# Temperature Dependence of the Raman Spectra in GeSn Films

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## Introduction

- In Si-based optoelectronic integrated circuits based on optical interconnects, Si photonics using CMOS-compatible processes has been made great progress through the development of Si-based waveguides, photodetectors and modulators in the past several decades.
- The direct-bandgap GeSn laser fabricated on Si substrates has been carried out below the temperature of 230 K which opens a new opportunity towards a Si-based light source.
- GeSn-based optoelectronics devices, such as Laser, LED, photodetector and MOSFET, will play a pivotal role in Si-based optical interconnect circuits.
- Since thermal effects is one of the main causes for device failure, measurement of the local temperature is of great significance
- Temperature dependent Raman scattering provides a very useful tool for the study of anharmonic properties of crystal vibrations and has been used in diagnostic applications, such as in situ measurements of temperature.

## Temperature dependence of Raman Shifts and line width

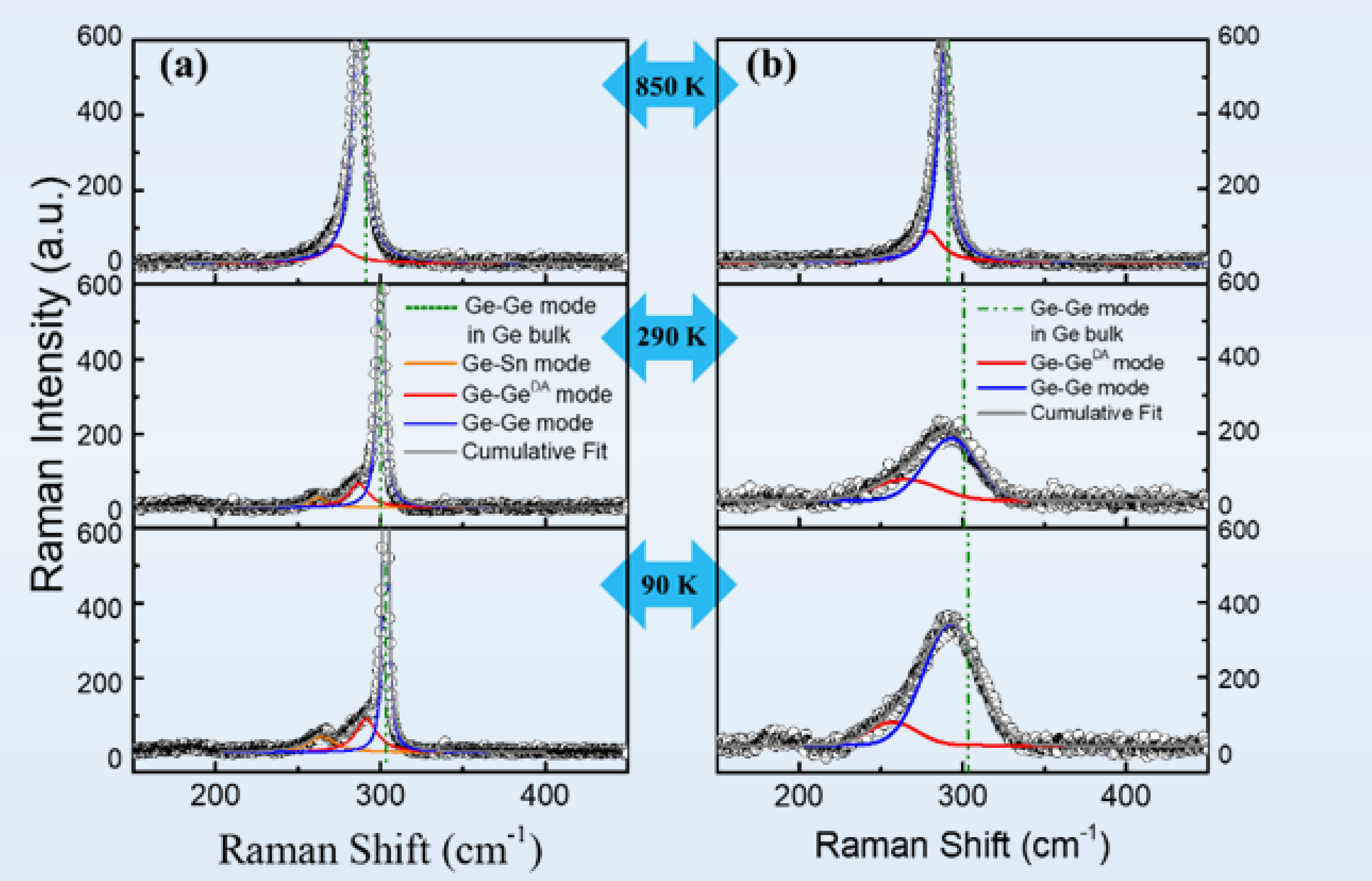


Figure 1. Raman spectra of (a) the $Ge_{0.95}Sn_{0.05}$ film sample and (b) the $Ge_{0.92}Sn_{0.08}$ film sample at the temperature of 90, 290 and 850 K. The vertical green line represents the Raman shifts of the Ge-Ge mode in the Ge bulk at the corresponding temperature.

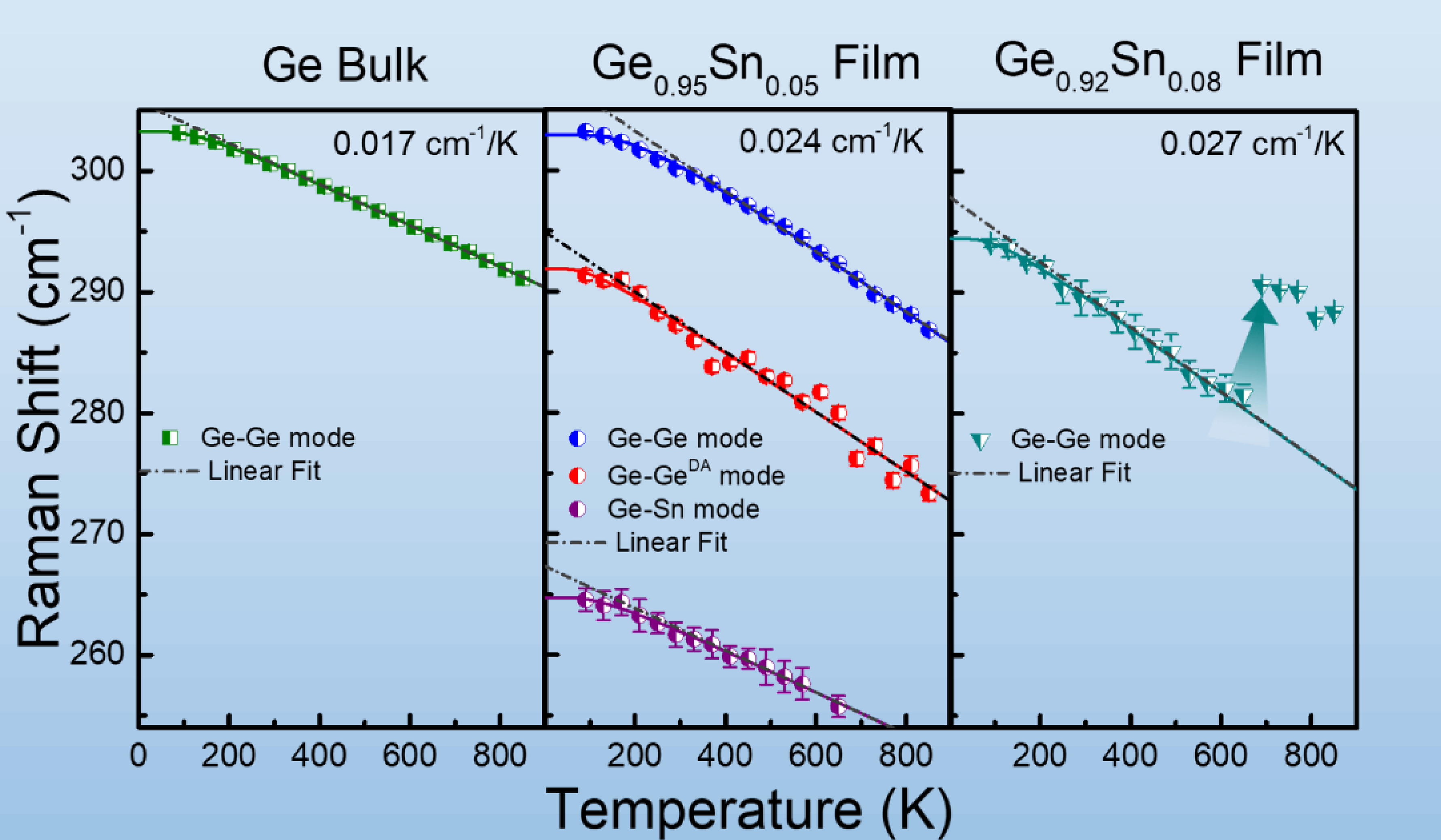


Figure 2. Temperature dependence of Raman shifts of vibration modes in the Ge bulk, the $Ge_{0.95}Sn_{0.05}$ film and the $Ge_{0.92}Sn_{0.08}$ film samples.

To describe phonon softening due to temperature increase, we used the following formula developed by Balkanski et al.,

$$\omega(T) = \omega_0 + A\left[1 + \frac{2}{e^x - 1}\right] + B\left[1 + \frac{3}{e^y - 1} + \frac{3}{(e^y - 1)^2}\right] \qquad (1)$$

Table 1. Calculated parameters from fit of Eqs. (1) to temperature dependence of the Raman shifts

| Samples | Ge Bulk | $Ge_{0.95}Sn_{0.05}$ Film | | | $Ge_{0.92}Sn_{0.08}$ Film |
|---|---|---|---|---|---|
| | Ge-Ge | Ge-Ge | Ge-Ge$^{DA}$ | Ge-Sn | Ge-Ge |
| $\omega_0$ (cm$^{-1}$) | 303.3 | 302.9 | 292 | 264.7 | 294.4 |
| A (cm$^{-1}$) | -0.19 | -0.20 | -0.32 | -0.17 | -0.32 |
| B (cm$^{-1}$) | -0.0010 | -0.0020 | 0 | 0 | 0.0015 |
| dω/dT$^{\#}$ (cm$^{-1}$/K) | 0.017 | 0.024 | 0.024 | 0.017 | 0.027 |

\# Temperature coefficient at the temperature range of 330 - 850 K

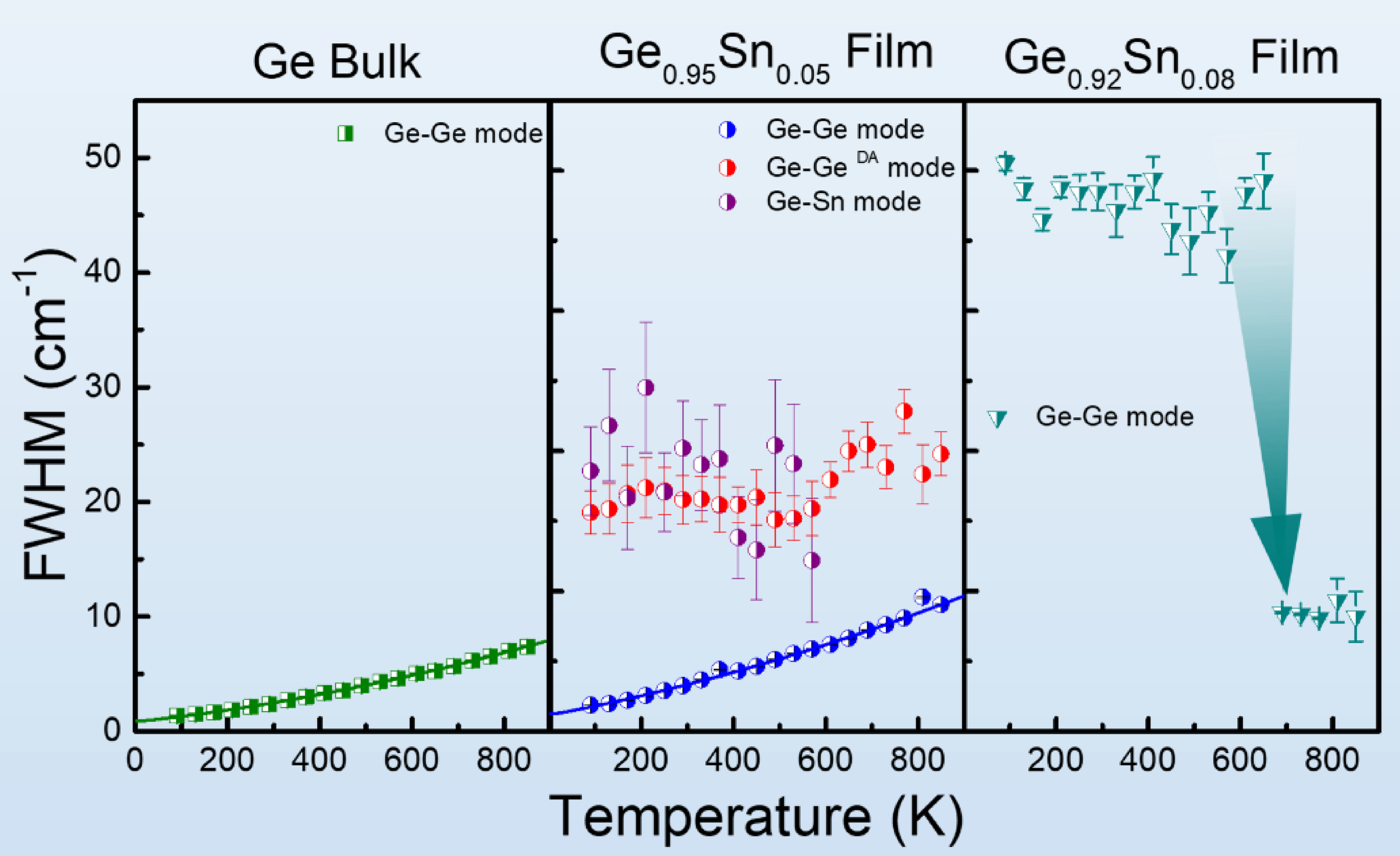


Figure 3. Temperature dependence of FWHM of vibration modes in the Ge bulk, the $Ge_{0.95}Sn_{0.05}$ film and the $Ge_{0.92}Sn_{0.08}$ film samples. .

## Conclusion

- Temperature dependence of the Raman scattering from the $Ge_{0.95}Sn_{0.05}$ and the $Ge_{0.92}Sn_{0.08}$ film samples were performed over the temperature range from 90 to 850 K.
- The nonlinear temperature dependence of Raman shifts for the Ge-Ge and the Ge-Sn modes has been observed and well described by an empirical formula.
- The first-order temperature coefficients of Raman shift for the Ge-Ge modes in the Ge bulk, the $Ge_{0.95}Sn_{0.05}$ and the $Ge_{0.92}Sn_{0.08}$ film samples at the temperature over 300 K were obtained to be 0.016, 0.024 and 0.027 cm$^{-1}$/K respectively. This result shows that the anharmonic decay process responsible for the temperature dependence is affected by the alloy perturbation in GeSn alloys.
- In addition, a sudden transition in Raman shift and line width for the $Ge_{0.92}Sn_{0.08}$ film sample at temperature of 650 K was observed, which was caused by the lattice relaxation and the Sn segregation.