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Harvesting of IR solar energy by thermoplasmonic nanoantennas

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Context

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.

Optical simulations

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 µm.

All nanoparticles have a height of 150 nm.

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
- Ambient temperature: TAmb = 20 °C
- Substrate of the PTI: Si
- Commercially available TEG

Temperature gradient through the TEG:
- 6 °C for perfect diabolo
- 4 °C for realistic structures

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, nanoinprint) 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.

Perfect 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

Realistic structures

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

Important impact of the fabrication defects on optical properties. Poor spectral matching between absorption and solar irradiance.