Temperature Dependence of the Raman Spectra in GeSn Films

Tao Liu[1], Yuanhao Miao[2], Liming Wang[2], Guangjian Zhu[1], Zhenyang Zhong[1], Xinju Yang[1], and Zuimin Jiang[1,*]

[1] State Key Laboratory of Surface Physics, Department of Physics, Fudan University, Shanghai 200433, China

[2] Wide Bandgap Semiconductor Technology Disciplines State Key Laboratory, School of Microelectronics, Xidian University, Xi'an, 710071, China

Introduction & Motivation

- 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

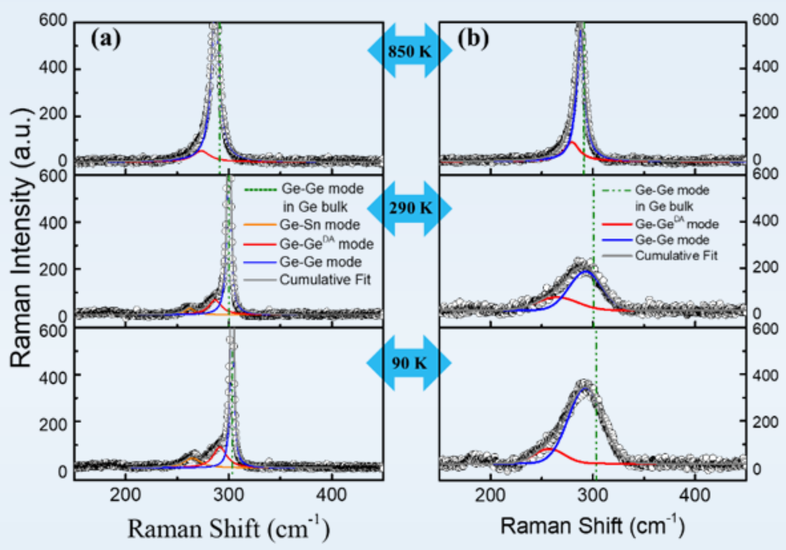

Figure 1. Raman spectra of (a) the $Ge_{0.95}Sn_{0.05}$ film sample and (b) the $Ge_{0.92}Sn_{0.08}$ film sample at the temperature of 90, 290 and 850 K. The vertical green line represents the Raman shifts of the Ge-Ge mode in the Ge bulk at the corresponding temperature.

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 shifte.

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
ω_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
$d\omega/dT$ [#] (cm^{-1}/K)	0.017	0.024	0.024	0.017	0.027

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

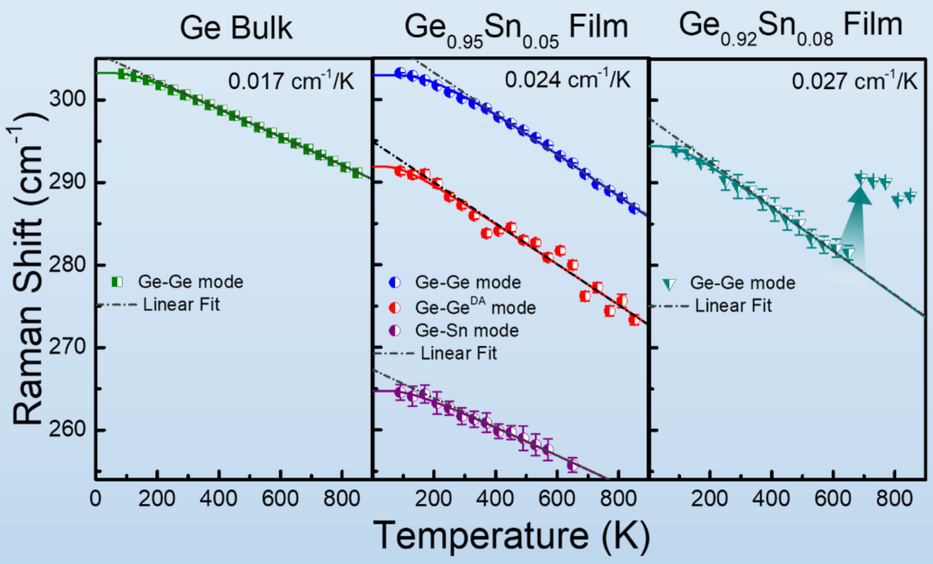

Figure 2. Temperature dependence of Raman shifts of vibration modes in the Ge bulk, the $Ge_{0.95}Sn_{0.05}$ film and the $Ge_{0.92}Sn_{0.08}$ film samples.

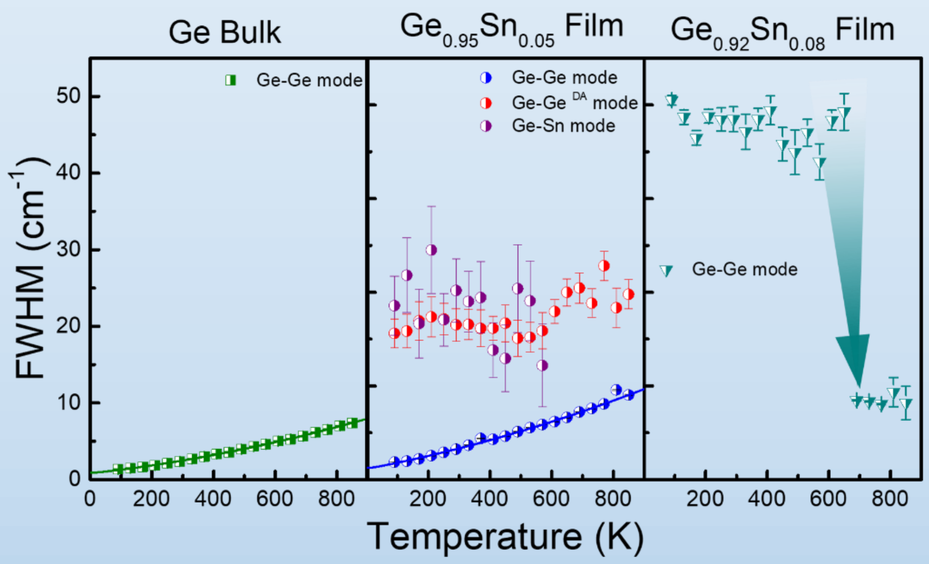

Figure 3. Temperature dependence of FWHM of vibration modes in the Ge bulk, the $Ge_{0.95}Sn_{0.05}$ film and the $Ge_{0.92}Sn_{0.08}$ film samples. .

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.