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Transmission electron microscopy of the textured silver back reflector of a thin film silicon solar cell

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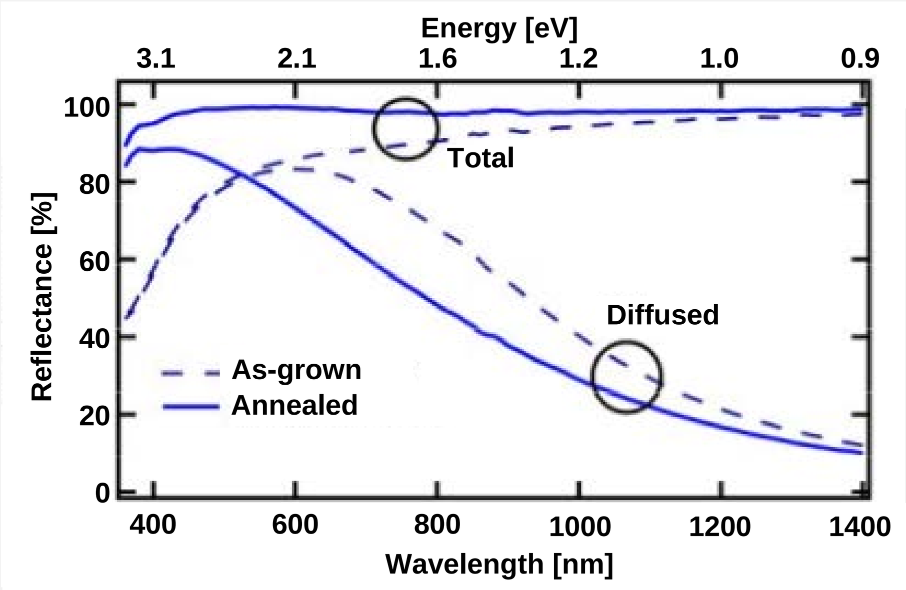
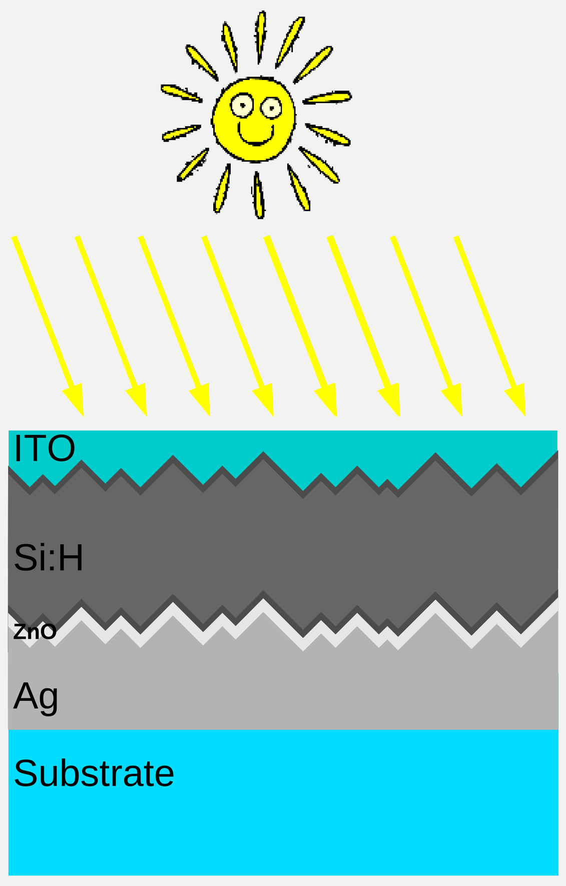
Optical absorption in thin film Ag layer

The light trapping for thin film Si solar cells is improved when they are grown on rough substrates. The use of a rough Ag reflector layer results in additionals optical absorption, partly, through the creation of surface plasmon polaritons [1].



Recently, standard cell characterization and optical measurements have shown an increase in reflection when the initially rough Ag layer is annealed at 150ºC [2].



Surface plasmons on Ag thin film

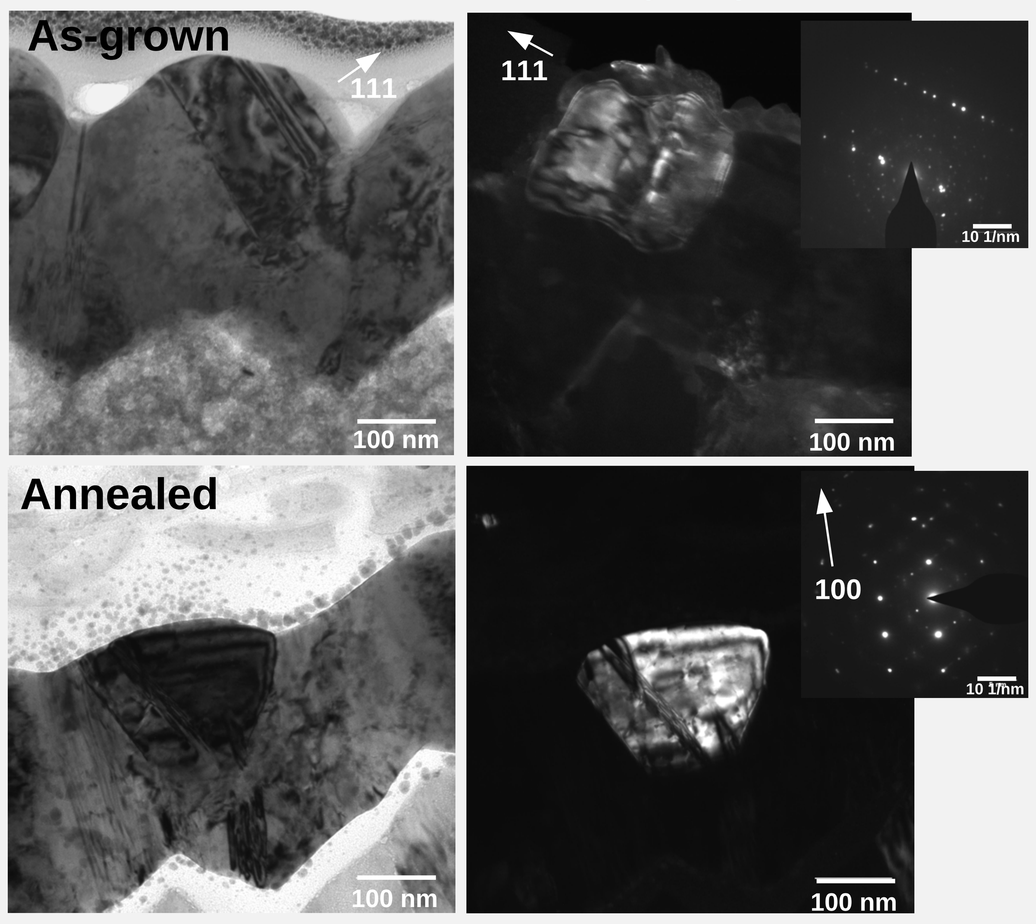
Electron-energy-loss spectrometry (EELS) performed in a transmission electron microscope (TEM) allows us to measure the energy losses of the electrons when travelling through the specimen within nm spatial resolution. Previously, surface plasmon absorption has been measured on individual Ag nanoparticles by scanning (S)TEM-EELS [3].

In thin film solar cells, Ag surface plasmons are suspected to absorb part of the visible light in the 1-3.5eV range

In this work, we intend to measure the plasmonic absorption in the as-grown Ag layer and present the methodology used to extract the surface plasmon absorption peaks [4].

As-grown and ex-situ annealed Ag layer

Diffraction contrast images (obtained in BF/DF TEM mode),

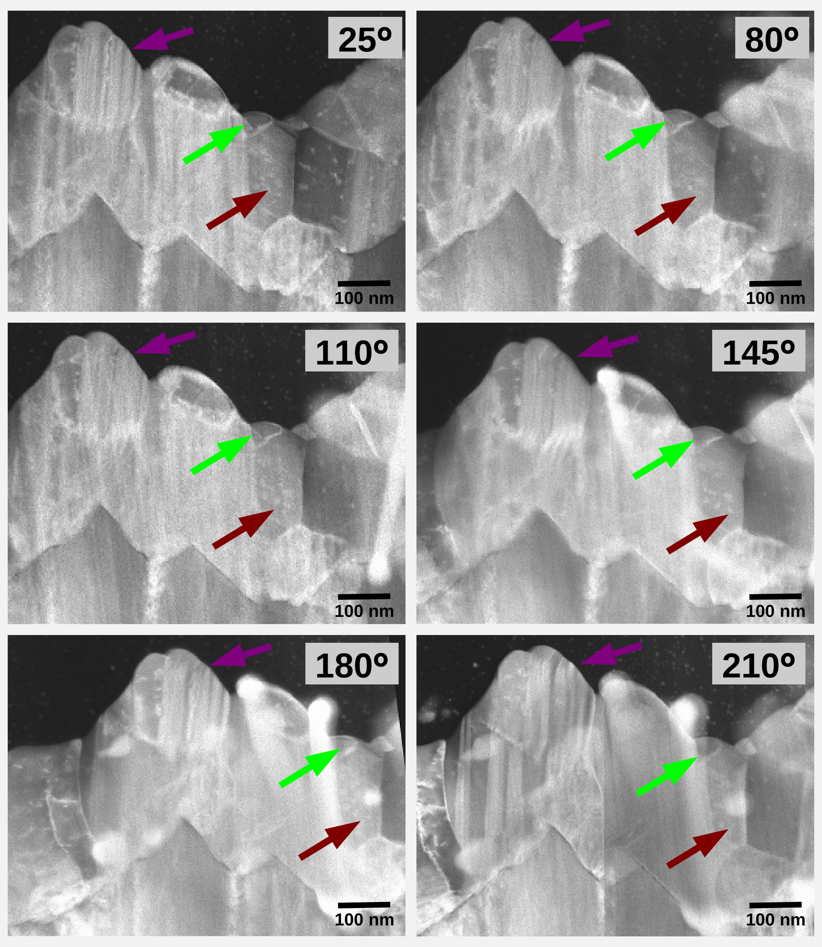


As-grown and *ex-situ* annealed samples show the same grain structure, i.e.
- crystal size ~100/200nm
- stacking of 1 or 2 Ag crystals

It seems that twin-boundaries in as-grown crystals are less present after annealing

In-situ TEM annealed Ag layer

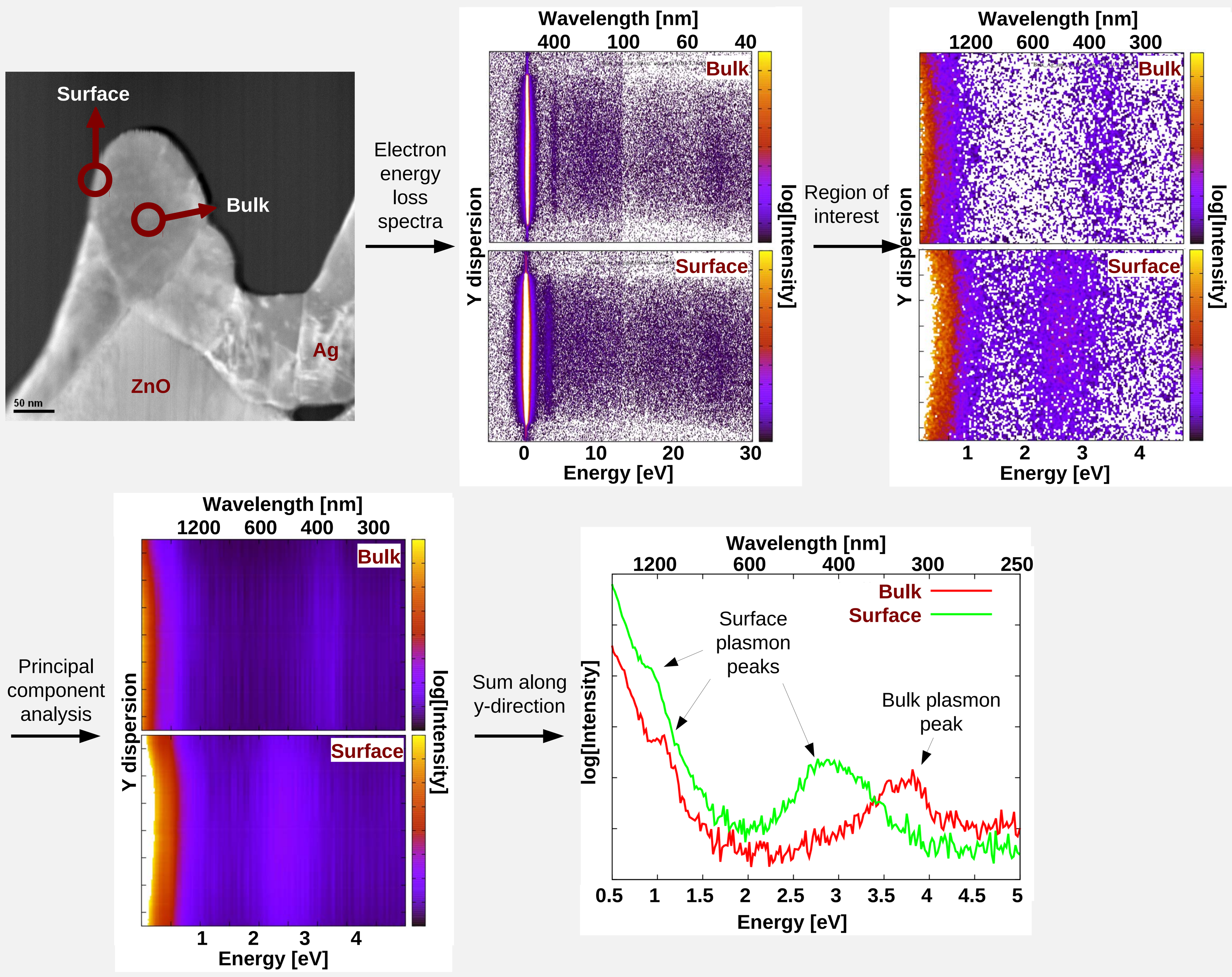
STEM images showing diffraction contrast



In-situ TEM experiments were used to track phase transitions induced by annealing.
- The contrast into the Ag layer is due to the different crystal orientations
- Arrows are guides to follow crystal positions.

For annealing below 210ºC, the twin-boundaries (blue arrow) are still present. Higher (in-situ) temperature may be needed to remove twin-boundaries.

Methodology used to extract Ag plasmon resonance peaks



Conclusion and perspective

Ex-situ and *in-situ* annealing TEM experiments have shown Ag layers may suffer crystalographic modifications for annealing below 200ºC.
We measured the plasmon absorption for energies as low as 1eV. The broad surface plasmon peak centered at 3eV is most probably responsible for the optical absorption observed in as-grown Ag thin film.
Futher experiments will be carried out to measure the evolution of the plasmon absorptions by doing *in-situ* TEM annealing experiments on Ag thin films.

Experimental details

Ag layers were grown on 2µm zinc oxide (grown by low pressure chemical vapor deposition) and deposited by DC sputtering at room temperature
TEM specimens have been prepared using conventionnal preparation techniques, i.e., polishing followed by Ar milling, final milling at 500V
Bright-field/Dark-field (BF/DF) TEM images were acquired at 200kV in an FEI Tecnai T20. Annular dark field (ADF) STEM images were acquired at 120kV, using a monochromated beam (full width at half maximun ~0.2eV) in an FEI Titan ST, using 47,4mrad and 10.2mrad inner ADF detector semi-angles for imaging and EELS acquisition, respectively.
Principal component analysis (PCA) was applied on the EELS data using code in Mathematica.

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