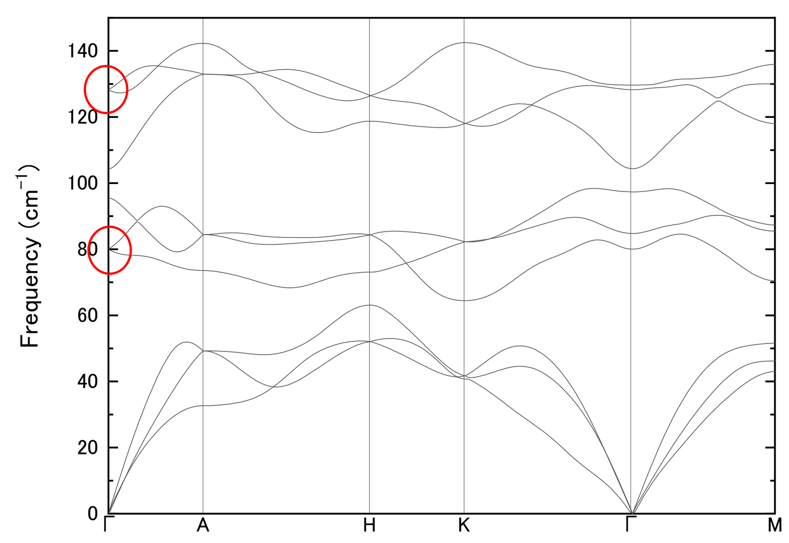

$l_{\mathrm{PAM}} = -1$

$q \cong 0$

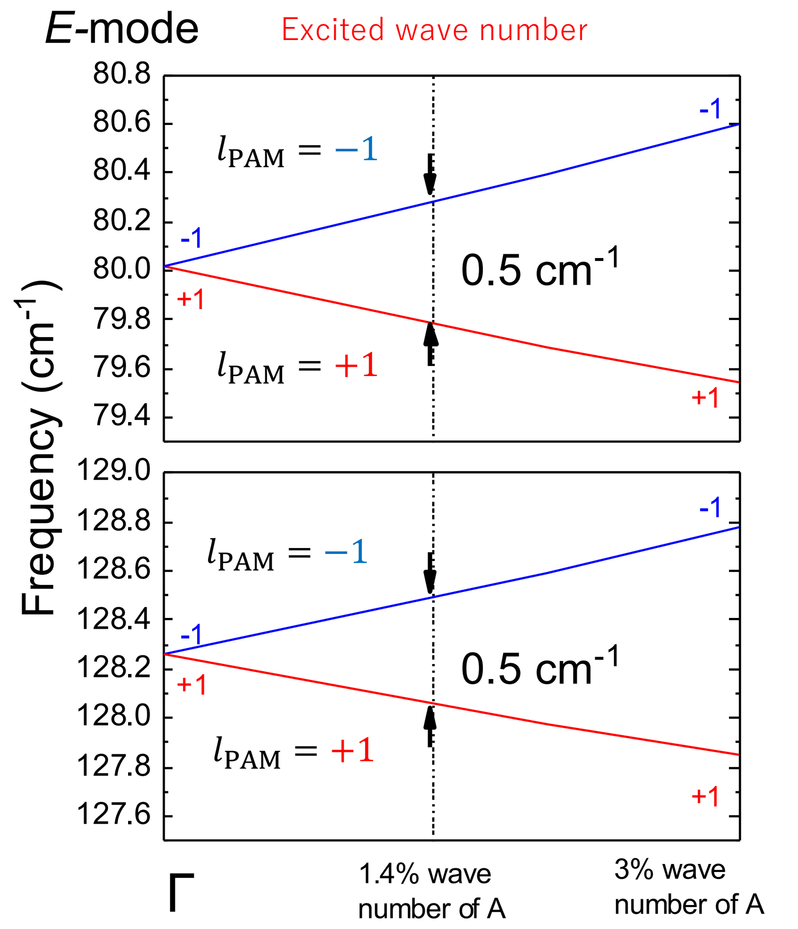
## Result and Discussion

**Result**

### Calculation

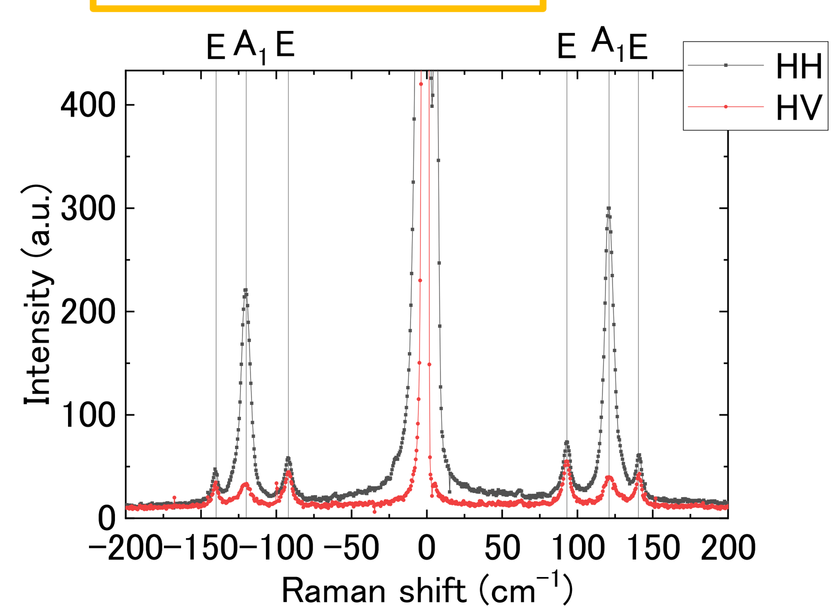


Phonon dispersion

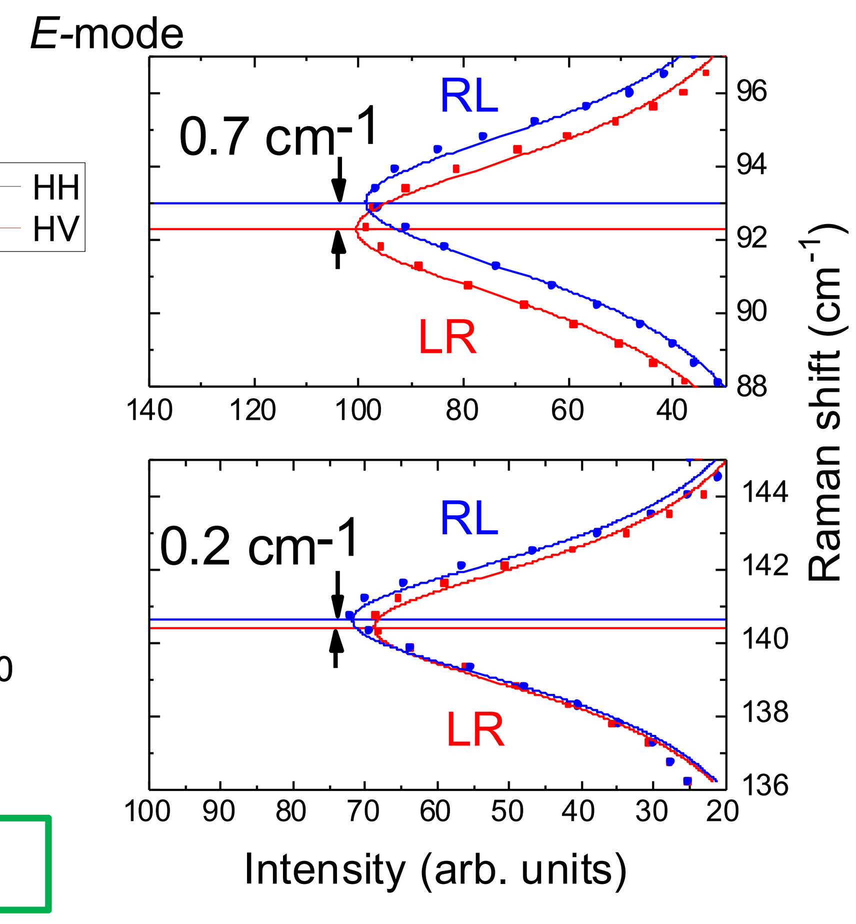



Right-handed Te

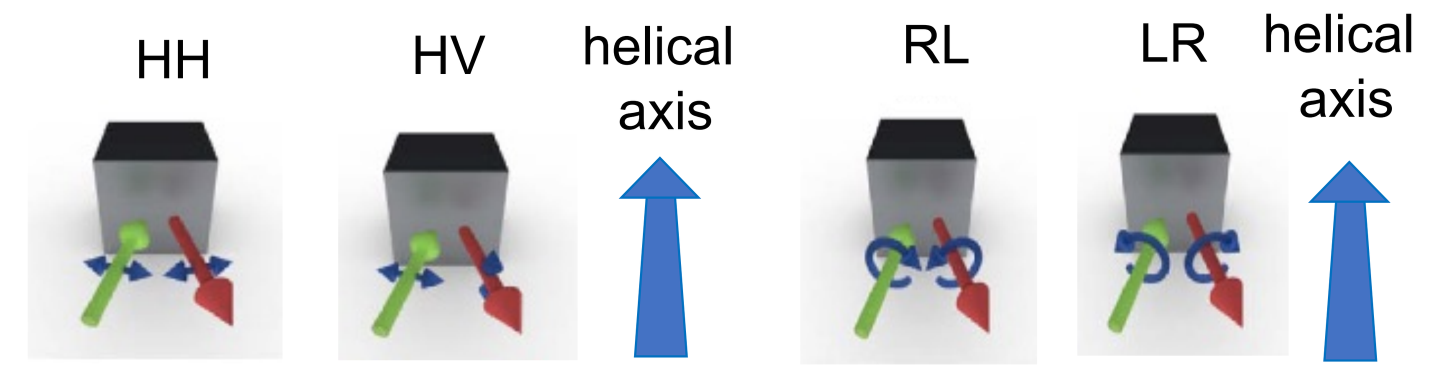
### Experiment




Raman spectrum




unknown handedness




Back scattering along c axis with linear and circular polarization

W. –H. Hsu et al. Phys. Rev. B **102**, 174432 (2020).

・$A_1$ and 2*E* modes are observed.

・*E*-modes split in RL and LR configuration.

・phonons at 1.4% wavenumber of A point are observed by momentum conservation law between photons and phonon.

**Discussion**

1. PAM conservation law :

$$\sigma_{\mathrm{i}} - \sigma_{\mathrm{S}} \equiv l_{\mathrm{PAM}} \pmod 3$$

$\sigma_{\mathrm{i,s}}$ : PAM of incident and scattering photons (R : +1, L : -1)

RL : $l_{\mathrm{PAM}} \equiv +1 - (-1) \equiv -1$

LR : $l_{\mathrm{PAM}} \equiv -1 - (+1) \equiv +1$

2. PAM of right-handed Te and experiment of unknown handedness Te are consistent.

PAM of left-handed Te is opposite in sign to that of right-handed Te.

→ We observe right-handed Te.

3. New method of chirality determination

・Non-destructive

・No solution needed.

## Conclusion

**Conclution**

・We measured chiral phonons in helical single crystal Te by circularly polarized Raman spectroscopy along the helical axis.

・*E*-mode split into two modes which are observed in RL and LR configuration, respectively.

・We identified handedness of helical single crystal Te by pseudoangular conservation law in Raman scattering process by comparison between experiment and *ab initio* calculation.