# Metal nanoparticles for Plasmon-enhancement in Si solar cell and Raman spectroscopy


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## Introduction and Aims

Metallic nanostructures supporting surface plasmons have been proposed as an alternative method to achieve enhancement in Si solar cells and also Surface Enhanced Raman Spectroscopy (SERS).

When metal nanoparticles (NPs) are excited by electromagnetic radiation of appropriate energy, their conduction electrons oscillate collectively exhibiting Localized Surface Plasmon Resonance (LSPR). The incident light near the resonance frequency can be resonantly absorbed or scattered by the nanoparticles, creating a localized near-field and a propagating far-field, depending on their physical parameters (size, shape and distance between them and the surrounding environment). In this work we explore the physical properties of silver (Ag) nanoparticles that can be best suited for each of these applications.

**AIM 1**: Explore the physical properties of Ag NPs for SERS applications. In this work, we developed a new kind of cost-efficient SERS substrate using Rhodamine 6G (R6G) as Raman probe (Fig. 1).

**AIM 2**: Development of Ag NPs that due to their plasmonic scattering properties, increase the light path in the active layer of the solar cell contributing to an improvement of the solar cell efficiency (Fig.2).

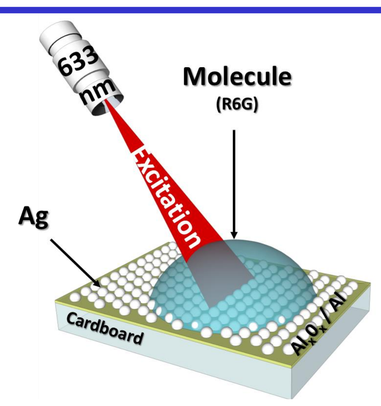



*Fig. 1 lustration of a nanoplasmonic cardboard SERS substrate used in the detection of R6G.*

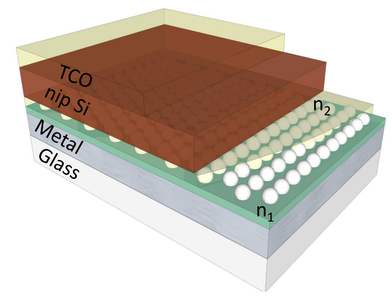


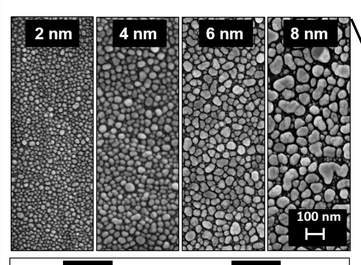

Fig. 2 Light trapping improvement in Si solar cells with metal nanoparticles

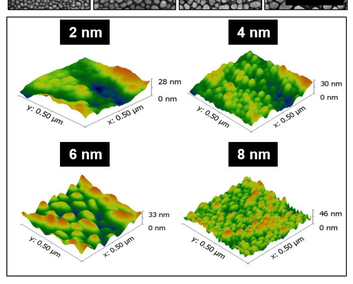
## Methodology

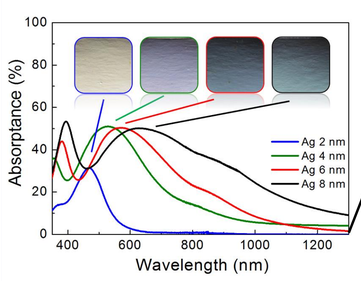
Metal nanoparticles (MNPs) were obtained by metal evaporation using an electron-gun assisted thermal evaporation technique. To form the MNPS, the process occurred at temperatures ranging from 150˚C up to 500˚C and for different atmospheric mediums. For Aim 1 Ag NPs are formed in situ during the thermal evaporation of thin films of silver onto cardboard packaging substrates heated at 150 º C. On the other hand, in Aim 2 Plasmonic structures were obtained through the deposition of Ag thin-films followed by annealing using the Rapid Thermal Annealing (RTA) system.

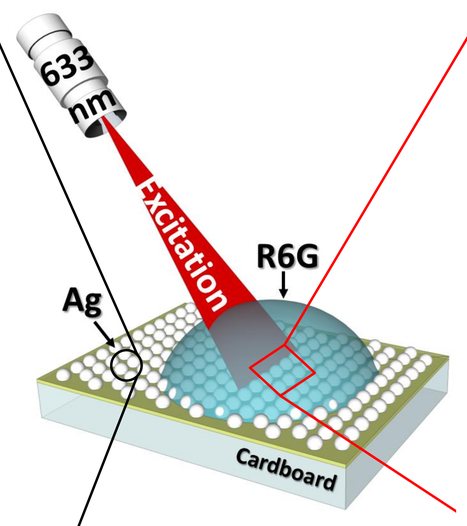
## Results (1) Highly efficient nanoplasmonic SERS on cardboard packaging substrates

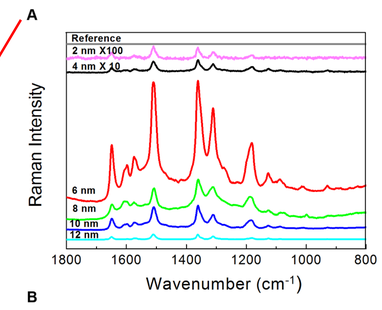
✓ Ag mass-equivalent layer thickness ranging from 2 to 8 nm were outlined

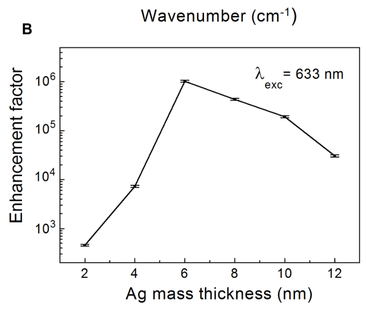


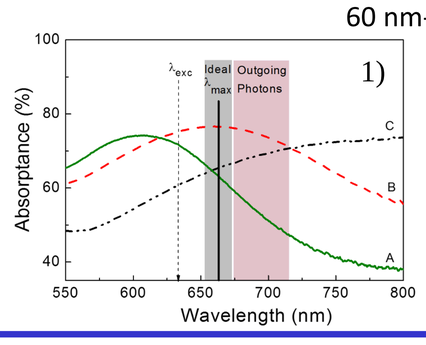



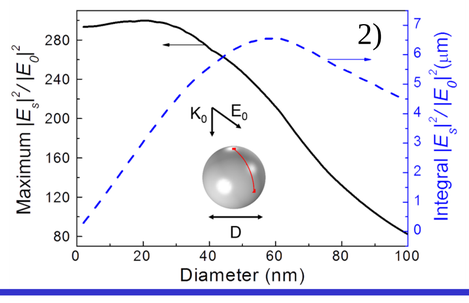




Enhancement factor (EF) data show that an average enhancement as high as **$1\times10^6$** is achieved for the nanoplasmonic cardboard SERS substrate obtained from 6 nm Ag mass thickness.

This is attributed to:

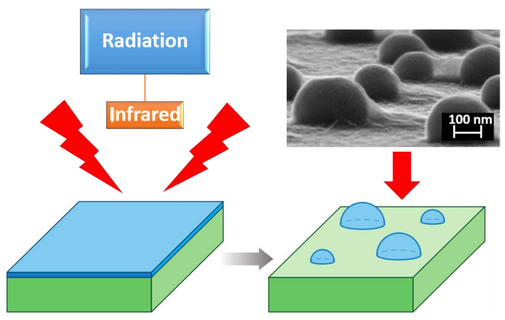
1) optimal spectral matching of the plasmonic resonance ($\lambda_{LSPR}$ = 660 nm)
2) high local electric field enhancement produced by the 60 nm-sized Ag NPs.



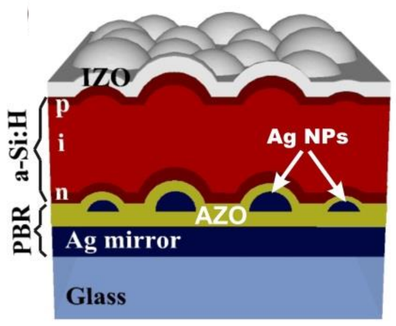




## Results (2) Plasmonic Ag NPs Back Reflector (PBRs) for Si Cells

**PBRs with Ag nanoparticles formed by *thin-film annealing***

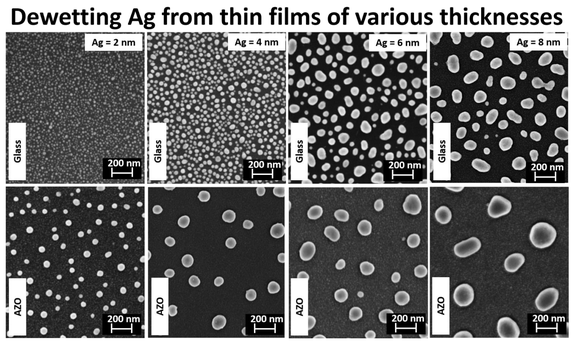


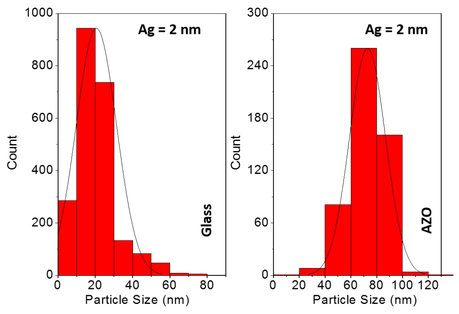

**Light-trapping Window of thin film Si solar cells**




**@ 500 ° C, t= 20 m, Nitrogen Atmosphere**

**Dewetting Ag from thin films of various thicknesses**

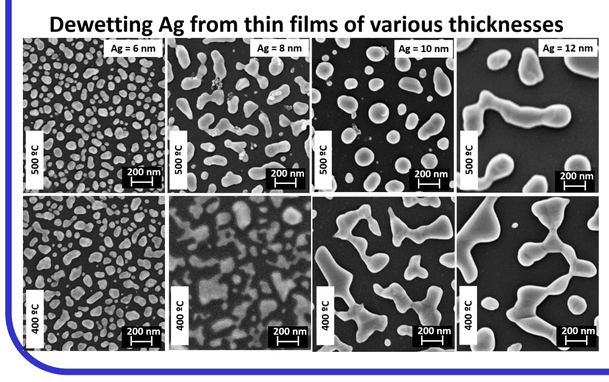


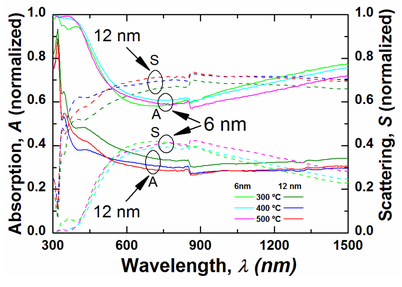




From the analysis of SEM images it was found that both the size and inter-particle distance increase significantly for NPs formed on AZO substrate.

**@ 400 - 500 ° C, t=20 m, Vacuum**

**Dewetting Ag from thin films of various thicknesses**




For samples resulting from 6nm Ag film, $A_{6nm} > S_{6nm}$ whereas for samples resulting from 12 nm Ag film, $A_{12nm} < S_{12nm}$.

## Conclusions

The ability to change the physical properties of the metal nanoparticles, makes them widely interesting to several different of research fields, namely SERS and solar cells.

Metallic nanostructures supporting surface plasmons are definitely an alternative method to achieve light trapping in thin-film solar cells, especially when incorporated in the rear side of the cell, acting as a plasmonic back reflector (PBR).

## Next Steps

The first experiment will be carried out with different lasers and different layers before the NPs deposition, in order to understand the effect of these parameters on the EF. We hope to see enhancements reaches a maximum to the red of the excitation source.

On the second experiment Ag NPs will be deposited on Al/AZO back reflector with different thicknesses of AZO, to choose the best structures for Si solar cells.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