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## **Thermal conductivity reduction measurement on Ge and Si NWs: heterostructuration and diameter size effect.**

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## Purpose of this study

- Measuring the thermal conductivity  $\kappa$  of heterostructured nanowires,
- Evaluating the influence of diameter and heterostructuration on  $\kappa$ .

## Application to thermoelectricity

➢ Thermoelectric materials: conversion of thermal energy into electrical energy and vice versa (nanoheater, nanocooler, power generator)

➢ Thermoelectric efficiency evaluated by the factor of merit:

$$ZT = \frac{S^2 \sigma}{\kappa} T$$

$S$ : Seebeck coefficient (V/K),  $\sigma$ : electrical conductivity ( $\Omega^{-1}m^{-1}$ ),  $\kappa$ : thermal conductivity ( $Wm^{-1}K^{-1}$ ).  
Typical value for bulk material: 1 at best,  
Objective: at least 3.

➢ Interest of nanostructuration:

dimension reduction ( $<$  phonon mean free path)  $\Rightarrow$  phonon boundary scattering and group velocity reduction

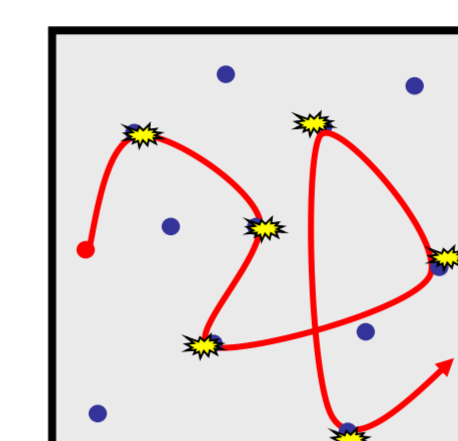
$\Rightarrow \kappa$  reduction

$\Rightarrow ZT$  increase

➢ Double challenge:

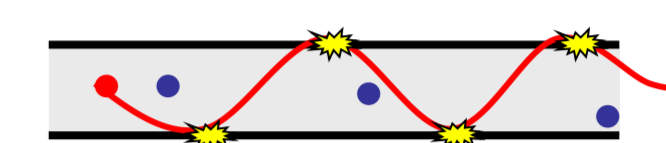
- find the best material with high  $\sigma$  and low  $\kappa$ : phonon glass and electron crystal  $\Rightarrow$  **semiconducting materials**,

- measuring  $\kappa$  at nanometric scale  $\Rightarrow$  AFM with thermoresistive tip in active regime: **3 $\omega$ -Scanning Thermal Microscopy (SThM)**.



Bulk

$\kappa$  limited by phonon-phonon  
And phonon-impurity interactions

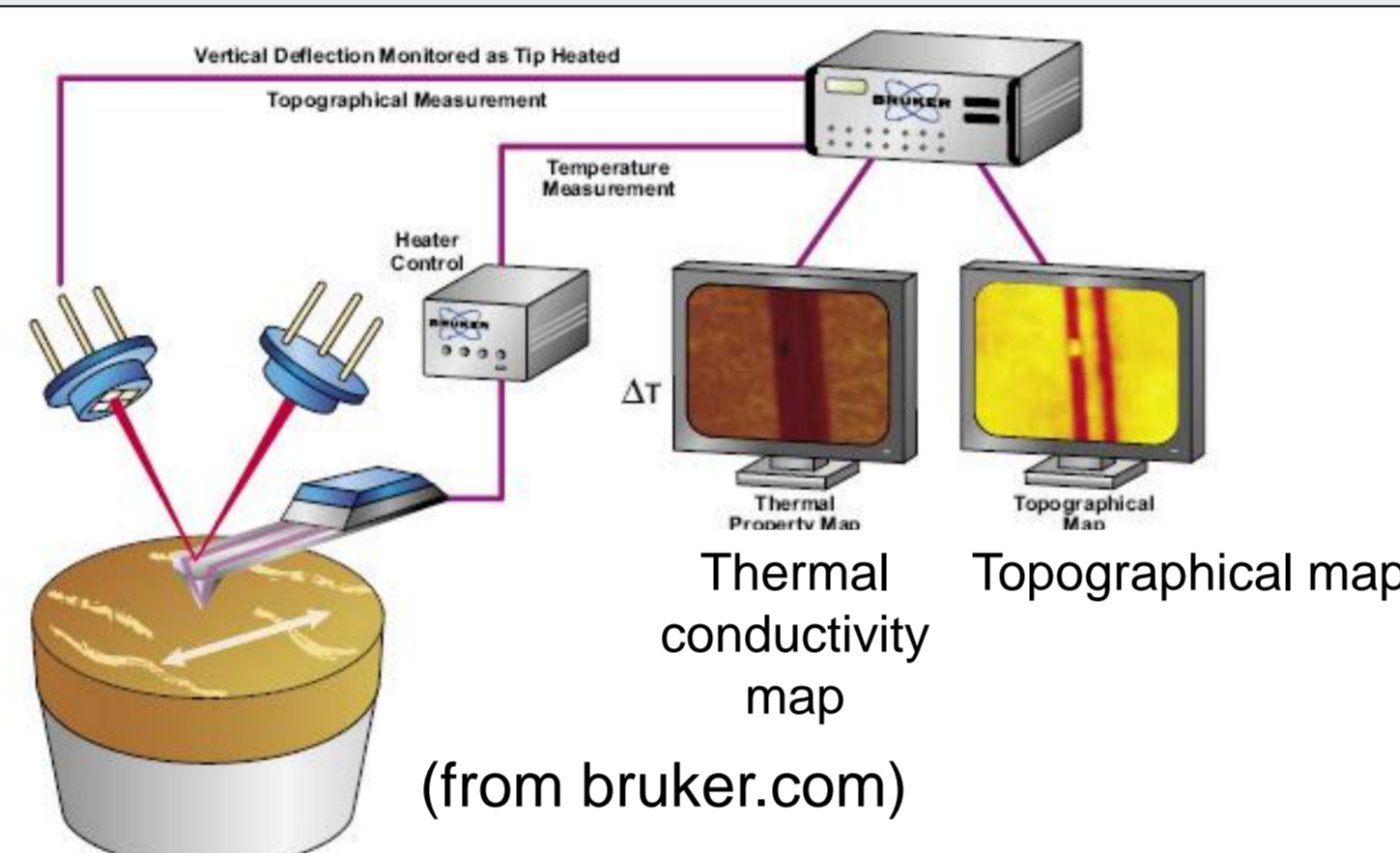
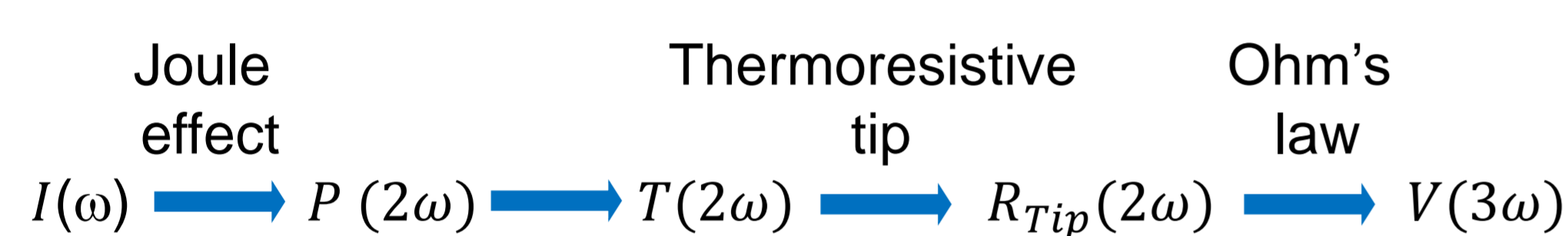


Nanostructured material

$\kappa$  limited by phonon boundary  
scattering

## Experimental protocole

➢ 3 $\omega$ -Scanning Thermal Microscopy (SThM):



➢ High  $\kappa \Rightarrow$  high heat flux  $\Rightarrow$  low  $T(2\omega) \Rightarrow$  low  $V(3\omega)$

➢ Simultaneously topographical and 3 $\omega$  - SThM thermal conductivity contrast images

➢ Only method to measure the thermal conductivity of individual nanowires (NWs) embedded in their matrix [1,2].

$$V(3\omega) = \frac{R_{Tip} \alpha_{Tip} I}{2} \times T(2\omega)$$

$\alpha_{Tip}$ : tip temperature coefficient ( $K^{-1}$ )

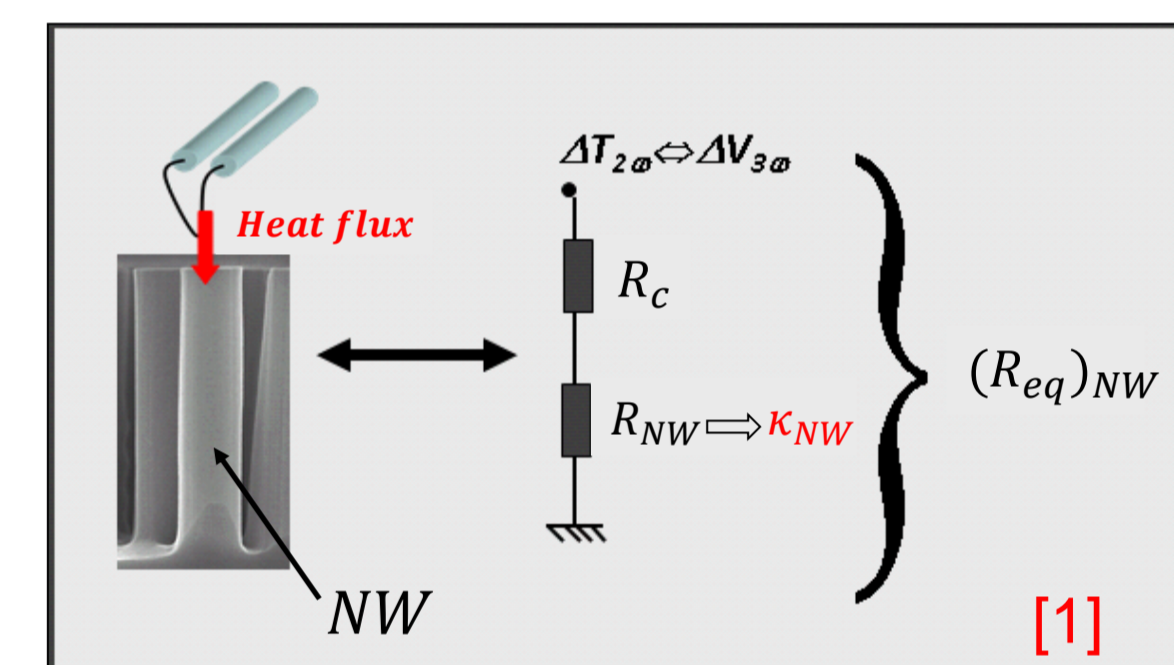
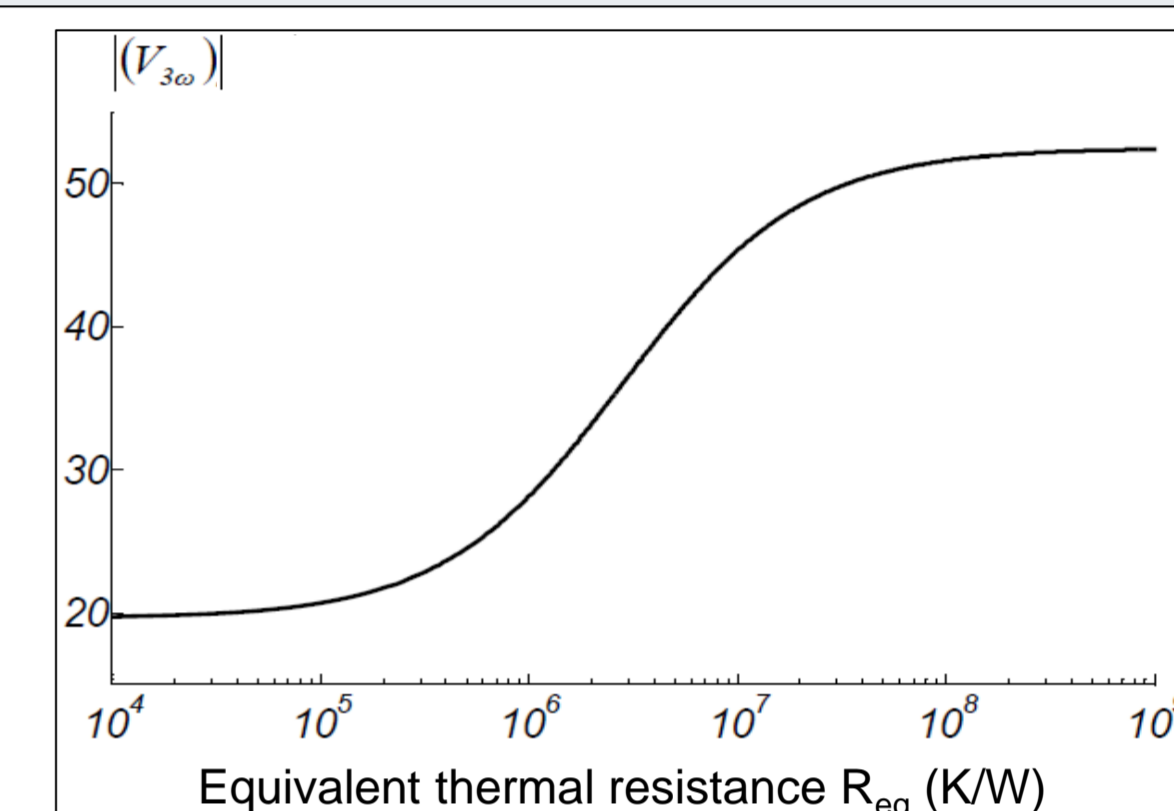
$T(2\omega)$

Tip thermal model

$(R_{eq})_{NW}$

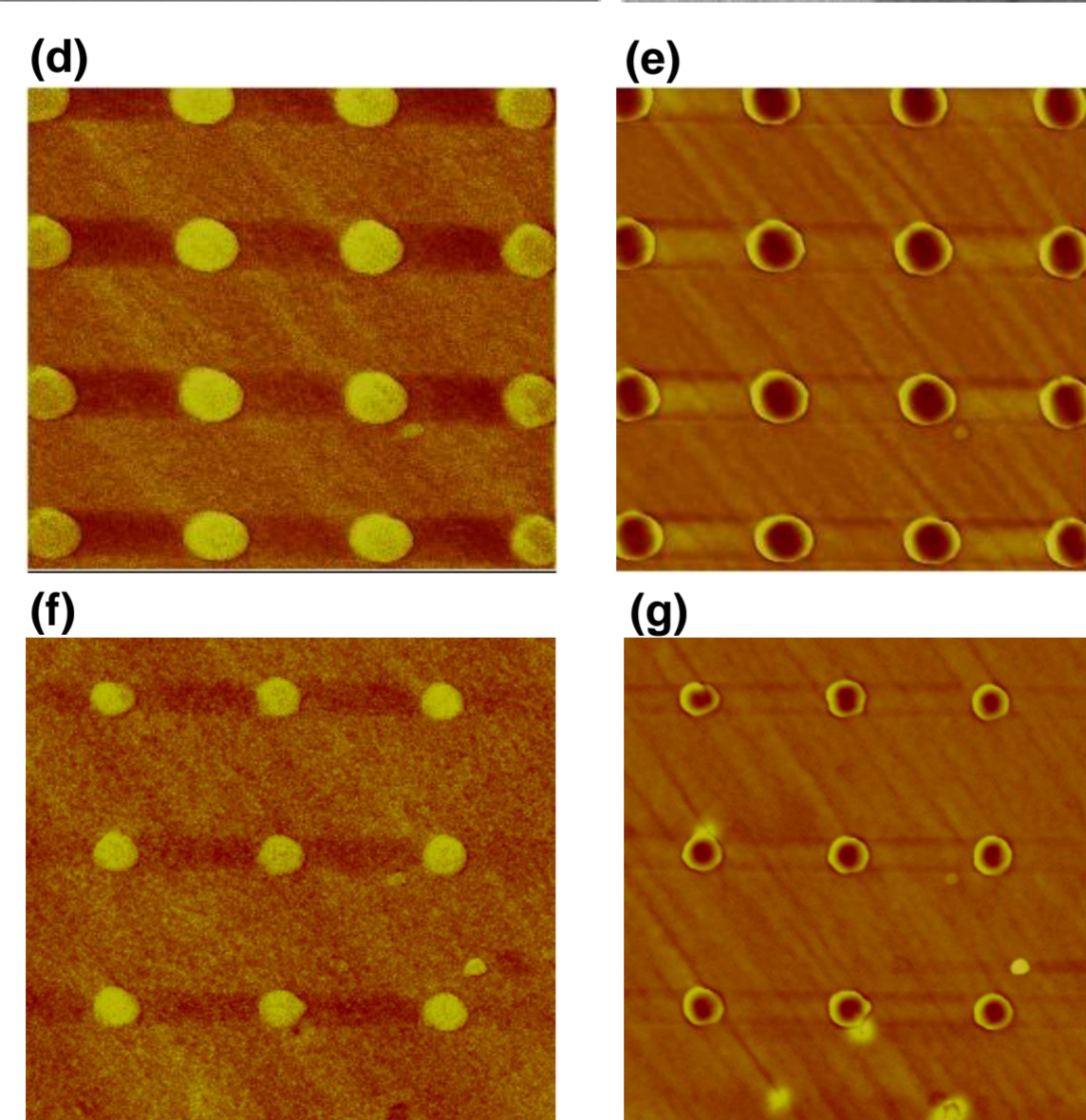
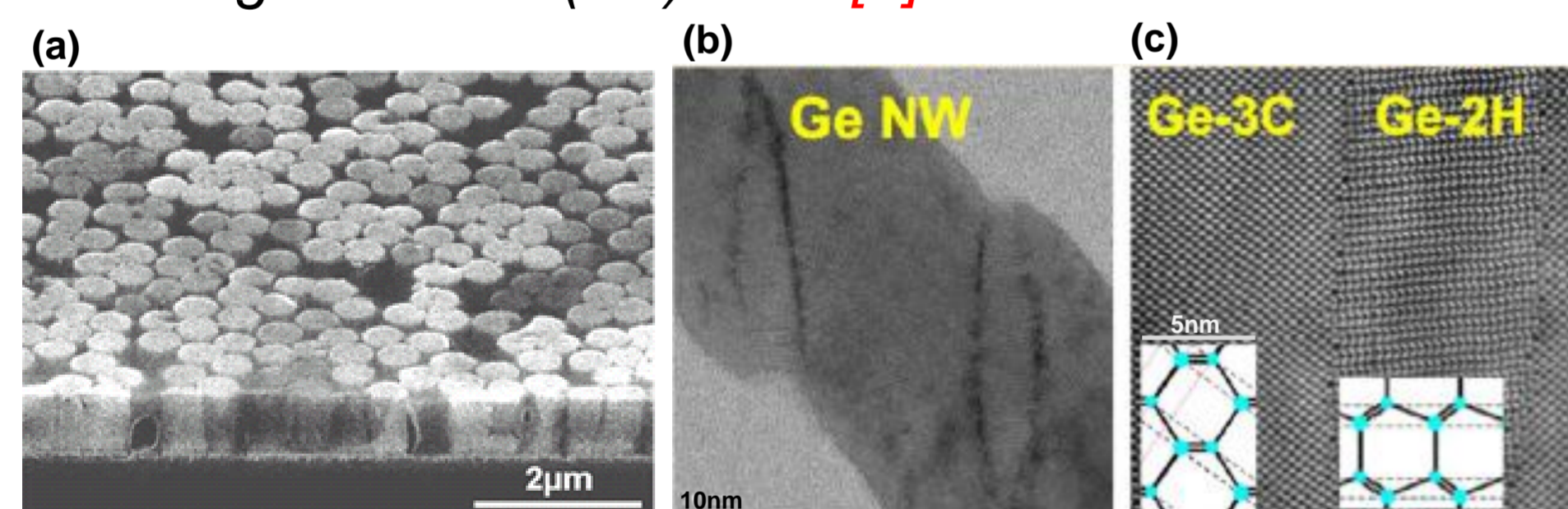
Tip-sample thermal exchange model

$\kappa_{NW}$

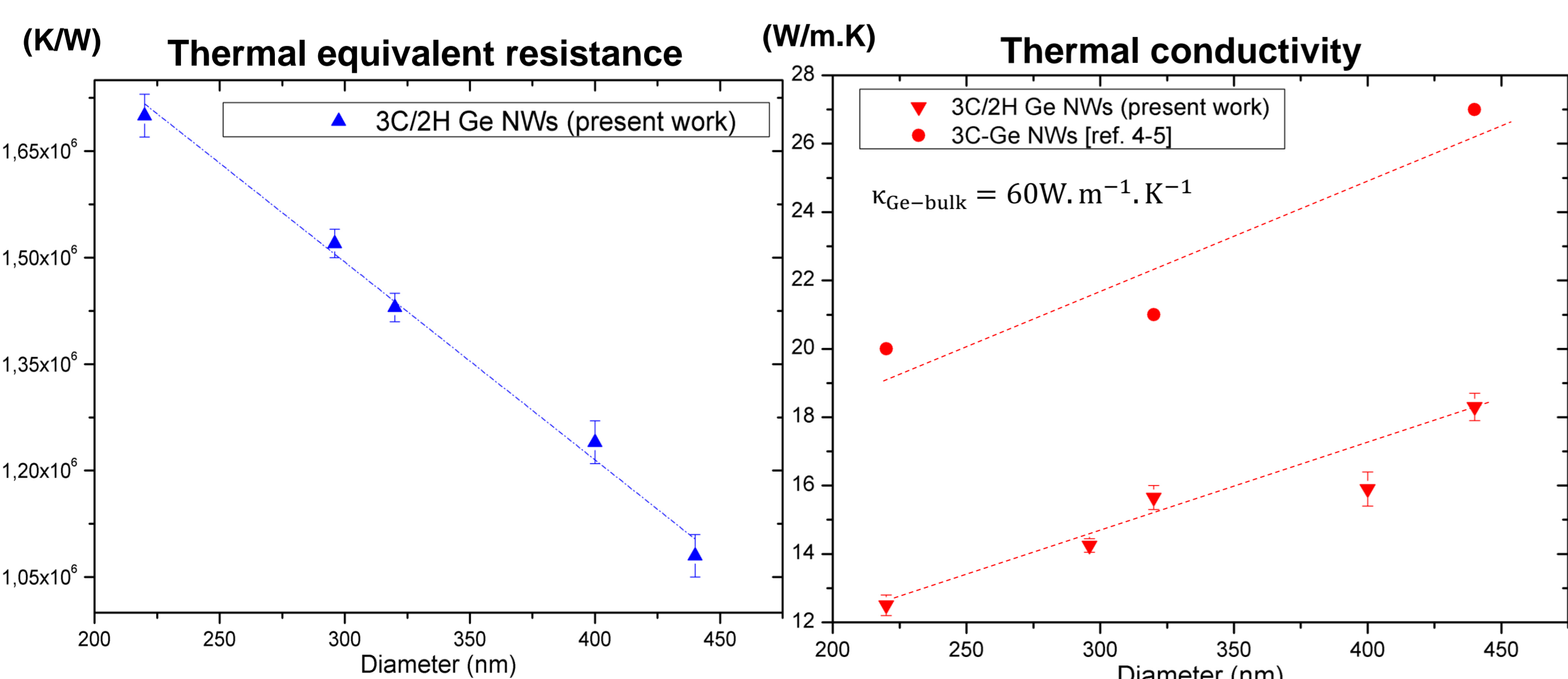


## Thermal conductivity of heterostructured nanowires (NWs)

➢ Heterostructured germanium (Ge) NWs [3]



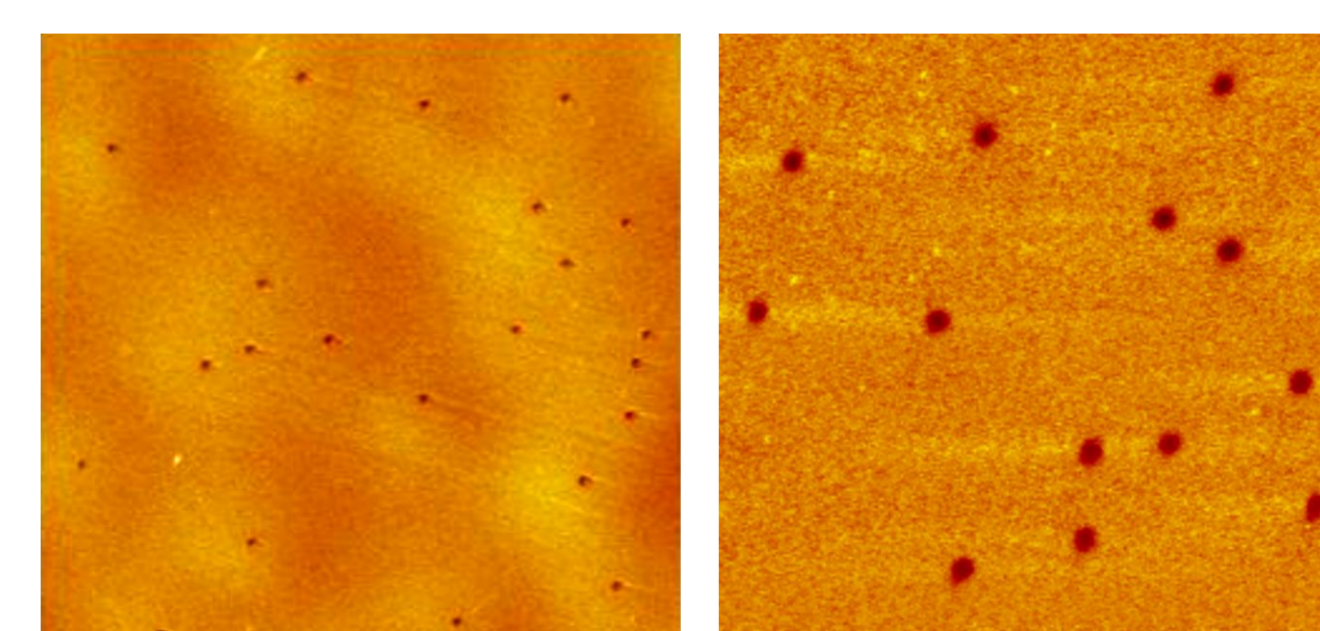
(a), (b) et (c) : SEM images of heterostructured 3C/2H Ge NWs.  
(e) and (g) are respectively 5 $\mu m \times 5\mu m$  3 $\omega$ -SThM images of Ge NWs with a diameter of 400nm and 220nm.  
(d) and (f) are their topographical images.



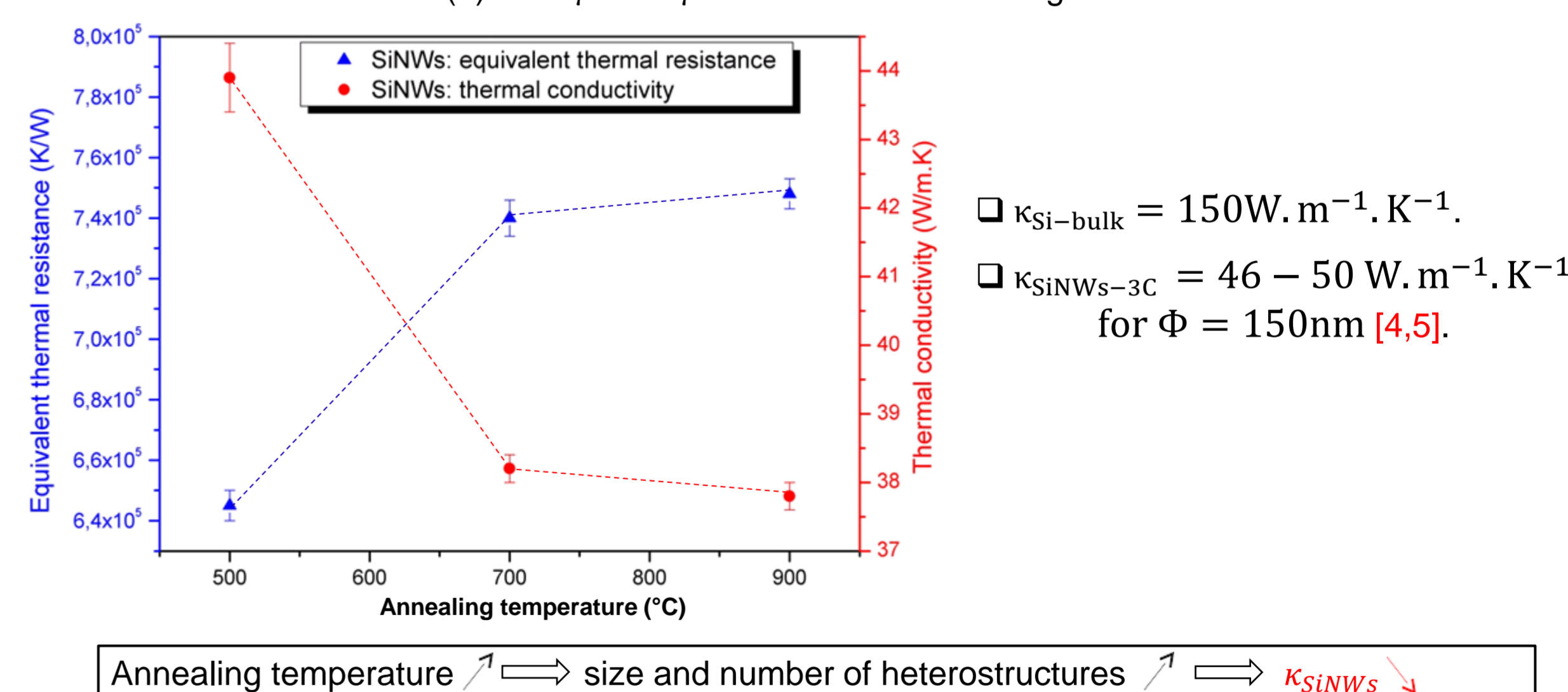
$$\phi \searrow, R_{Th} \nearrow \Rightarrow \kappa_{NWs} \searrow$$

Possible causes: - diameter reduction,  
- structure change  $\Rightarrow$  3C/2H...

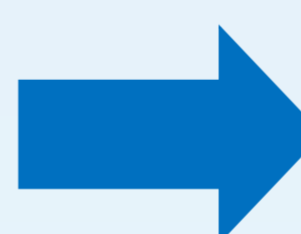
➢ Heterostructured silicon (Si) NWs: same diameter (150nm) and different annealing temperatures ( $T=500^\circ C, 700^\circ C$  and  $900^\circ C$ ):



3 $\omega$ -SThM thermal images of Si nanowires transformed at 900°C. (a) is a 13 $\mu m \times 13\mu m$  thermal image in which the dispersion of the NWs on the surface of the sample is seen and (b) is a 6 $\mu m \times 6\mu m$  zoomed thermal image.



$\kappa_{Si-bulk} = 150 W \cdot m^{-1} \cdot K^{-1}$ .  
 $\kappa_{SiNWs-3C} = 46 - 50 W \cdot m^{-1} \cdot K^{-1}$   
for  $\phi = 150nm$  [4,5].



## Conclusions and prospects

- Diameter and heterostructuration lead to a thermal conductivity reduction in Si and Ge nanowires,
- In the future:
  - Confirmation on new samples, in particular at 1100°C (more heterostructured domains with larger size),
  - Development of new experimental set-ups to measure  $\sigma$  and  $S$  in order to estimate  $ZT$ .

## References

- [1] E. Puyoo, S. Grauby, J-M. Rampnoux, E. Rouvière, and S. Dilhaire, *J. Appl. Phys.* **109**, 024302 (2011).
- [2] E. Puyoo, S. Grauby, J-M. Rampnoux, E. Rouvière, and S. Dilhaire, *Rev. Sci. Instrum.* **81**, 073701 (2010).
- [3] L. Vincent and al., *NanoLett.* 2014, **14**, 4828-4836.
- [4] W. Li and N.Mingo, *J. Appl. Phys.* **114**, 054307 (2013).
- [5] P. Martin, *Nano Lett.* **2010**, 10, 1120-1124.