The Micro and Nano Scale Heat Transfer group

Olivier Chapuis, Séverine Gomès, Stéphane Lefèvre, Olivier Merchiers and Rodolphe Vaillon

The Micro and Nano Scale Heat Transfer Group
(03/2015)

▪ 5 Permanent researchers

Olivier Chapuis	Séverine Gomès	Stéphane Lefèvre	Olivier Merchiers	Rodolphe Vaillon
CNRS CR2	CNRS CR1	INSA LYON Ass.Prof.	INSA LYON Ass.Prof.	CNRS DR2

▪ 5 PhD candidates

Wassim Jaber 2012-…

Olivier Dupré (with UNSW Sydney)

Mouhannad Massoud (with INL and LN2 Sherbrooke) 2012-…

Etienne Blandre 2013-…

2012-…

Yanquing Liu (with Inst. Néel, Grenoble) 2012-…

▪ Currently no Master student

▪ 4 Post-docs

Trang Nghiem 2013-…

Ahmad Darwiche 2014-…

Carolina Abs Da Cruz 2014-…

Ali Assy PhD thesis 2011-2015 Post-doc 2015-…

▪ Project manager

Sylvie Rault 2014-

▪ 2 Engineers

David Renahy 2014-…

Farida Bouhacine 2014-…

Modeling and simulating conduction and radiative heat transfer

Developing and applying thermal metrologies

at the micro and nano scales

A. Conduction heat transfer and coupled transport phenomena

C. Developping thermal nanocharacterization tools

B. Radiative heat transfer at the nanoscale – thermal near-fields

D. Measurements of nanoscale heat transfer

Modeling and simulating conduction and radiative heat transfer

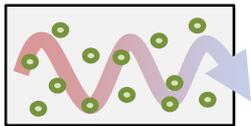**A. Conduction heat transfer and coupled transport phenomena**
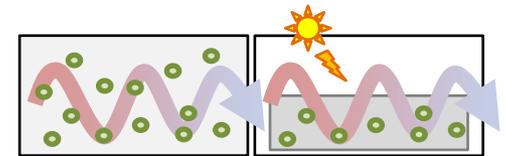
B. Radiative heat transfer at the nanoscale – thermal near-fields
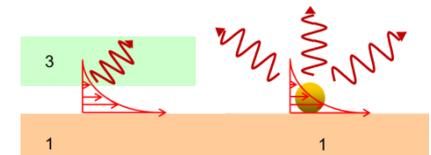
A. Conduction heat transfer and coupled transport phenomena

▪ **Objectives:**   **Nanoscale heat conduction** in dielectric solids : **« Particle approach »**
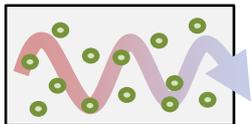
Boltzmann Transport Equation $\dfrac{\partial f}{\partial t} + \vec{v}_g \cdot \vec{\nabla}_{\vec{r}} f = -\dfrac{f - f^0}{\tau(\omega)}$ stationary $\xrightarrow{\times \hbar\omega.v_g.\frac{g(\omega)}{4\pi}}$ $\dfrac{dI}{ds} = -\dfrac{I - I^0}{v_g \tau(\omega)}$ EPRT

▪ **Method:** Thermal phonon transport simulated with Ballistic-Diffusive Equations (BDE) or Discrete Ordinate Method (DOM)
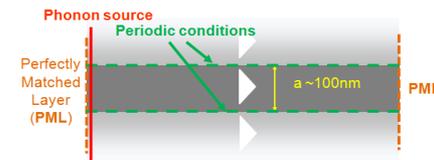
E. Nefzaoui, Post-Doc
2013-2014

C. Abs Da Cruz, Post-Doc
2014-2015

▪ **Objectives:**   **Nanoscale heat conduction** in dielectric solids : **« Wave approach »**

$$\rho \frac{\partial^2 u}{\partial t^2} = \nabla T \qquad T = \bar{\bar{C}} \, \nabla \varepsilon \qquad \varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)$$

Phonon source
Periodic conditions
Perfectly Matched Layer (PML)
a ~100nm
PML

▪ **Method:** Phonons simulated as acoustic waves with Finite Elements
- in stationary regime → **Dispersion**   - in Time Domain → **Finite structures**

T. Nghiem, Post-Doc
2013-2015

Application: in dielectric solids, rectification based on nanostructuration

Modeling and simulating conduction and radiative heat transfer at the micro and nano scales

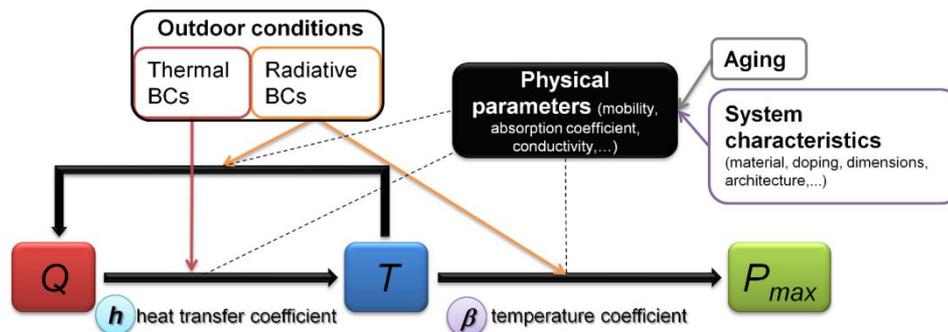## A. Conduction heat transfer and coupled transport phenomena

O. Dupré
Ph.D. candidate
2012-…

with

UNSW
AUSTRALIA

- **Objectives:** **Impact of the thermal losses on photovoltaic device efficiency**
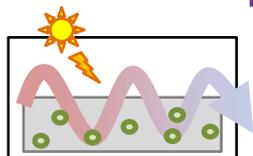
  - **Method:** analysis of the physics of the temperature coefficients; optimization of solar cells including the thermal impacts
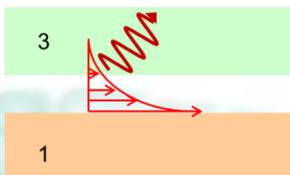

B. Radiative heat transfer at the nanoscale – thermal near-fields

Y. Tsurimaki
Master student
2012-2014

with

TOHOKU
UNIVERSITY

- **Objectives:** **Thermal radiation with interferences**

  Impact of the **interferences** on the net radiative heat flux between two semi-infinite parallel plates

- **Methods:** stochastic Maxwell equations and fluctuational electrodynamics

B. Radiative heat transfer at the nanoscale – thermal near-fields

E. Blandre
Ph.D. candidate
2013-…

with

THE UNIVERSITY OF UTAH
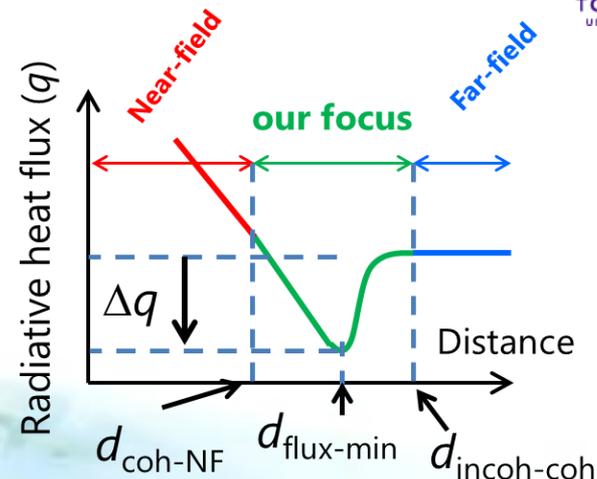
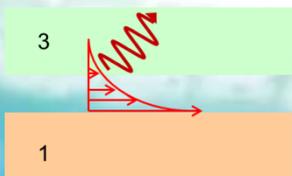- **Objectives:** **Radiative heat transfer between layered structures**
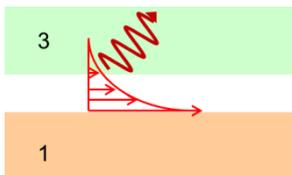
Impact of the **interference effects** for the propagative modes and of the **evanescent modes**

- **Methods:** stochastic Maxwell equations and fluctuational electrodynamics (solution by means of the scattering matrix method)
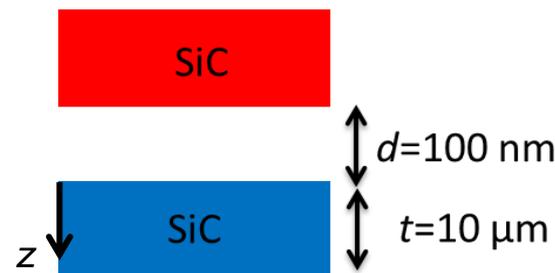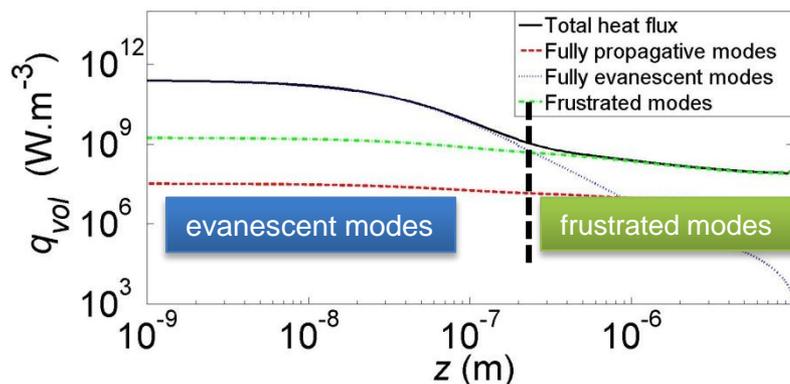
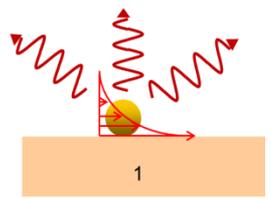- **Objectives:** **Near-field heat transfer in nanoscale gap ThermoPhotoVoltaic devices**

- **Methods:** Numerical solution of the coupled thermal – NF radiation – electrical transport problems

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B. Radiative heat transfer at the nanoscale – thermal near-fields

with **INSTITUT FRESNEL**
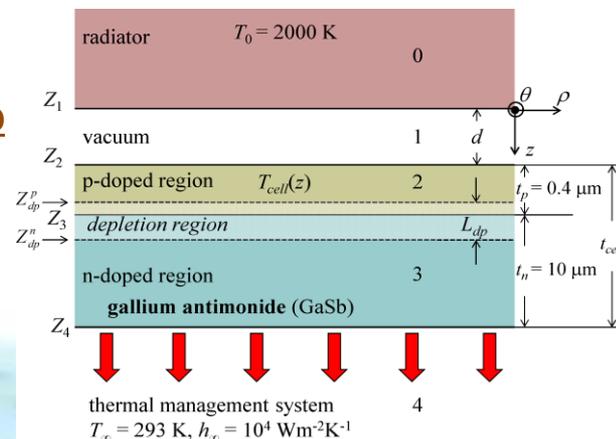
- **Objectives:** **Near-field analysis of the EM fields radiated by complex objects**
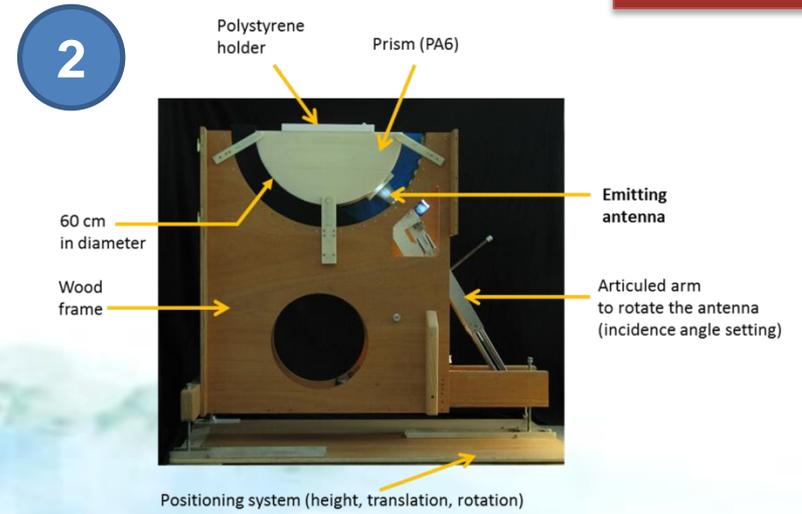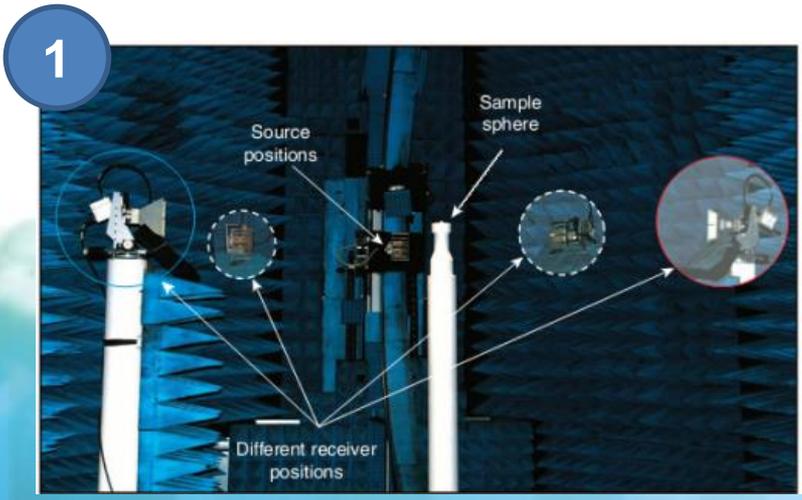
  Measuring in the near-field and the far-field, EM fields scattered by **analogs** in the microwave regime of nanostructures excited by (optical, NIR) waves
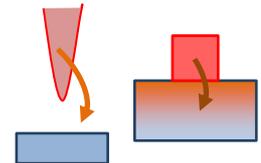
- **Methods:**
  1. Plane waves incident on floating targets: development of a unique experimental setup (at Institut Fresnel, Marseille)
  2. Evanescent waves exciting targets on a surface: new setup with far-field and near-field measurements (built at CETHIL, operated at Institut Fresnel)

  + simulations

Source positions — Sample sphere — Different receiver positions

Polystyrene holder — Prism (PA6) — 60 cm in diameter — Wood frame — Emitting antenna — Articuled arm to rotate the antenna (incidence angle setting) — Positioning system (height, translation, rotation)
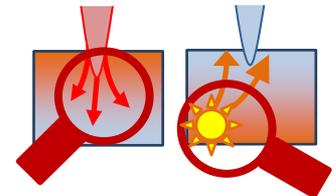
Developing and applying thermal metrologies

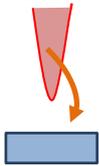**C. Developping thermal nanocharacterization tools**

D. Nanoscale thermal measurements

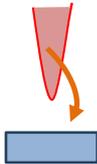## C. Developing thermal nanocharacterization tools

- **Objectives:** **Scanning thermal microscopy (SThM) as a tool to probe nanoscale heat transfer mechanisms:** **understanding the probe/sample thermal interaction**

Assy PhD Thesis 2011-2015

- **Methods:** Scanning Thermal Microscopy:
experiments under various configurations (relative humidity degree, pressure, probe/sample distance…)

- **Objectives:** **Scanning thermal microscopy (SThM): Improvements of the technique** **in terms of sensitivity, spatial resolution, ability of multiphysics analysis**

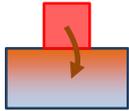Liu PhD Thesis 2012-

NÉEL institut

- **Methods:**
Development of:
       - calibration standards and protocols
       - modeling approaches depending on the probe
       - new SThM probes

C. Developing thermal nanocharacterization tools

- **Objectives:** <u>**Deposited microwires for thermal and thermoelectrical characterizations**</u> **of micro and nanostructured materials**
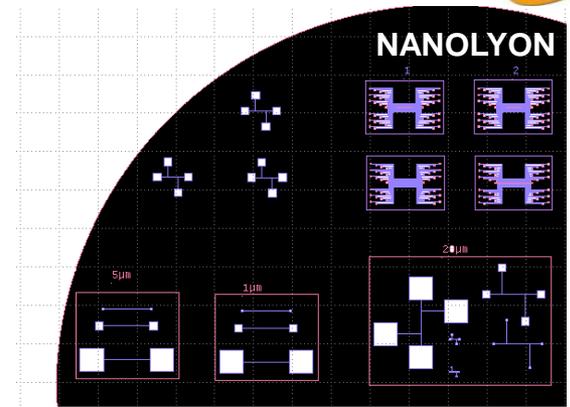
    - **Methods:** deposited sensors for 2ω and 3ω method measurements of the thermal conductivity

ESIEE
PARIS

- **Objectives:** <u>**Deposited nanowires for analysing nanoscale heat conduction**</u> **in asymmetric geometry**
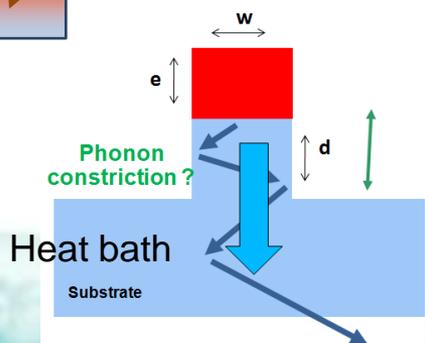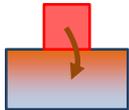
    - **Methods:**
        - Nano and microheaters
        - Design of nanometer-scale silicon ridges
        - Electrical measurements

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Phonon constriction ?

d

Heat bath

Substrate

NANOLYON

inl

Wassim Jaber
PhD Thesis
2011-

D. Nanoscale and microscale thermal measurements

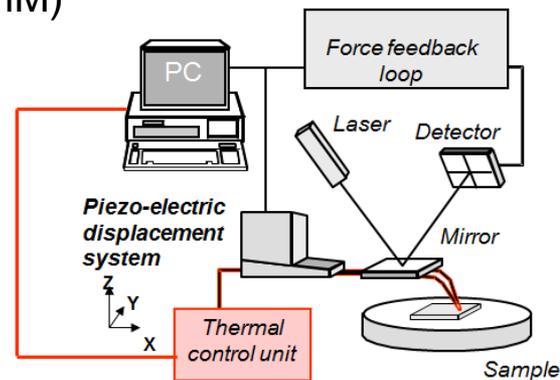- **Objectives:** **Measuring effective thermal conductivities** **to characterize the heat transport in micro and nanostructured materials (thin films, interfaces, nanoporous materials…)**

    - **Methods:** Scanning Thermal Microscopy (SThM)

        - *Predictive modeling of the measurement*

        - *Calibration procedure*

- **Example:** Mesoporous Si thin films
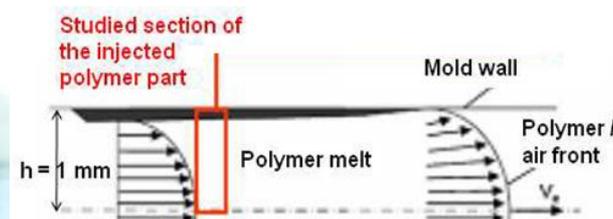
- **Objectives:** **Measuring micro- and nanocalorimetric properties** **to correlate localized thermal and thermo-mechanical properties**

    - **Methods:**

        SThM-based technique

Application: to polymer materials

- **European Projects**
  - EC FP7 - NMP
    QuantiHeat. Coord: S. Gomes (2013-2017)

- **ANR (French Research Agency) Projects**
  - JCJC   Nanometreter   Coord: S. Gomes
  - PNANO   Cofisis   Coord: ESIEE Paris (S. Gomes, 2009-2013)
  - RPDOC   NanoHeat   Coord: P.O. Chapuis (2011-2015)

- **Projets Carnot**
  - I@L   SPLM   Coord: R. Vaillon (2014)

- **CNRS Projects**
  - Energy   Nano-1D   Coord: P.O. Chapuis (2012-2013)
  - Energy   AZIN   Coord: CEMCA Brest (R. Vaillon, 2013-2014)

- **INSA BQR**
  -               Coord: S. Gomes
  - Manatherm   Coord: P.O. Chapuis (2014-2015)