Investigation of semiconductior qutantum nanostructures and plasmonic structures for photovoltaic applications

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Interdisciplinary Ph.D. Studies in Materials Engineering with English as the language of instruction
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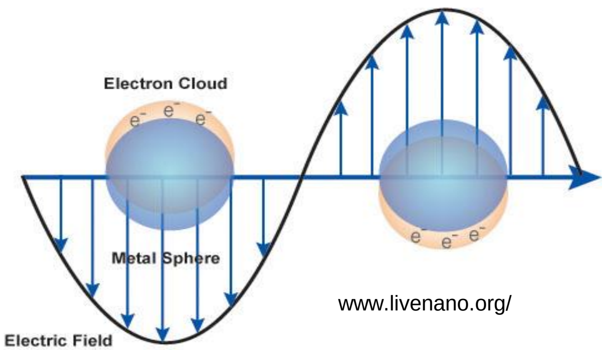
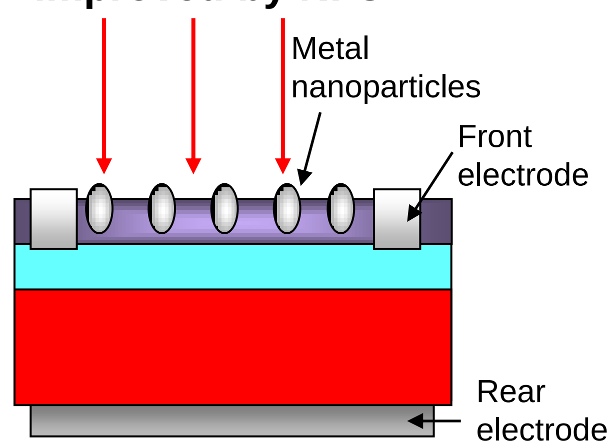
General concept

- Surface palsmon resonance localized in metal nanoparticles (NPs) is a new phenomenon providing efficient light scattering and trapping which results in reduction of cell optical losses.
- Application of these materials is a new approach in the field of photovoltaics.

Nano particle electron cloud interaction with electric field of light



Idea of antireflection coating improved by NPs



This field divided in to three subtasks:

1) Development of nanoparticles deposition methods,
2) Structure parameter optimization using computer simulation,
3) Preparation of optimal layer and application of the cell.

Since we wanted to avoid high temperatures and reduce costs we proposed alternative methods based on colloidal solutions

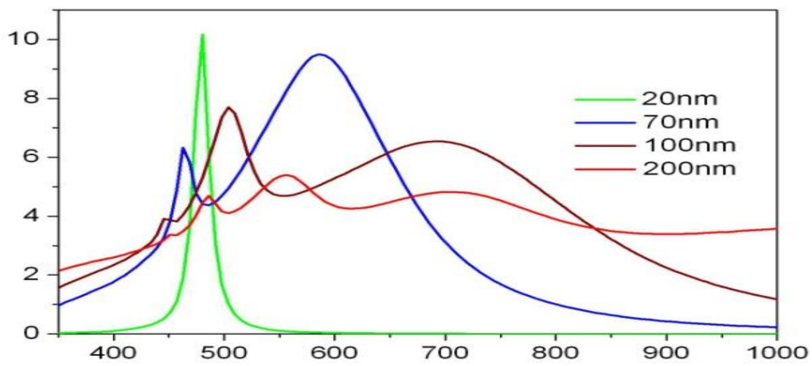
HUMAN CAPITAL
HUMAN - BEST INVESTMENT!

INSTITUTE OF METALLURGY AND MATERIAL SCIENCE POLISH ACADEMY OF SCIENCES

EUROPEAN UNION EUROPEAN SOCIAL FUND

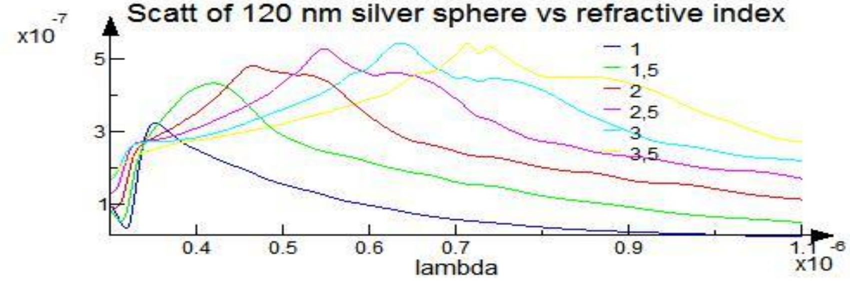
Theoretical and simulation studies on plasmonic particles

- **Simple scattering and absorption cross section done by open software – Nanoshpere Optics Lab.**



Normalized C_{scat} of Ag particles vs. Wavelength

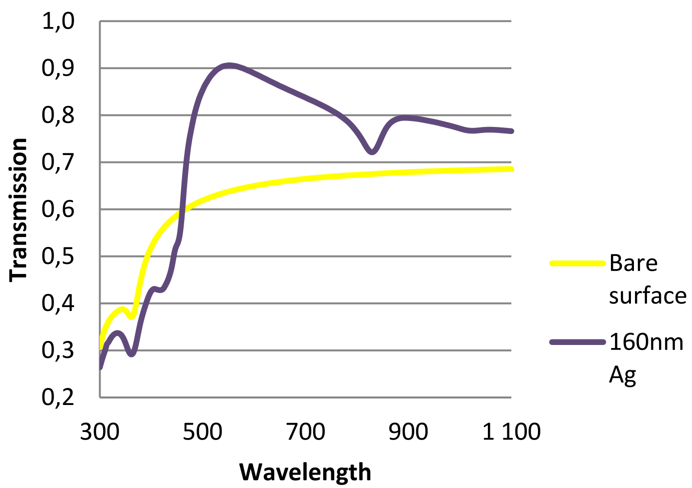
- **These results allowed to assess surface coverage range to 10 -20 %. On that basis was created division into mostly absorbing small (<50nm) particles and mostly scattering larger particles.**
- **Further simulation were performed using trial version of FDTD Solution software.**
- **Red shift of plasmon resonance pick position with increasing background refractive index**



- **Significance of this last result increase when particles are placed on the cell where destructive interference decreases absorbed power for wavelength shorter than LSPR – Fano Effect.**
- **Then increase of transmission to silicon were studied for different diameter of silver sphere with and without TiO_x anti reflection coating(ARC).**
- **On that basis taking to account solar radiation spectrum silicon cell short circuit current density have been calculated**

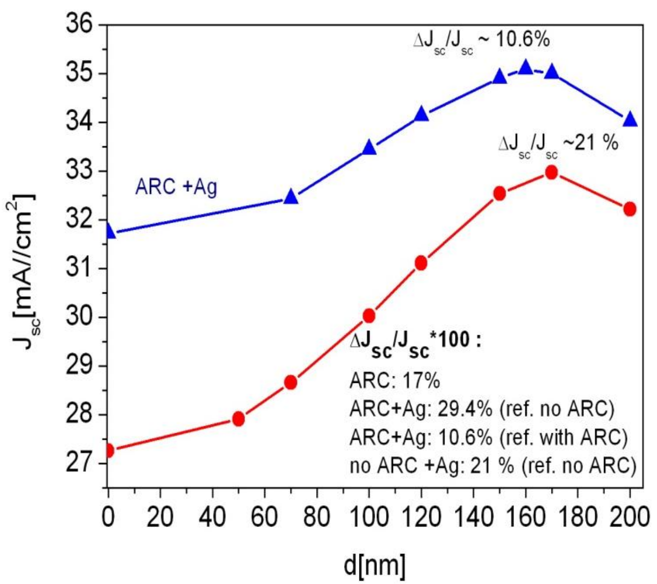
Short circuit current density versus silver particles diameter

Transmission to silicon substrate



Without ARC		
D [nm]	Jsc[mA/cm2]	ΔJsc/Jsc *100 [%]
Bare surface	27.3	0
50	27.9	2.4
70	28.7	5.1
100	30.0	10.2
120	31.1	14.1
150	32.5	19.4
170	**33.0**	**20.9**
200	32.2	18.2

With ARC		
D [nm]	Jsc[mA/cm2]	ΔJsc/Jsc*100[%]
No particles	31.7	0
70	32.4	2.3
100	33.4	5.4
120	34.1	7.6
150	34.9	10.0
160	**35.1**	**10.6**
170	35.0	10.3
200	34.0	7.3



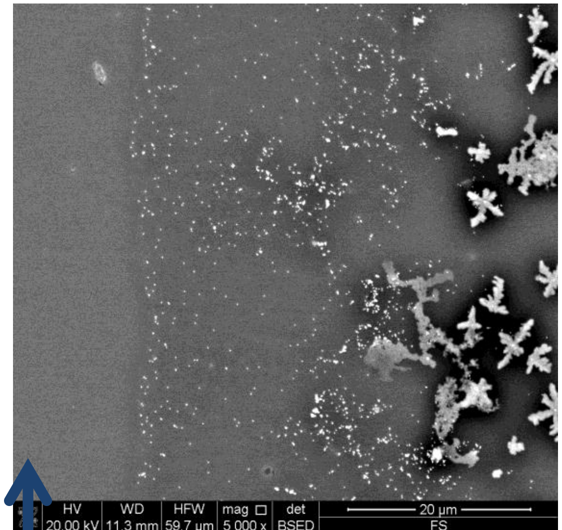
- **Simulation revealed that mostly relevant diameter for silver particles is 160nm.**

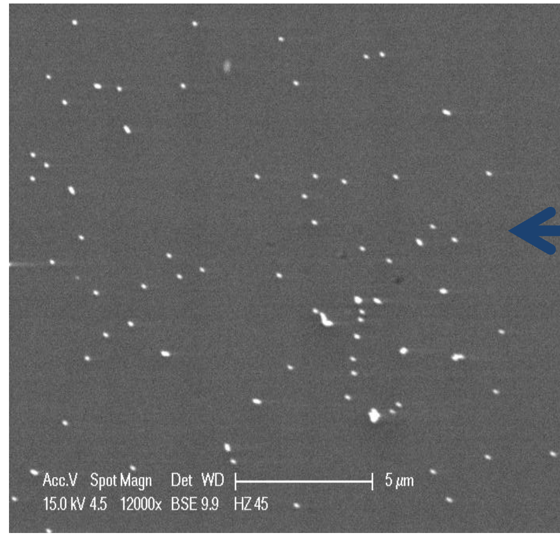
Experimental deposition methods:

- **simple spin coating,**
- **multiple spin coating,**
- **solvent evaporation,**
- **dip coating (different immersion times)**
- **injection on spinning sample**
- **Ag nano particles in organic vehicle**
- **deposition assisted with Palladium nucleation**
- **last promising approach is connected with surface charges modifications.**

<u>Investigation methods were: SEM, AFM ,UV-VIS Spectroscopy, SPV, cells I – V curve measurements,</u>

Obtained microstructures

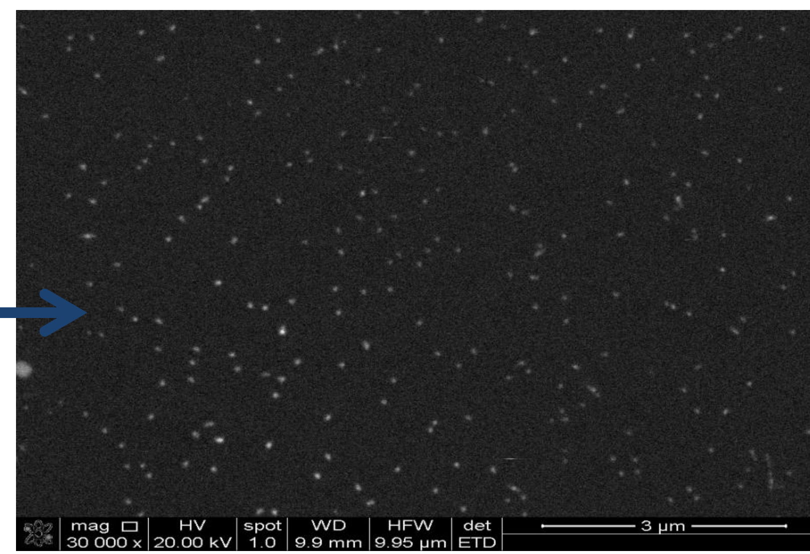




Dip coating – usage of this method provide more uniform distribution on larger area

Solvent evaporation – by this method for the first time high density of nano particles was found, but it was only localy connected with surfactants precipitation.

Injection on spinning sample – the highest obtained concentration - 3 x 10^8 /cm^2



Ag 70nm particles deposition on silicon solar cells

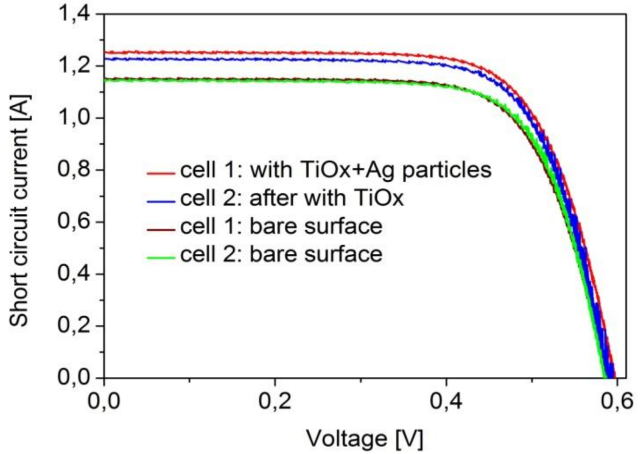
- **Cell based on mono-Si with texture and ARC – electrical parameters downfall,**

Cell number	I_{sc} [mA]	V_{oc} [mV]	FF [%]	E_{ff} [%]
1a	1040	558	74.7	9.8
1b	1093	560	74.4	10.3
1c	**1097**	**560**	**75.8**	**10.6**
1d	1075	558	74.7	10.1

- **Bare cell – observed up to 5,5 % of short circuit current improvement.**

- **Bare cell covered with composite ARC provided ~35% increase of Isc instead of 30% for ARC without nanoparticles**

Cell number	I_{sc} [mA]	V_{oc} [mV]	FF [%]	E_{ff} [%]
Cell 1 – bare	928	578	73,3	8,93
Cell 1 with Ag + TiOx	1253	599	71,3	12,09
Cell 2 - bare	940	576	73,9	9,09
Cell 2 with TiOx	1227	590	72	11,85



Conclusions

- **Simulations indicated 160nm silver particles fo that application.**
- **Optimal coverage must be determined**
- **For bare cell few percent improvement of short circuit current was achieved.**
- **The highest obtained concentration is 3x 10^8 /cm^2**
- **Optimal and non-random way of NPs deposition need to be found.**