Synthesis and characterization of plasmonic composites (Fe/La)/Au for enhanced optical properties

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MOTIVATION

Metallic nanoparticles based on gold (Au) attract more and more attention due to their ability to enhance optical extinction by excitation of Surface Plasmon Resonance (SPR) that manipulates light-matter interaction.

Mixing gold with magnetic materials like Iron (Fe) can lead to enhanced magneto-optical effects [1-3].

As iron is sensitive to oxidation, its evolution as an element of an nanoalloy will be studied together with the properties of the as-formed Au-Fe-Fe_xO_y composite.

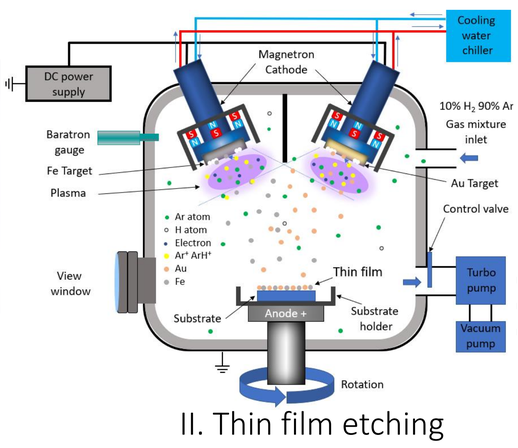
$LaFeO_3$ can substitute Fe_2O_3. Both oxides are semiconductors but the former adopts a perovskite structure and it is considered as a promising photocathode material.

Adding a gold buffer layer to perovskite affects the optical properties of the plasmonic oxide/Au composite, as shown by Wang *et al*. [4], in a way that is still to be investigated.

Comparison between NPs synthesized by electrical discharges in liquid nitrogen and femtosecond laser ablation will be achieved in a second step and reported elsewhere.

METHODS

I. Thin film deposition by PVD



Substrates:

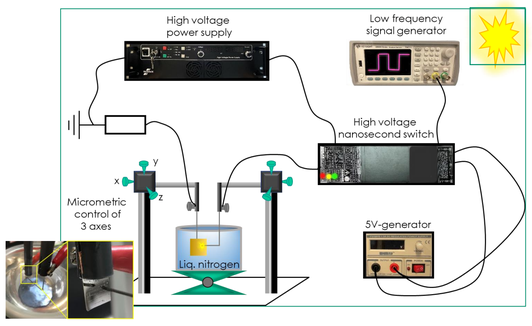
- **Silicon wafer** for electrical discharge treatment in liquid nitrogen
- **Fused silica** for laser ablation and **study of** optical properties

Experimental parameters:

- Gas mixture: 90 % Ar - 10 % H_2
- Pressure : 5.8×10^{-3} mbar
- Power : depends on target's metal

II. Thin film etching

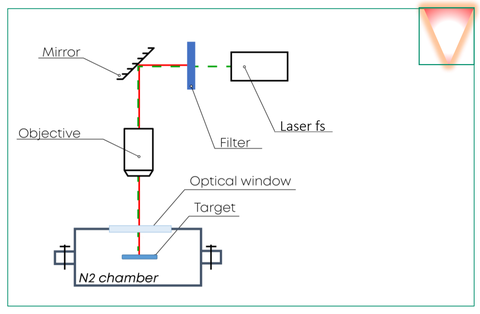
Electrical discharges in liquid nitrogen



Discharge parameters:

- Pin electrode is made of tungsten (W)
- Frequency - 10 Hz
- Amplitude - 5 kV
- Pulse duration - 100 ns
- Etching duration - 30 min
- Electrode (thin film) is grounded
- Dewar 100 ml filled with liquid nitrogen
- Inter-electrode distance is fixed at 100 ± 10 µm

Femtosecond laser ablation



Laser parameters:

- Central wavelength λ ≈ 1030 nm
- Pulse duration τ = 240 fs
- Repetition rate up to 1 MHz
- Laser pulse energy 10 µJ

3 steps of synthesis:

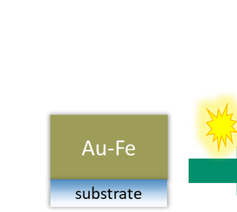
1. Applying treatment to **Au-Fe** thin films
2. Applying treatment to **Au-Fe-La** thin films
3. Applying treatment to **$LaFeO_3$/Au** bi-layer thin films

SYNTHESIZED OBJECTS

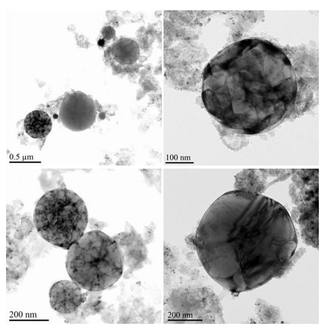
After applying treatment by electrical discharges in liquid nitrogen to Au-Fe thin films nanoparticles with two size distributions were produced: quite homogeneous Au-Fe nanoparticles with typical sizes around 20-80 nm and core-shell silicon-based nanoparticles with sizes around 200-500 nm, where the source of silicon is the substrate (Si wafer).

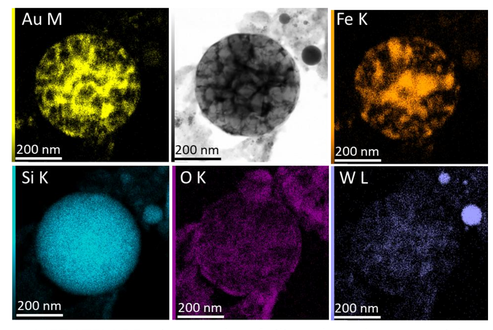
Here, we focuse on larger particles for future studies devoted to their optical properties.

Au/Fe COMPOSITES

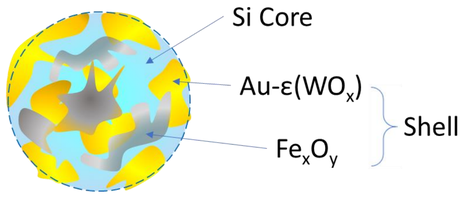


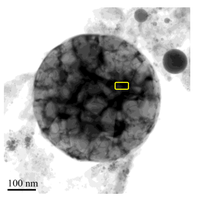
Element	AN	series	[norm. at.%]
Au	79	L-series	55.2
Fe	26	K-series	44.8
		Sum:	100

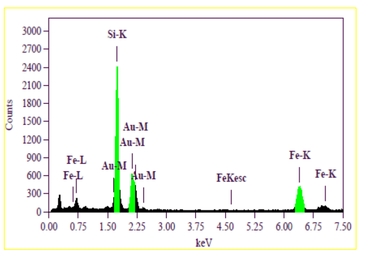




MET STEM BF micrographs of silicon-based nanoparticles with EDS mapping





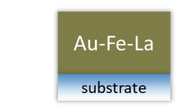


Element	(keV)	Mass%	Counts	Atom%
Si K (Ref.)	1.739	37.37	18006.98	71.01
Fe K	6.398	17.56	5338.37	16.78
Au M	2.120	45.07	5615.52	12.21
Total		100.00		100.00

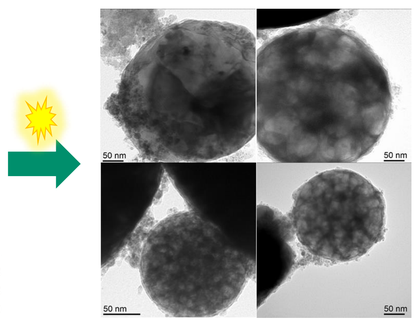
MET-EDS spectra and element concentration corresponding to the squared region depicted on the picture of silicon-based nanoparticle

- It can be noted that gold is associated with tungsten that is present in traces
- Traces of tungsten are coming from the power electrode
- Iron seems to be associated with oxygen
- W is likely oxidized and associated with gold
- The particle core is made of silicon

Au/Fe/La COMPOSITES



Element	AN	series	[norm. at.%]
Au	79	L-series	50.4
La	57	L-series	20.8
Fe	26	K-series	28.8
		Sum:	100



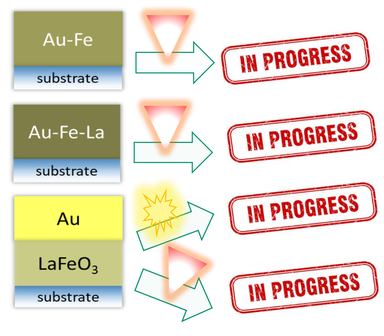
Similar kinds of nanoparticles were synthesized but those are low in lanthanum (about 1 %)

The composition of thin films in order to raise the lanthanum content must be adjusted

DISCUSSION & FUTURE DIRECTIONS

- Original large (Si) core - (Au-Fe_xO_y-ε(WO_x)) shell nanoparticles were produced by applying electrical discharge treatment in liquid nitrogen to Au-Fe thin films deposited on silicon wafers.
- The discharge melts both the thin film and a part of the substrate, leading to these specific objects. Their optical properties are under investigation.
- It is not clear why iron and gold remain on top of silicon, as they separate but do not mix with the core of the particle.
- Adding lanthanum is showed to be possible, even though the amount of the latter is low in this first set of experiments.
- The possible substitution of iron by lanthanum has not been demonstrated yet.
- Smaller particles are currently being investigated.

Other experiments are in progress to compare the present results with those by laser treatment. This is shown in the figures aside.



References

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Acknowledgements

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