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## Harvesting of IR solar energy by thermoplasmonic nanoantennas

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## Context

### Mono-junction photovoltaic cells have intrinsic limitations:

- Non-absorption of low energy photons ( $< E_g$ );
- Thermalization of high energy photons ( $> E_g$ );
- Heating of the cell while operating, which reduces its efficiency.

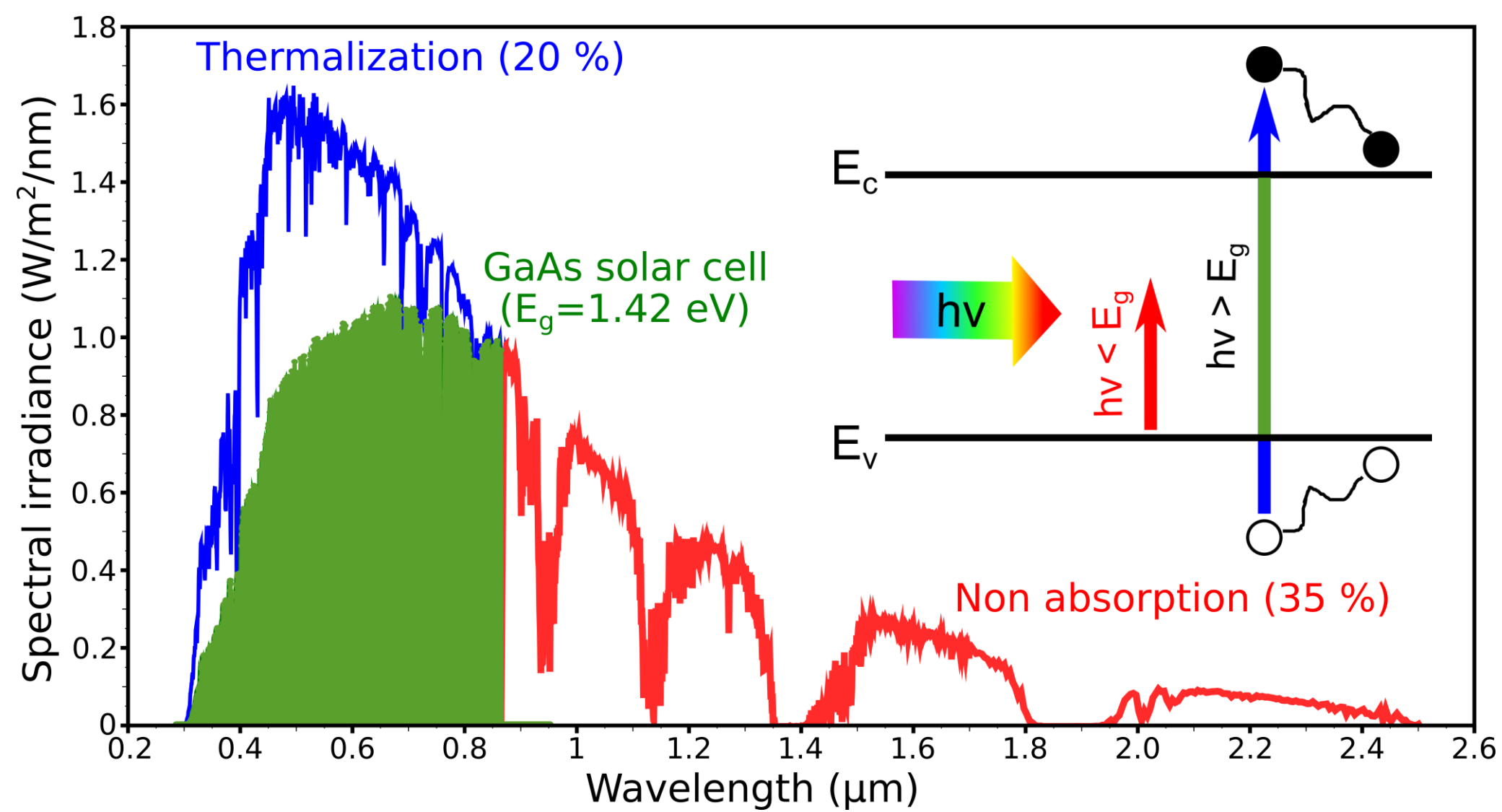


Figure 1: Scheme of the intrinsic losses in a PV cell and importance of the different phenomena for a GaAs cell with regard to the AM 1.5G solar spectrum.

**Hybrid photovoltaic-thermoelectric (PV-TE) devices** have been shown to increase the energy conversion efficiency by compensating the thermal losses in a PV cell [1-3].

Several studies aimed at optimizing the efficiency of PV-TE by including a **photothermal interface (PTI)** in between the PV cell and the thermoelectric generator [4-5].

**Objective of the PhD: to design a PTI using thermoplasmonic nanoantennas to convert solar IR radiation into heat.**

### Characteristics of an optimal PTI:

- High absorption and matching with the solar IR spectrum;
- High thermal conductivity;
- Electrically insulating.

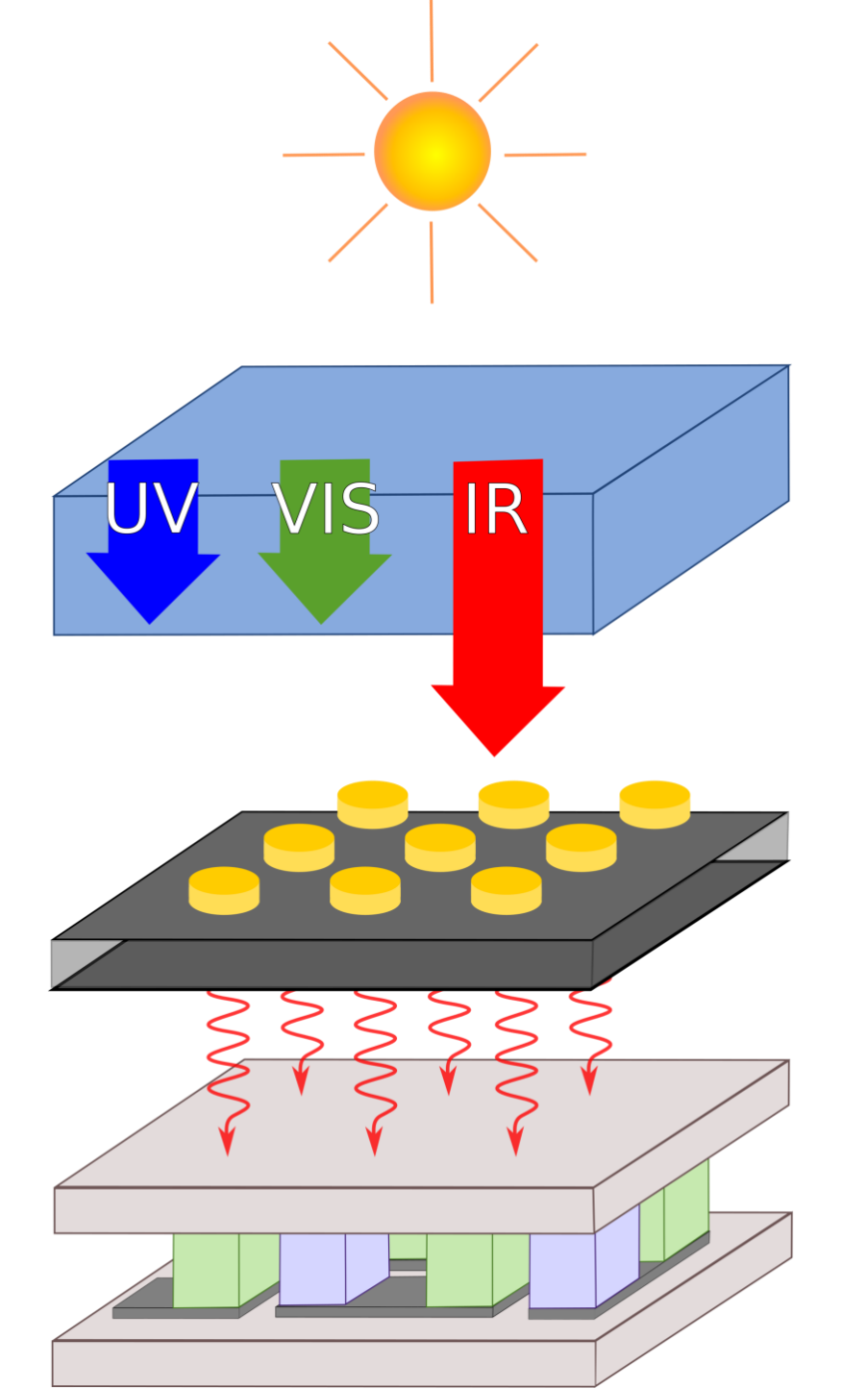


Figure 2: Schematic representation of a PV-TE device including a photothermal interface made of thermoplasmonic nanoantennas.

## Optical simulations

### Perfect structures

We use numerical simulations to study isolated nickel nanoparticles of different shapes and sizes, in order to find the structure which is best suited for IR solar harvesting.

- The absorption and scattering cross-sections of these particles are extracted from discrete dipole approximation (DDA) calculations, using the open-source code *DDSCAT* [6].
- The absorption spectra are compared to the AM1.5G spectrum to calculate the absorbed solar power over the range 0.875-2.5  $\mu\text{m}$ .

All nanoparticles have a height of 150 nm.

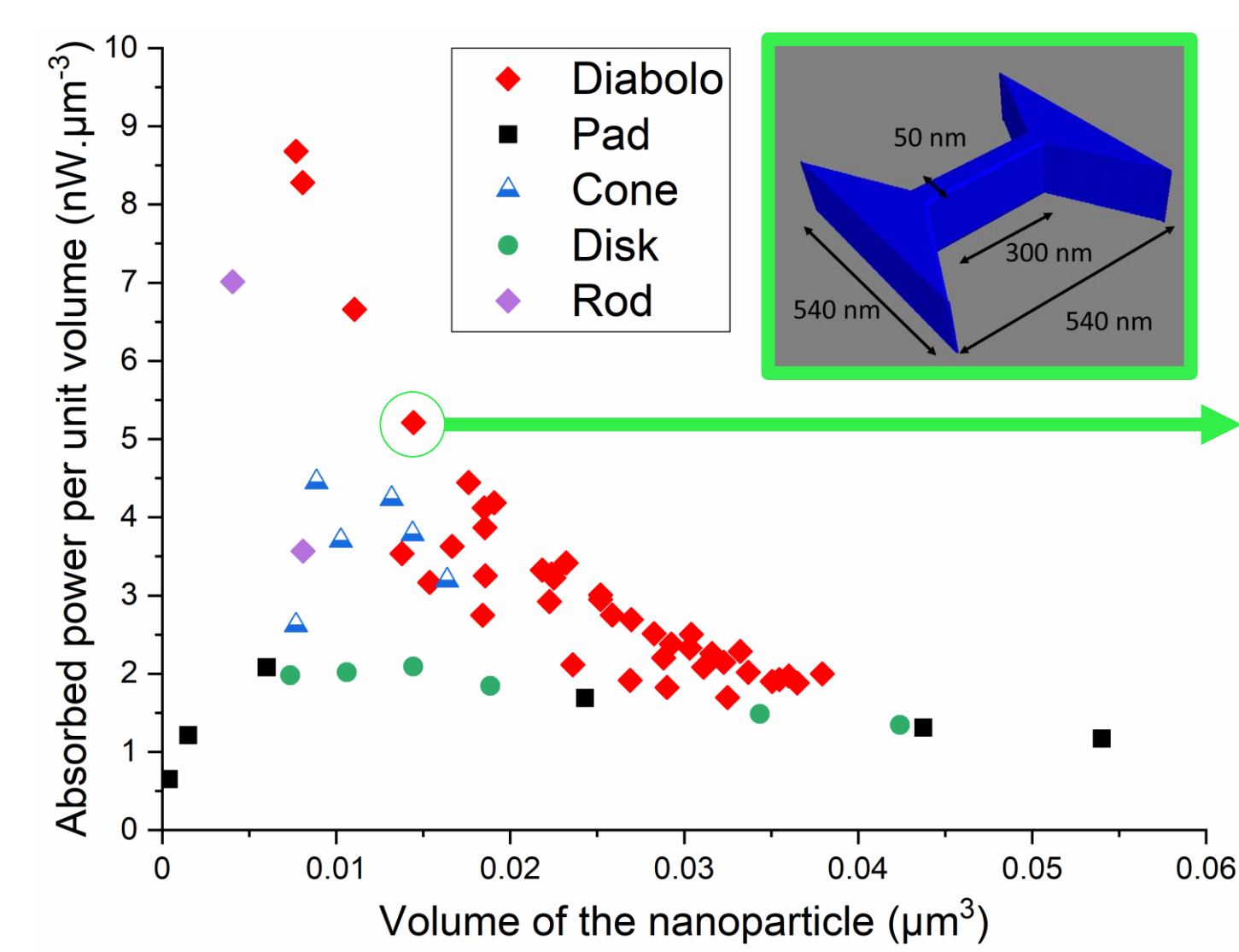


Figure 3: Calculated solar absorption over the range 0.875-2.5  $\mu\text{m}$ , normalized by volume, for isolated nickel nanoantennas of different shapes. The circled entry corresponds to the presented diabolo.

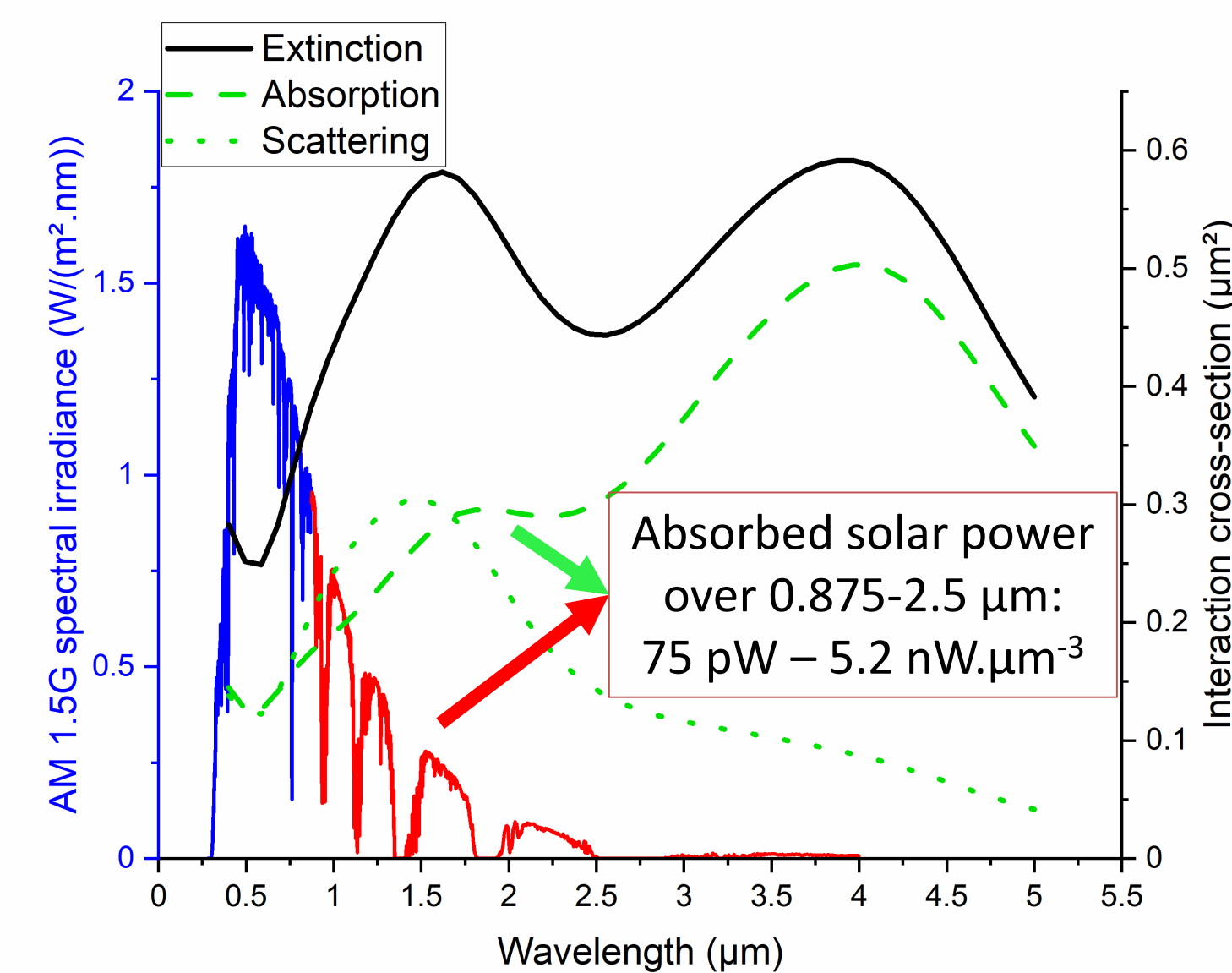


Figure 4: Calculated interaction cross-sections for a perfect Ni diabolo and AM 1.5G solar spectrum, below (red) and above (blue) the energy gap of a GaAs PV cell.

**Smaller nanoparticles tend to have a better absorption-to-volume ratio.**

**Choice of Ni diabolo as a promising structure.**

### Realistic structures

We developed a process to fabricate Ni nanoantennas on Si substrate using e-beam lithography, and study the impact of the fabrication defects.

- SEM and AFM characterization to reconstruct the surface topology of a real particle
- DDA simulations on the realistic structure

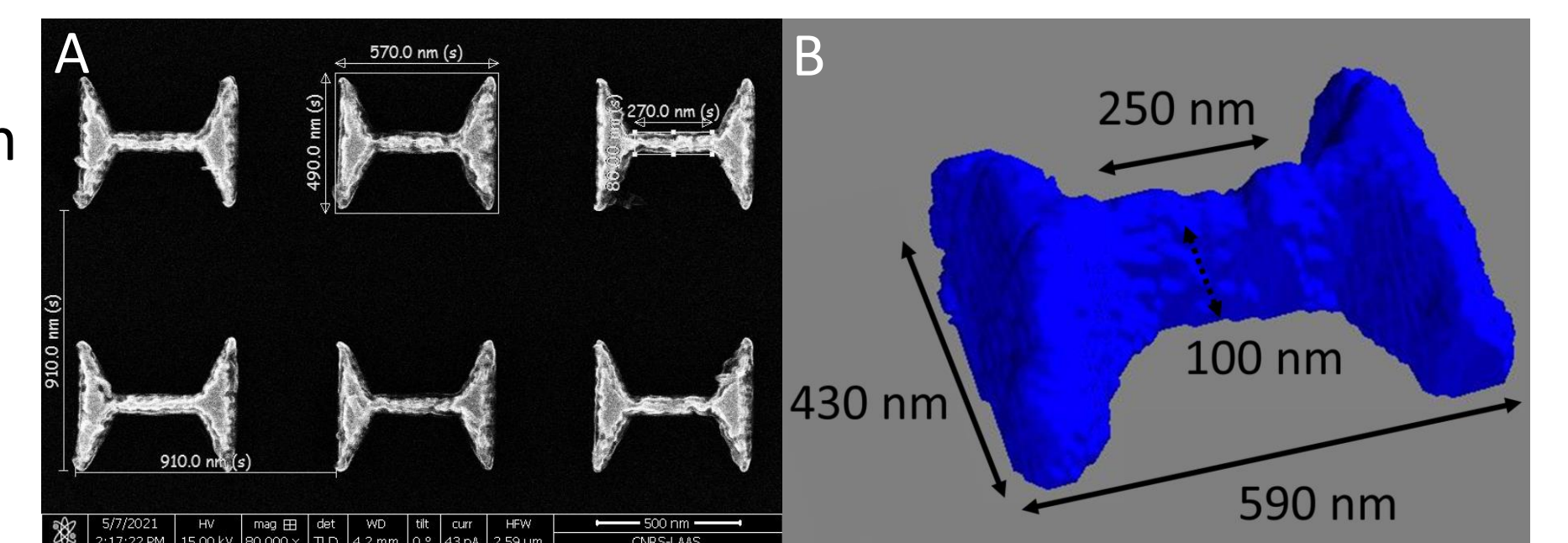


Figure 5: (A) SEM image of Ni diabolos on Si and (B) Simulation target extracted from AFM measurements to represent a real Ni diabolo.

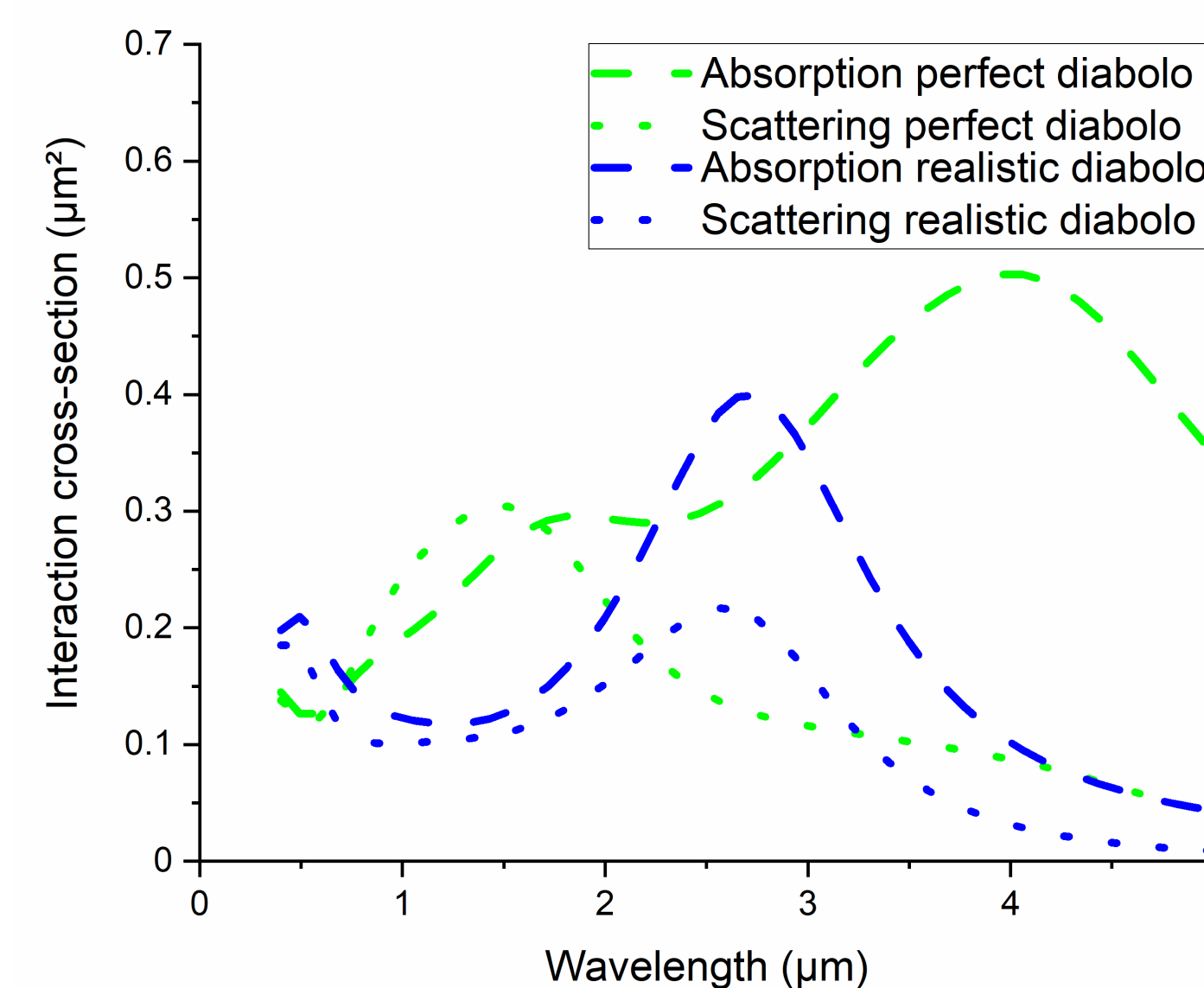


Figure 6: Comparison between the interaction cross-section spectra of a perfect Ni diabolo and the associated realistic structure.

Shift of the absorption peaks when switching from perfect to realistic structure, due to:

- Surface roughness
- Change in the dimensions

Absorbed solar power over 0.875-2.5  $\mu\text{m}$ :

- Perfect: 75 pW - 5.2 nW. $\mu\text{m}^{-3}$
- Realistic: 46 pW - 2.5 nW. $\mu\text{m}^{-3}$

**Important impact of the fabrication defects on optical properties.**

**Poor spectral matching between absorption and solar irradiance.**

## Thermal model

What is the temperature elevation that could be expected for a photothermal interface under IR solar illumination ?

Model of a photothermal interface on a TEG

- Absorption by a 2D array of perfect Ni diabolos (75 pW each) - **85 % surface coverage**
- Illumination: solar IR ( $\lambda < 875 \text{ nm}$ )
- Ambient temperature:  $T_{\text{amb}} = T_0 = 20 \text{ }^\circ\text{C}$
- Substrate of the PTI: Si
- Commercially available TEG

Temperature gradient through the TEG:

- **6  $^\circ\text{C}$  for perfect diabolos**
- **4  $^\circ\text{C}$  for realistic structures**

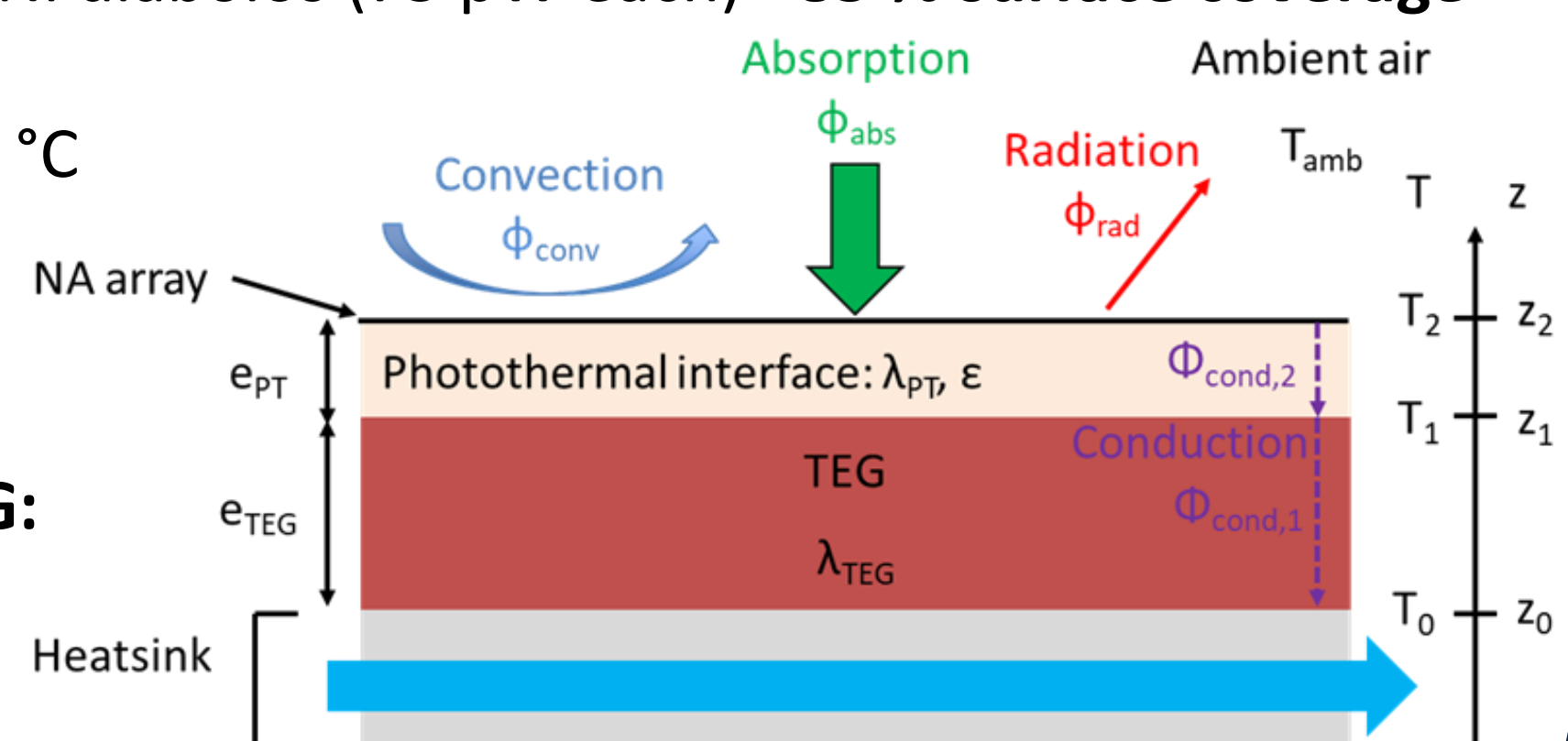


Figure 7: Scheme of the thermal model of the PTI+TEG system showing the thermal fluxes.

## Conclusion & perspectives

- Identification of a nanoantenna design capable of efficient IR solar harvesting.
- Development of a proven process to fabricate metallic nanoantennas on various substrate (Si, glass), and study of the fabrication defects:
  - Need to optimize the dimensions of the fabricated nanoantennas;
  - Working on alternative fabrication processes (electrochemical deposition, nanoimprint) to reduce the surface roughness or the fabrication time.
- The thermal model can be improved to estimate the temperature of a photothermal interface integrated in a hybrid PV-TE device.
- The optical and thermal properties of the PTI need to be experimentally characterized:
  - IR spectroscopy;
  - Measure of localized heating using Raman spectroscopy.

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