Plasmonic nano-composites for optical coatings

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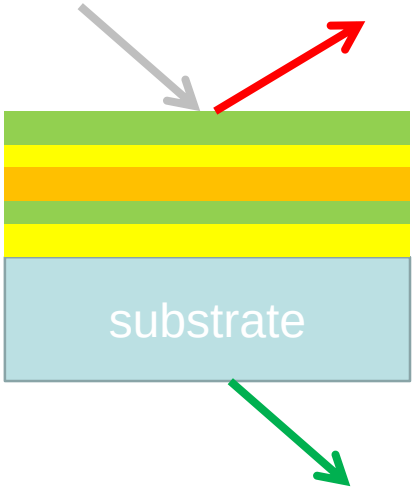
MP1401 Annual Conference – WG1, 12-15th April 2016, Zadar

Outline

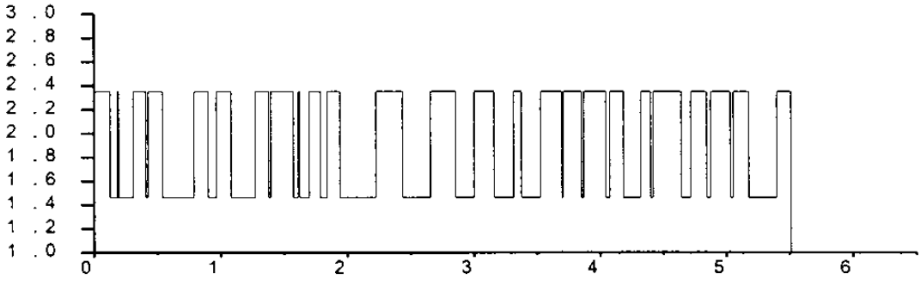
- Optical interference coatings
- Plasmonic nano-composite thin films
- Plasmonic-based optical coatings
- Conclusions

Optical interferential coatings



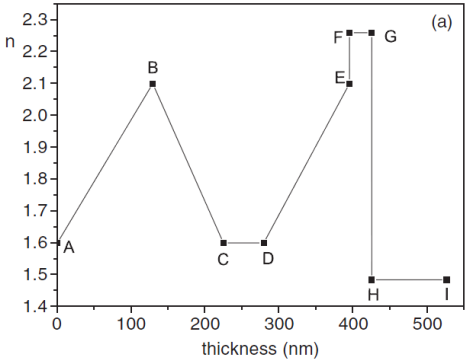
Optical properties of multilayer systems tailored by adjusting films thicknesses and refractive index

Optical coating design limited by available materials ⇒ use of composites



Narrow-band reflector

Applied Optics 37, 2428 (1998)

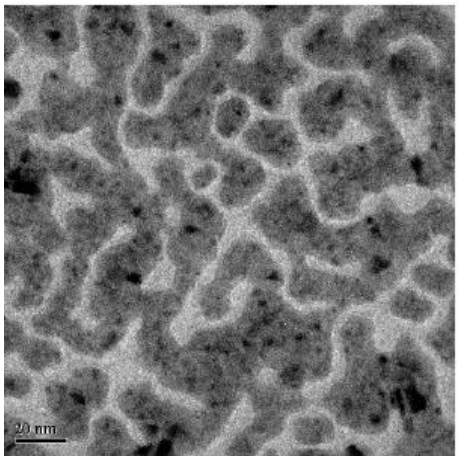


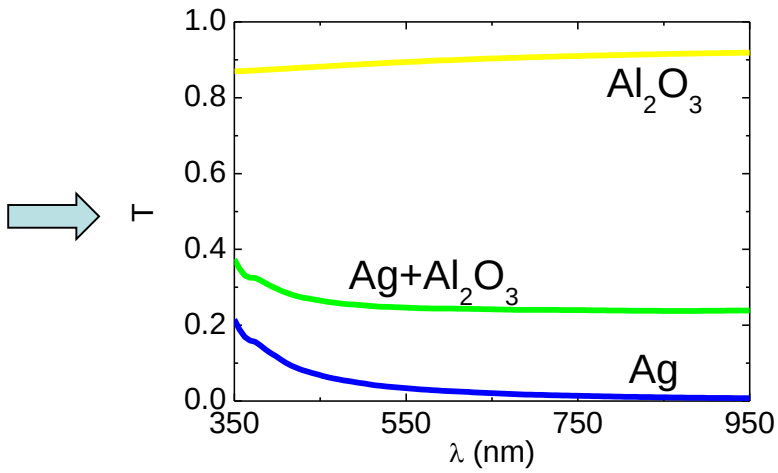
Omnidirectional antireflective coating

J. Opt. A: Pure Appl. Opt. 7, L9 (2005)

Optics of metal-dielectric composites

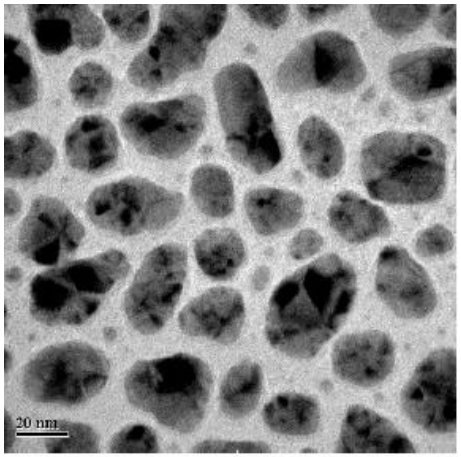
Mixed thin film layer (50 nm, Al_2O_3 + Ag, SiO_2 substrate)

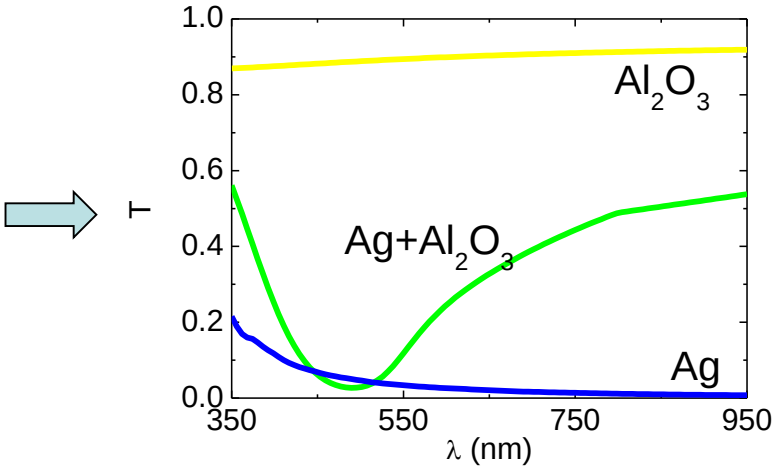




$T_{mixture} \cong$

$\alpha T_{Al2O3} + \beta T_{Ag}$



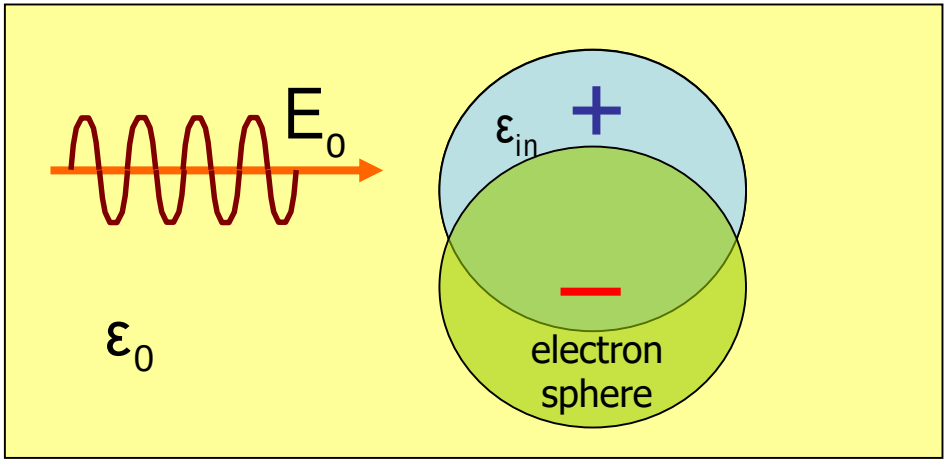


$T_{mixture} \cong$

… ???

Localized surface plasmon resonance

Metallic sphere embedded in dielectric host:

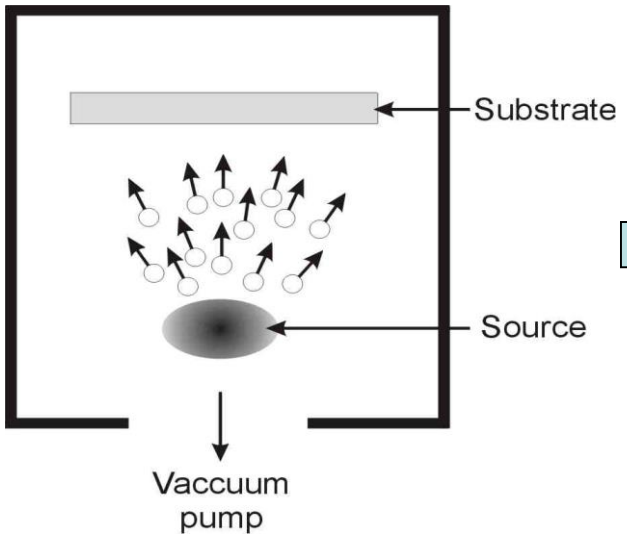


Polarizabilty $\alpha = \frac{\varepsilon_{in} - \varepsilon_0}{\varepsilon_{in} + 2\varepsilon_0} r^3$

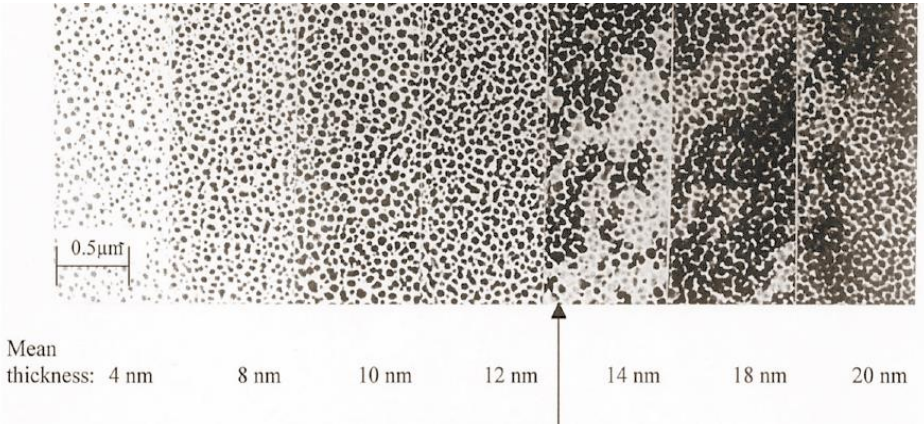
Resonance: $\varepsilon_i + 2\varepsilon_0 \rightarrow 0$

- Surface plasmon resonance line-shape depends on shape, orientation, size, distributions, interactions,…
- SPR used since ancient times (i.e., stained glass). Current applications in selective absorbers, surface enhanced spectroscopy, non-linear optics, wave-guides, metamaterials, medical diagnose and therapy

Metal island films as plasmonic composites



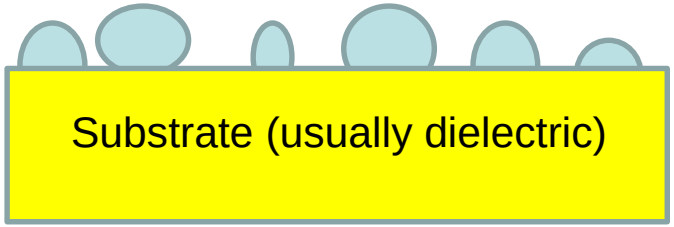
Metals “like” to grow as islands...

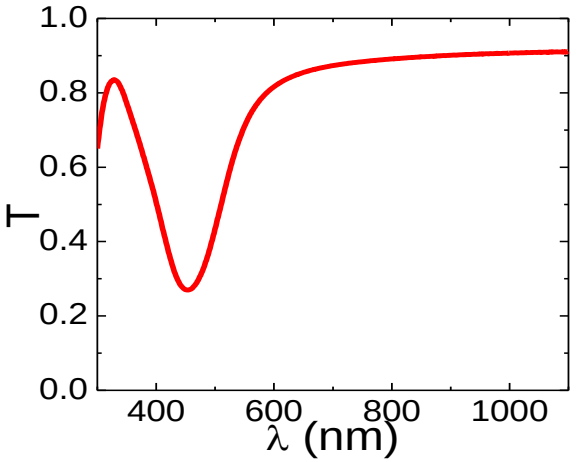


N. Kaiser Applied Optics, 41, 3053 (2002)

... showing SPR properties

Metal clusters (~5-30 nm)

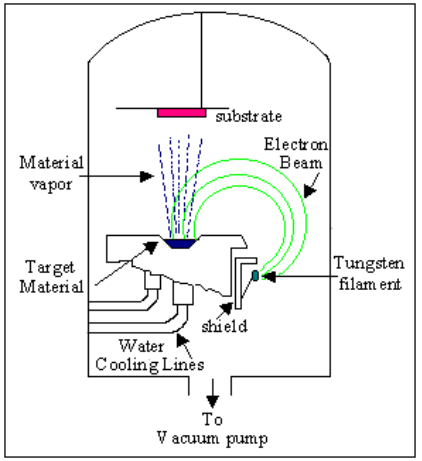




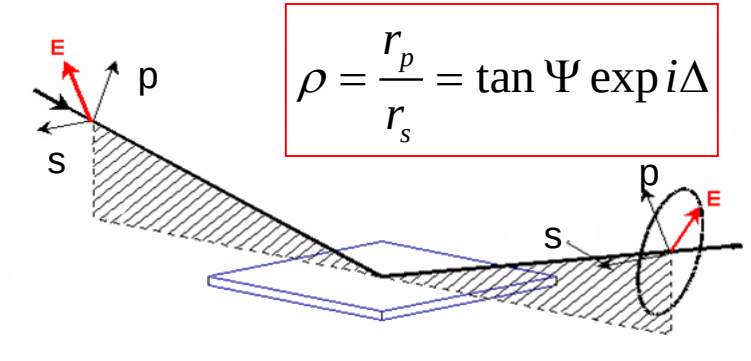
Sample fabrication & characterization

• Deposition of metal and dielectrics by e-beam evaporation (modified Varian chamber)

• Thickness controlled by quartz crystal monitoring, Temperature controlled with quartz heaters



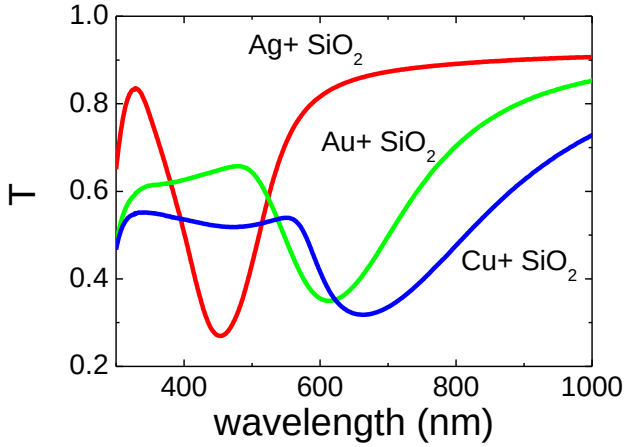
• Optical characterization: spectrophotometry and ellipsometry



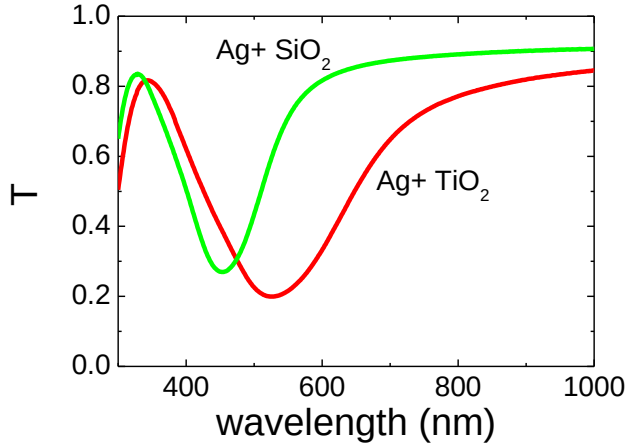
$$\rho = \frac{r_p}{r_s} = \tan\Psi \exp i\Delta$$

Tailoring the SPR of metal island films

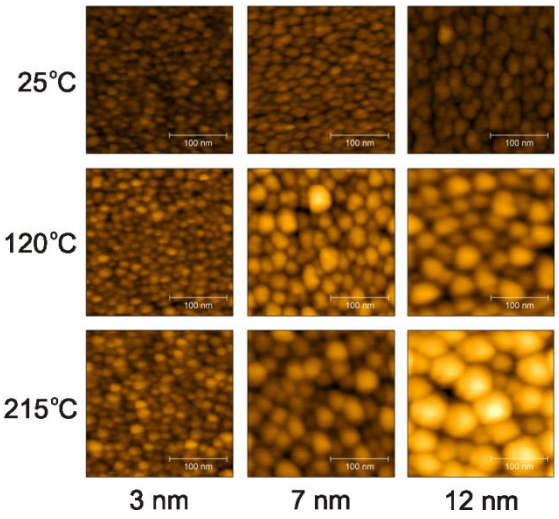
i) Use of different metals

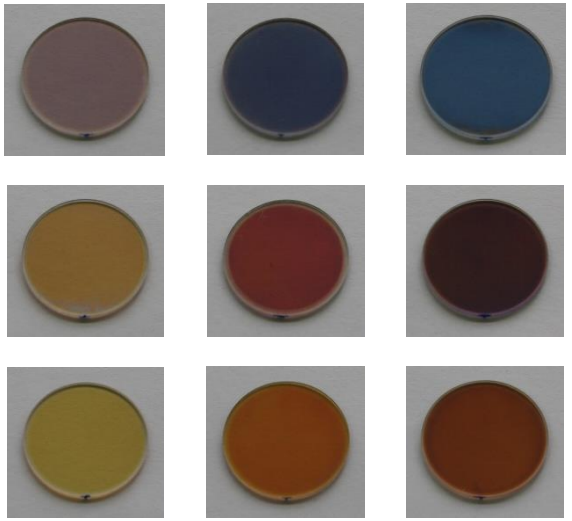


ii) Changing the dielectric environment



iii) Control deposition conditions (amount of metal and substrate temperature)

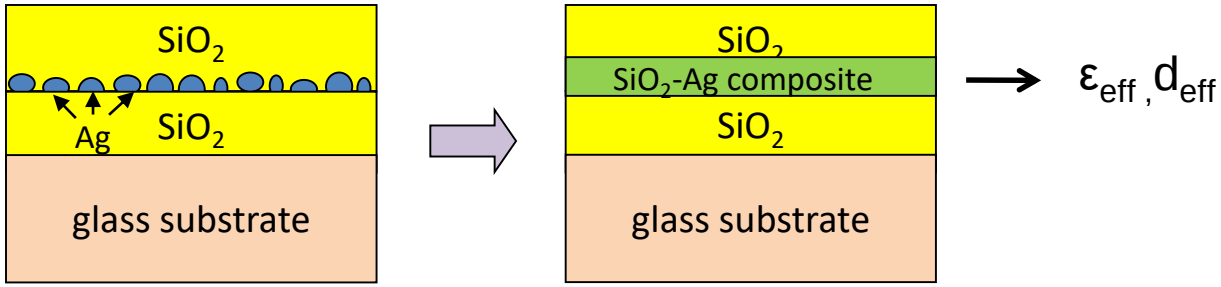




Vacuum. 84 (2009) 1; 188-192

Effective medium modelling

- In the optical range λ>> clusters size → **homogeneization**

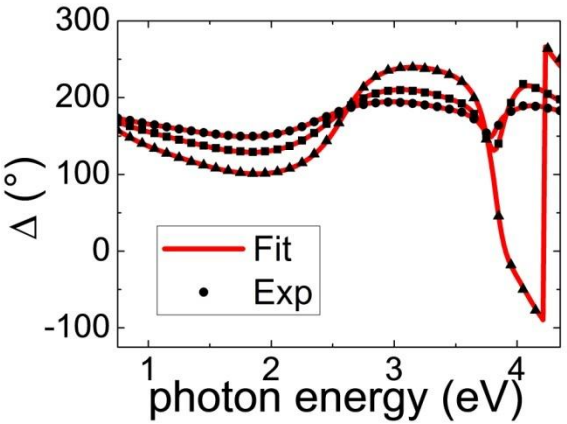


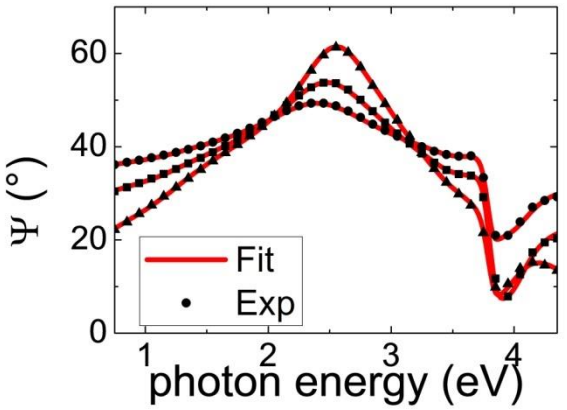
- Ellipsometry measurements:

  Δ, ψ at different angles of incidence, λ: 300-2200 nm →ε_{eff} , d_{eff}

- $\varepsilon_{eff}(\lambda)$ → multiple oscillator model

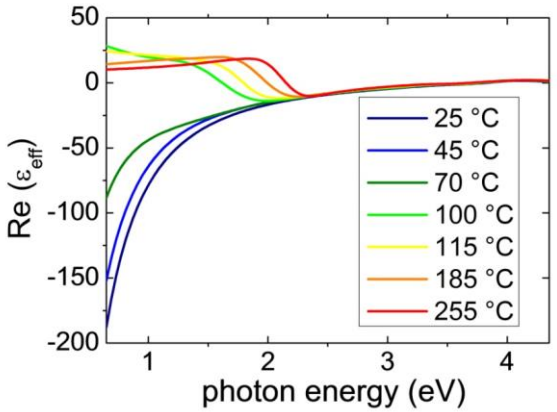
$$\varepsilon_{eff}(E) = \sum_{n=1}^{N_{osc}} \varepsilon_n(E) + \varepsilon_\infty$$

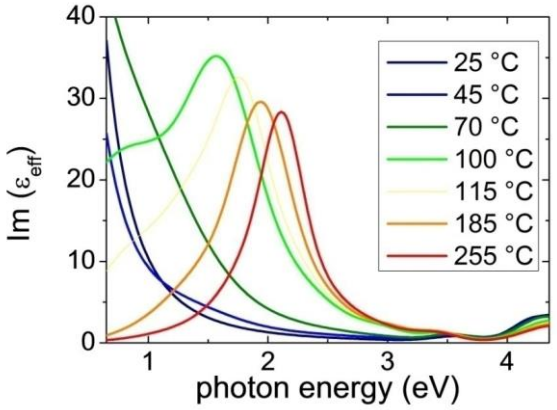




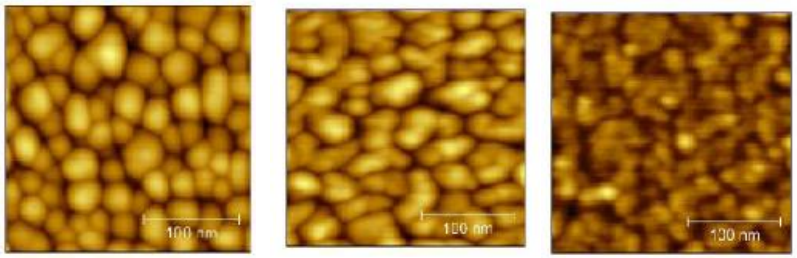
Characterization results

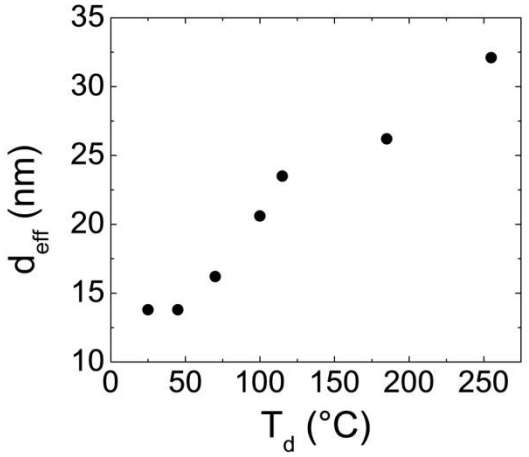
- Ag islands between SiO_2 layers @ different substrate temperatures





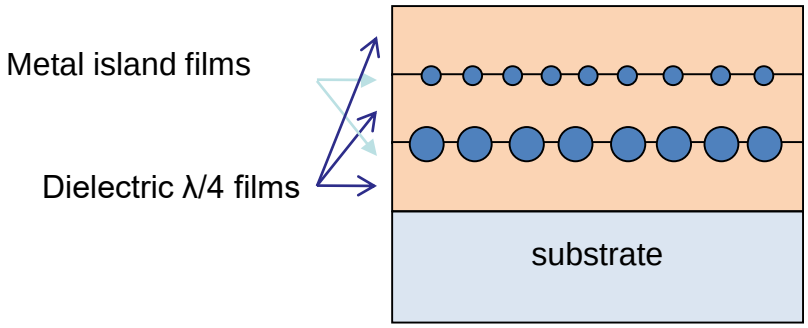
⇒ From metal-like (Drude) to narrow SPR absorption as T↑ due to morphological changes

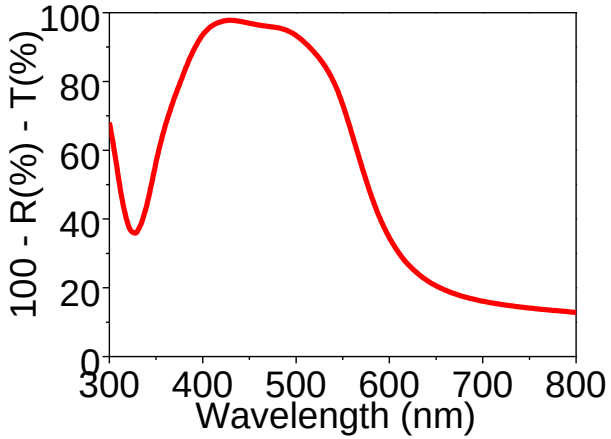




Overall, broad **tuning of ε_{eff}** can be obtained by changing **T**!

Example I: highly absorbing coating

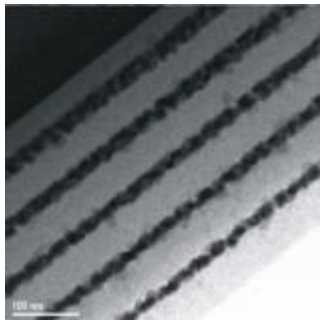




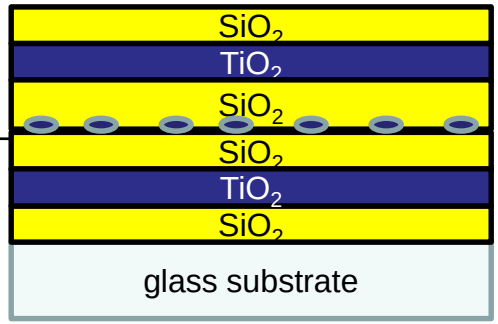
S. Kachan, Appl. Physics B, 84, 281, (2006)
V. Janicki et al. Appl. Optics 50, C228 (2011)

- Combination of surface plasmon resonance of MIFs with interferential behavior of dielectric multilayers.

- High absorption = anti-reflective effect (gradient structure) + absorption of several plasmonic layers.



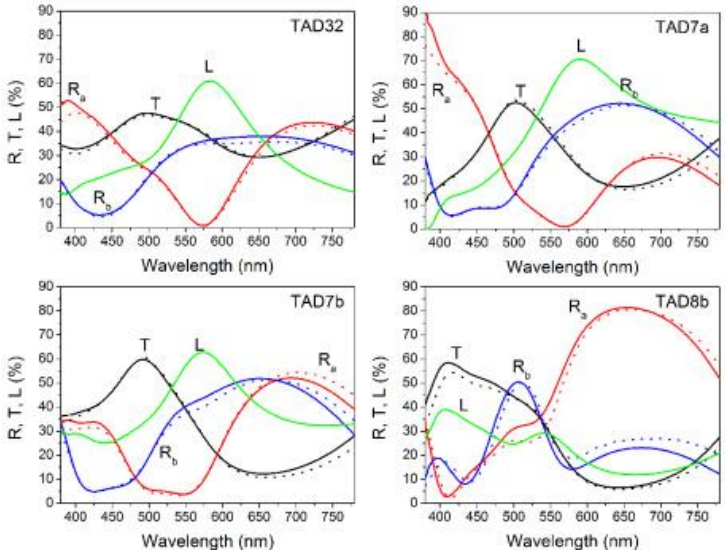
Example II: Bi-colour coatings



V. Janicki et al. Optics Express 19, 25521 (2011)

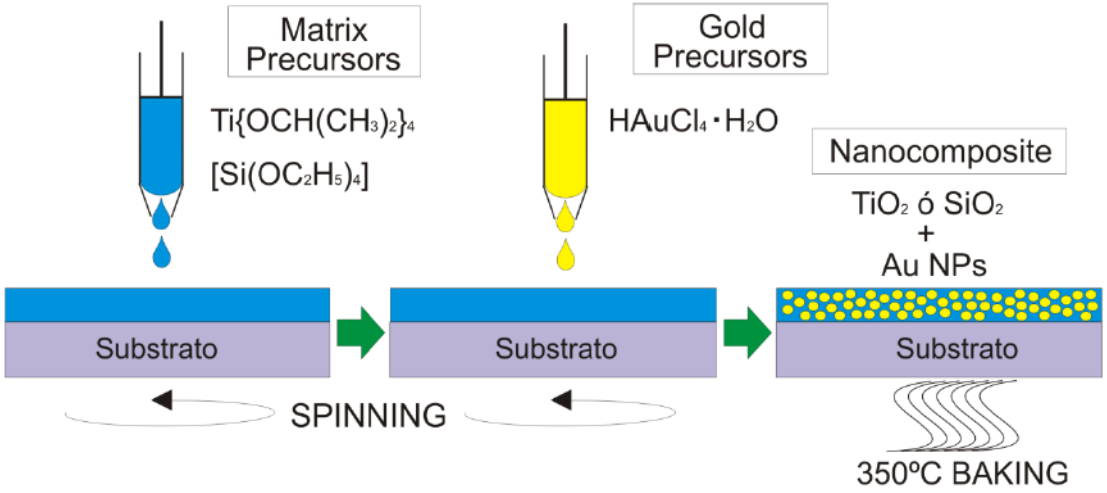
⇒ Different colours from both sides + large transmittance

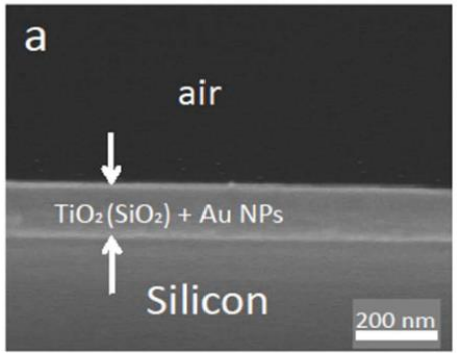
⇒ Design process needs to incorporate surrounding of Au island film.

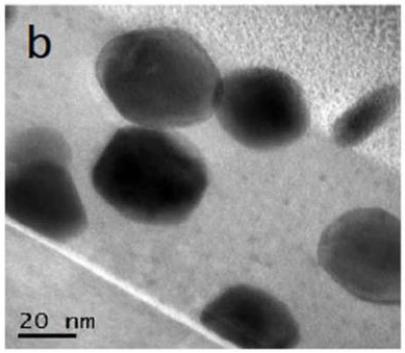


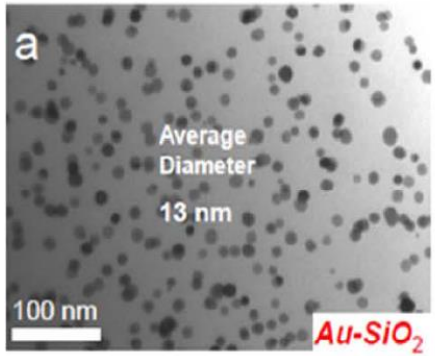
Sol-gel plasmonic nanocomposites

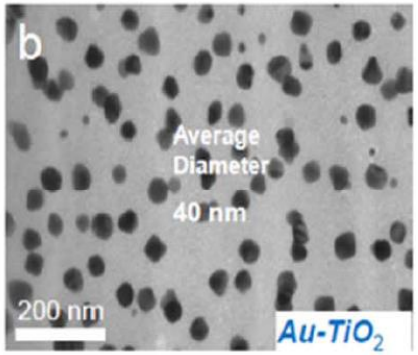
Nanocomposites made by spin-coating → good monodispersity, narrow SPR







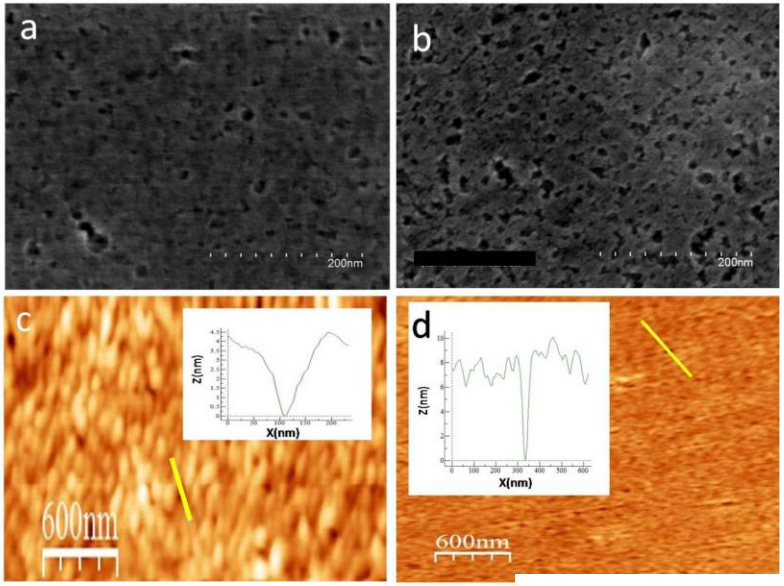


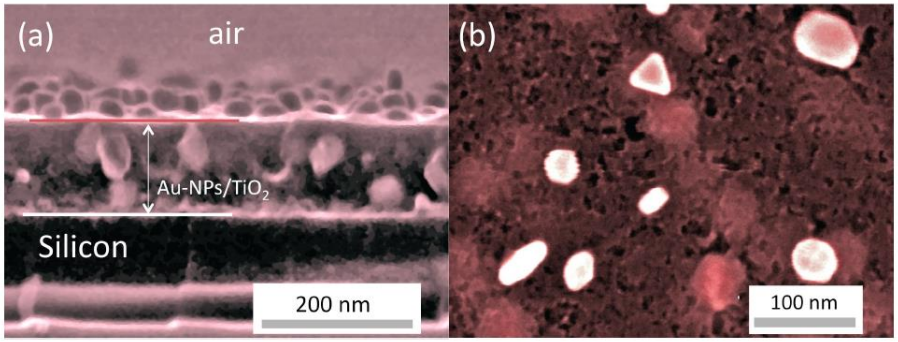


E. Pedrueza et al. Adv. Fun. Mater. *21, 16,* 3502 2011

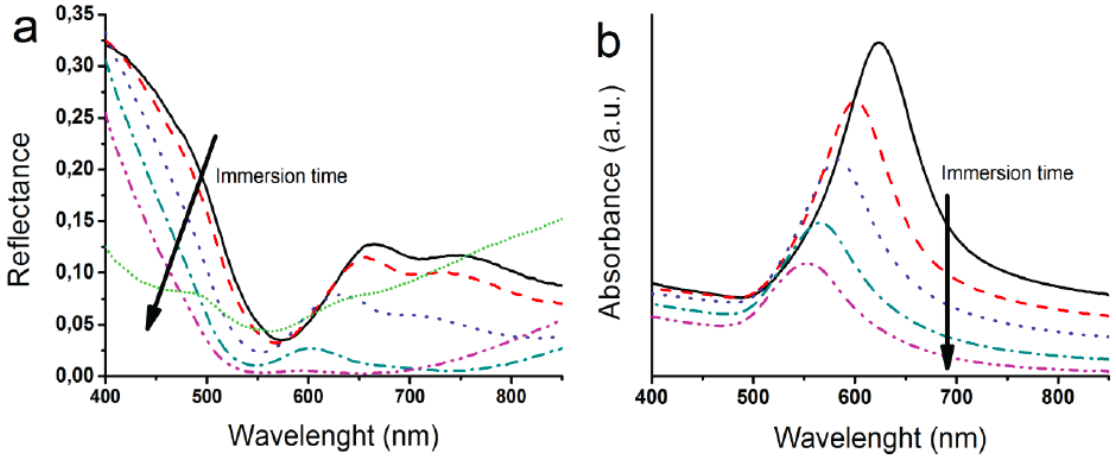
Etching and Anti-Reflective effects

- HF etching (10 – 100 s) increases film porosity



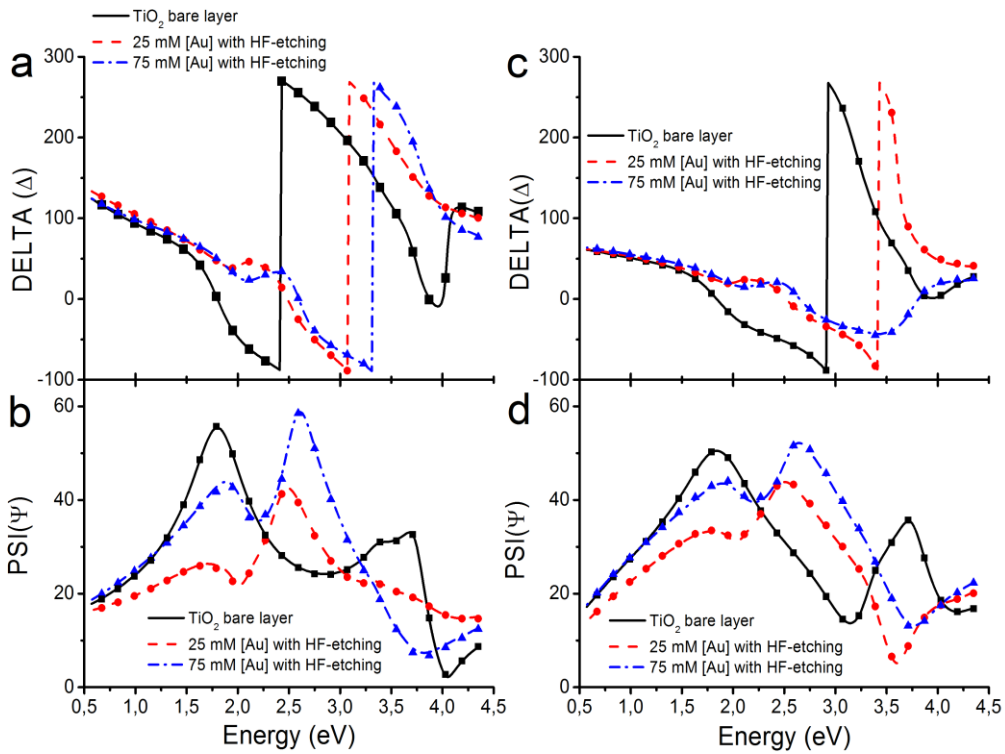


- AR effect + SPR blue-shift as etching ↑ (potential for photovoltaic applications)



Nanotechnology 24 (6), 065202

Characterization of etched samples



- Blue-shift of SPR resulting from lower-density matrix
- Large surface roughness values (~ 20 nm) ⇒ generation of a gradient structure with AR effect

Conclusions

- Plasmonic nano-composites show unique optical behaviour due to surface plasmon resonance. Broad tailoring of properties can be achived by controlling the deposition conditions.

- Effective medium description of plasmonic composites allows design of coatings and their characterization from experimental data (spectroscopic ellipsometry).

- Metal island films and sol-gel composites have been used for several coating design and fabrication: high absorption, bi-colour reflection, anti-reflective, high luminosity mirrors, ...