Universidade do Minho
Escola de Engenharia

CENTRO DE CIÊNCIA E TECNOLOGIA TÊXTIL

Variation in nanoparticle size, color and deposition methods of photonic nanocrystals for structural coloration of textiles

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Introduction

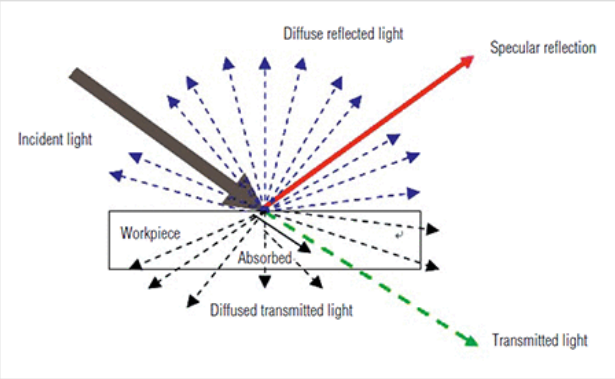
https://www.trustedclothes.com/blog/2016/06/23/impact-of-dyes/

http://maateeusa.com/what-is-wrong-with-synthetic-dyes/

https://phys.org/news/2013-07-fashion-industry.html

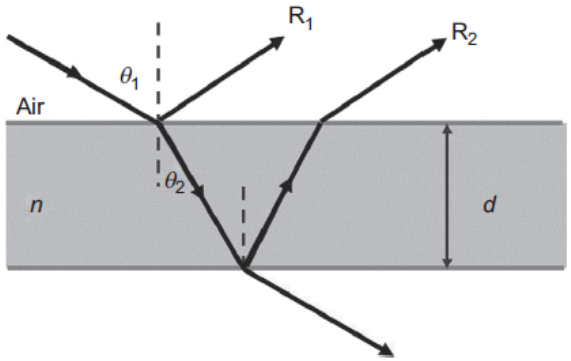
Introduction

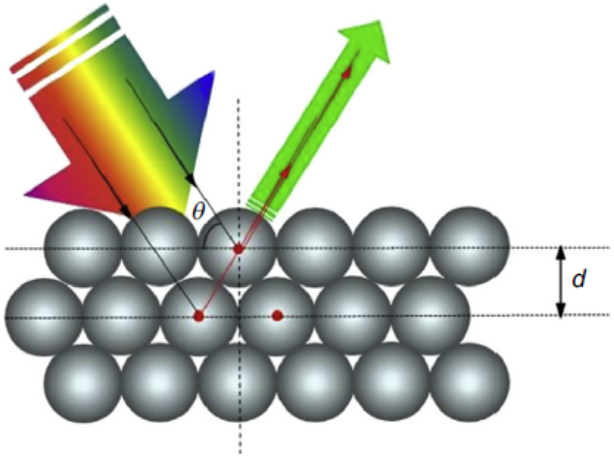
LIGHT AND COLOR



Conventional
Dyed Substrate

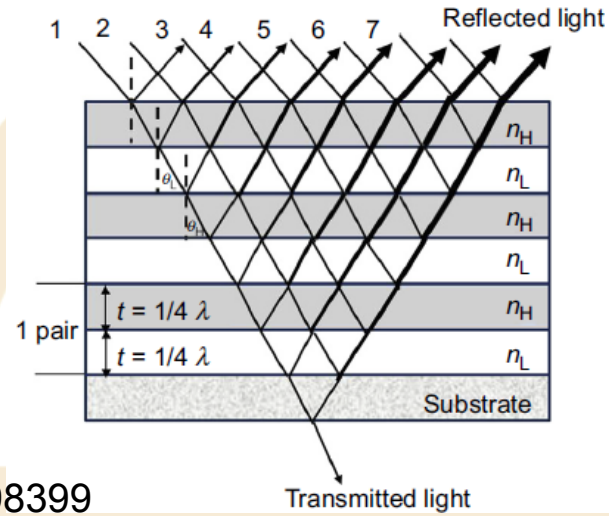
Thin-film
Interference





Multilayer
Interference

Bragg's diffraction law
(3D photonic crystals)



Hu, J., *Active Coatings for Smart Textiles,* **2016**. ISBN: 9780857098399

Introduction

PHOTONIC CRYSTALS + textiles?

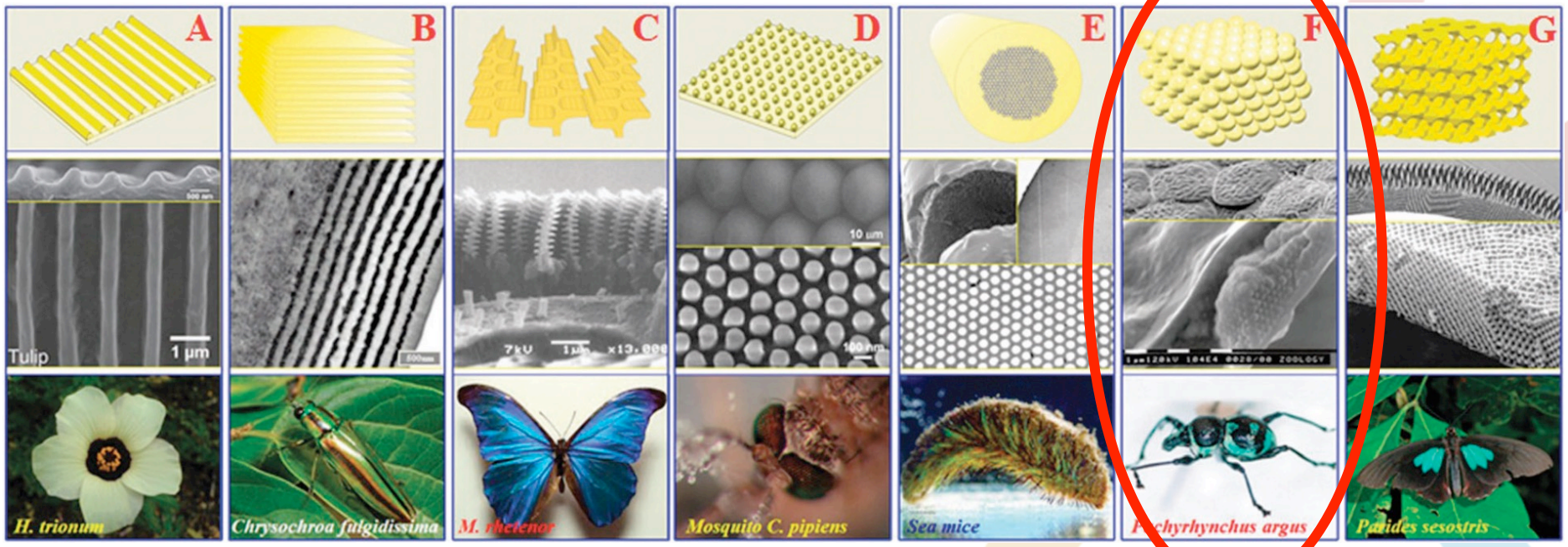
- Dielectric materials;
- highly periodic structure;
- spatially ordered lattices;
- capable of controlling the propagation of light due to the photonic band gap (PBG).

Applied in sensors, inkjet, lithography, light-emitting diodes (LEDs) and electronic devices.

https://imgur.com/gallery/DpCkOpH

Introduction

PHOTONIC CRYSTALS

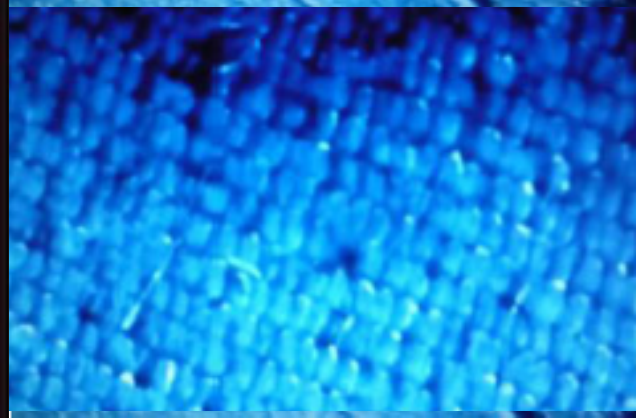
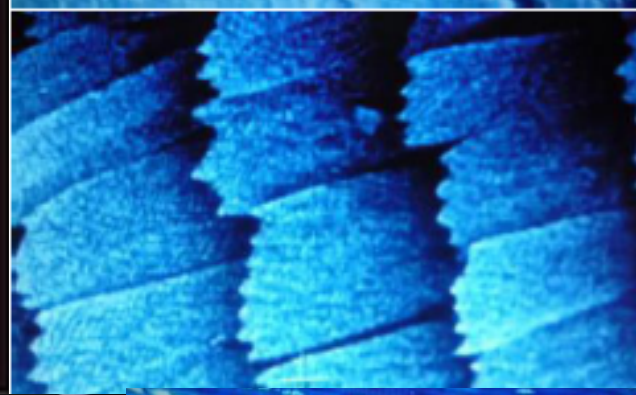
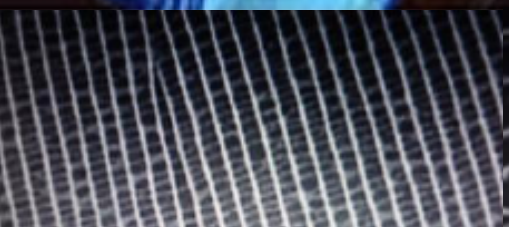


10.1039/c2cs15267c

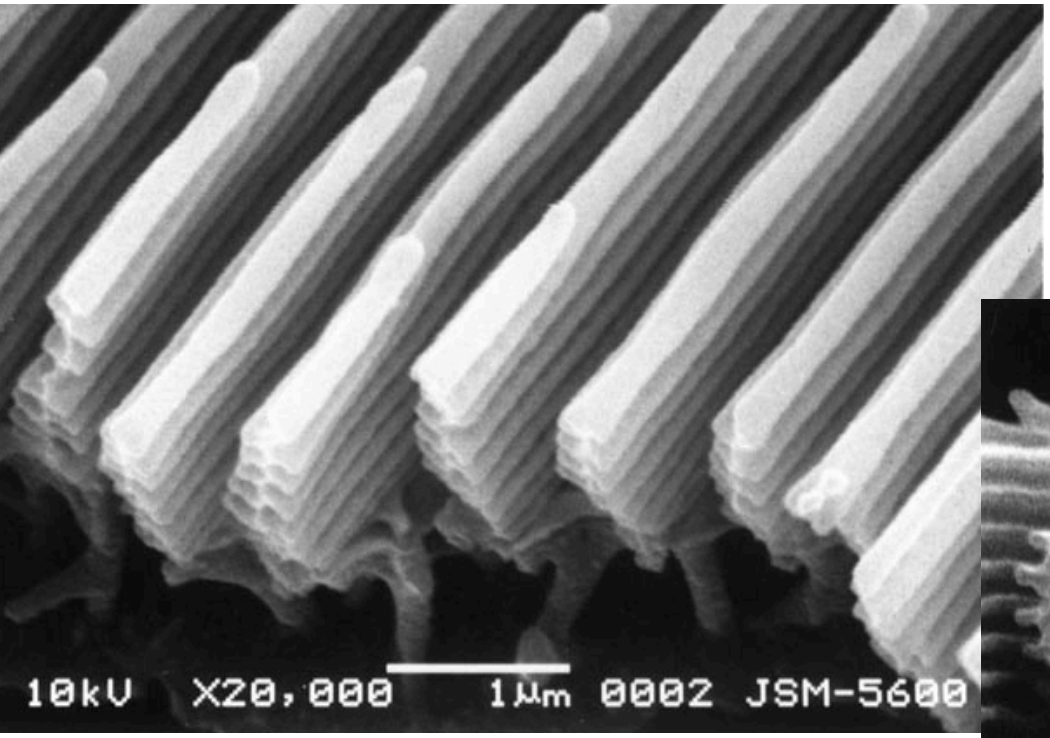
A, B, C – 1D structures
D, E – 2D structures
F, G – 3D structures

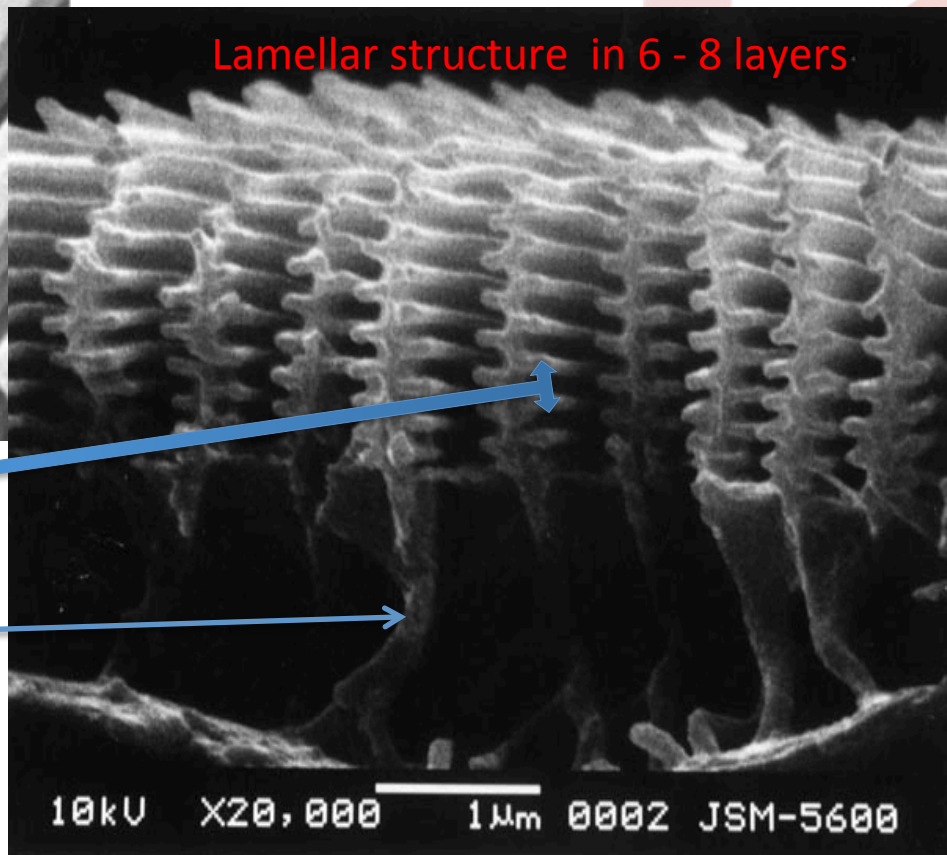
Photonic Crystals 1D
Morpho butterfly




Photonic Crystals 1D
Morpho butterfly



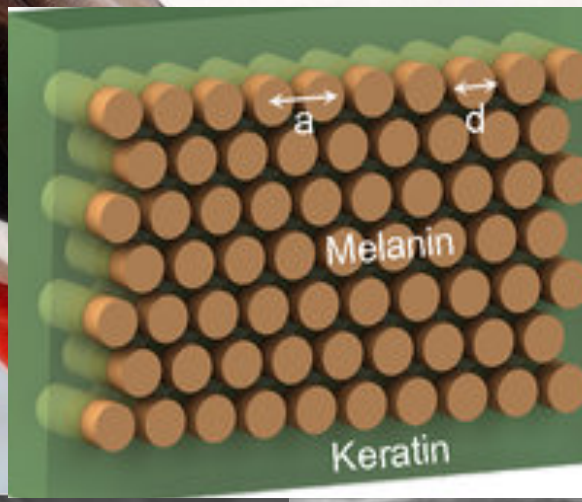


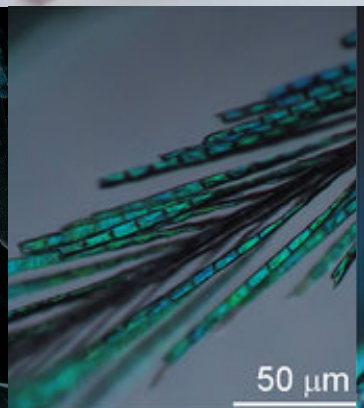
doi: 10.1098/rspb.2002.2019

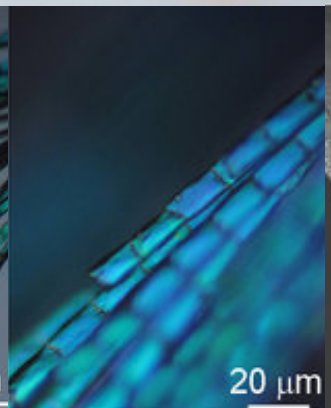
200 nm

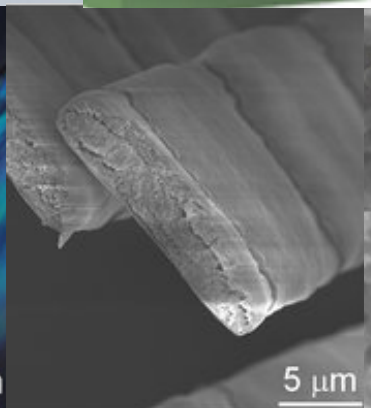
The pigmentation in the scale absorbs the extraneous green to red light and enhances the blue coloring

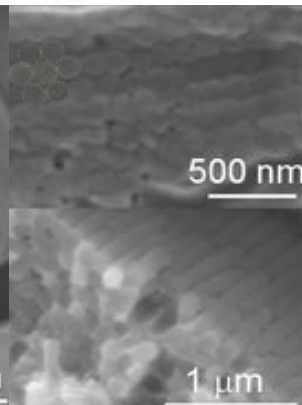
Photonic Crystals 2D
Mallard duck



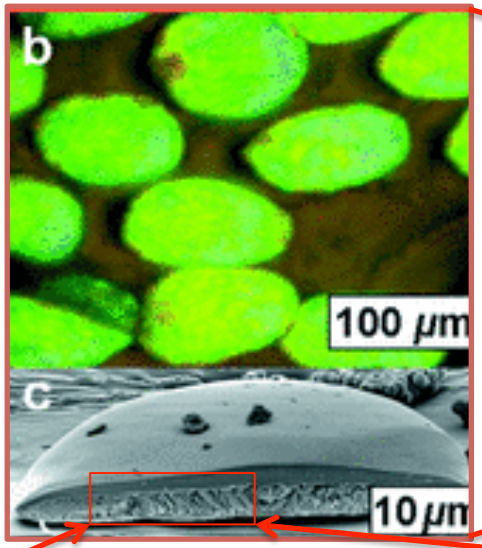


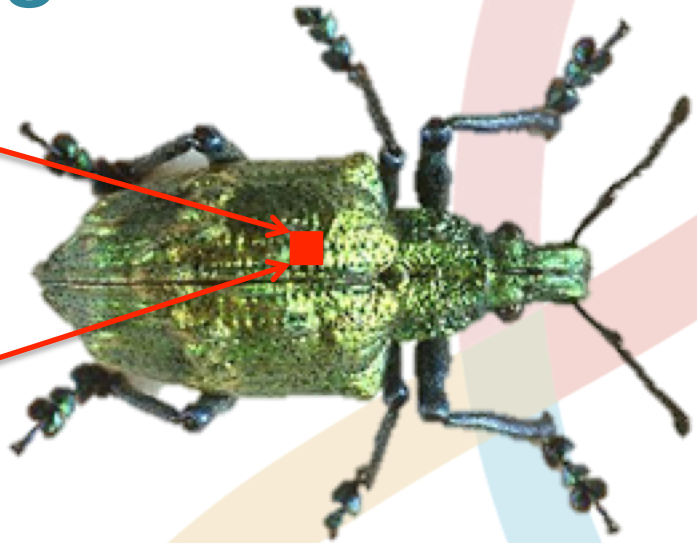




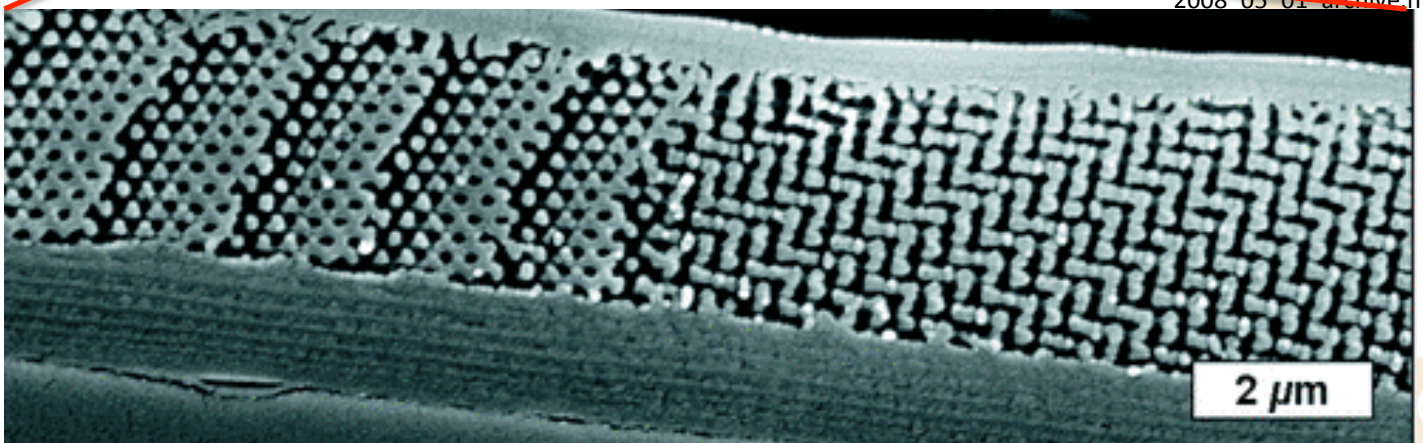


Photonic Crystals 3D diamond-based structure in the beetle L. augustus

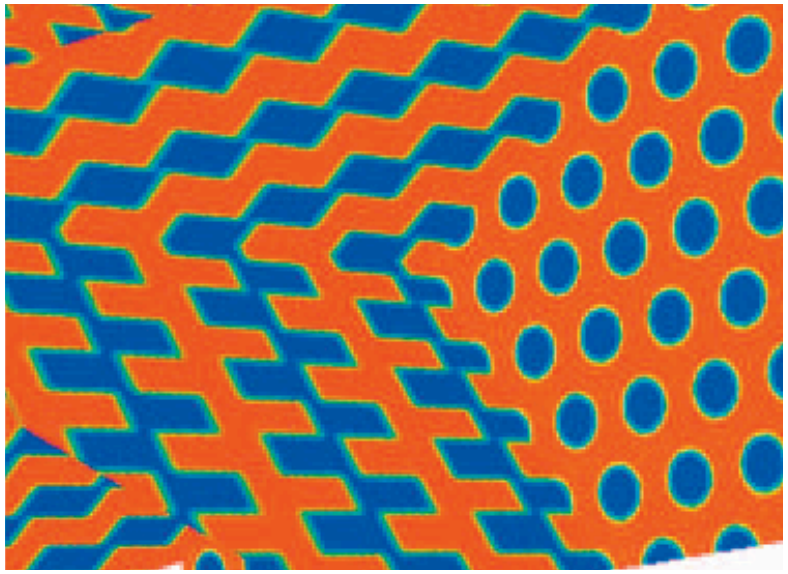


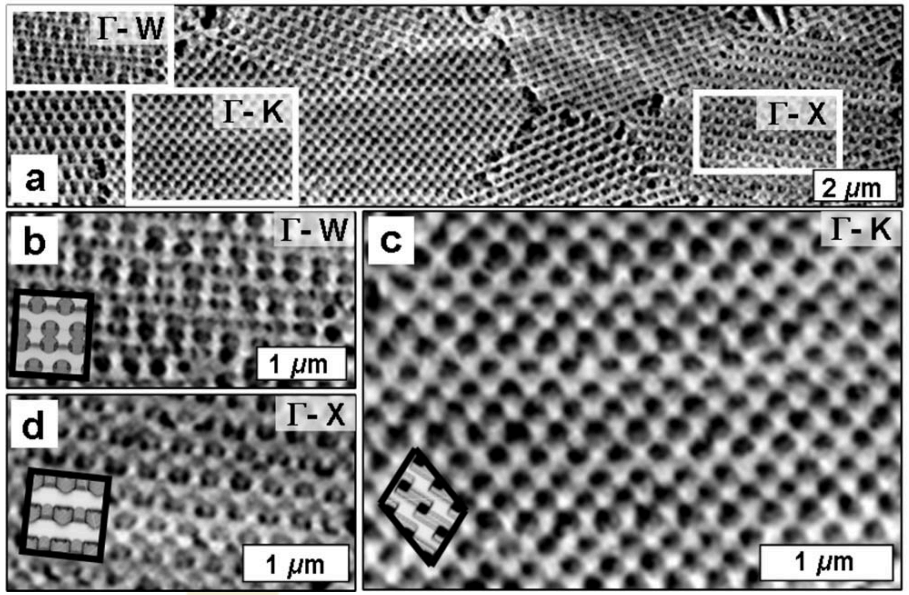


http://physicsbuzz.physicscentral.com/2008_05_01_archive.html



Photonic Crystals 3D diamond-based structure in the beetle L. augustus



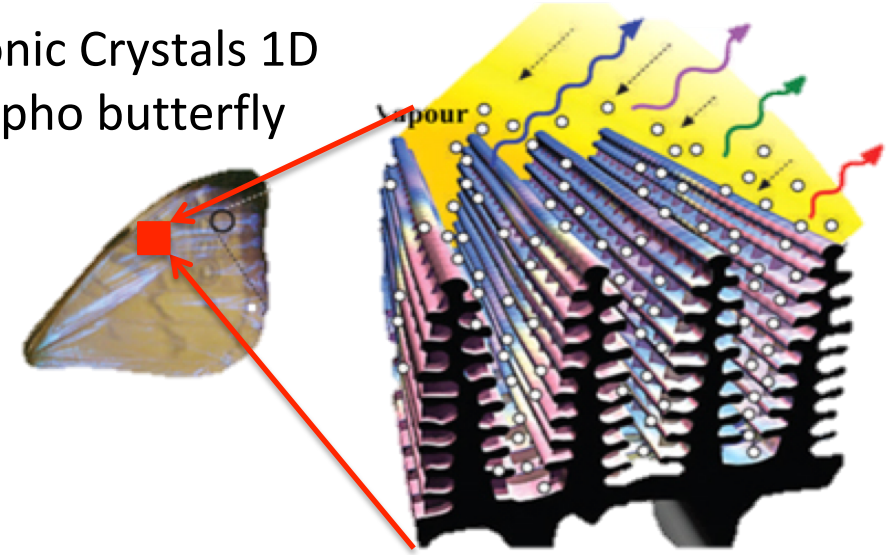


http://physicsbuzz.physicscentral.com/2008_05_01_archive.html

Sensors made of Photonic crystals

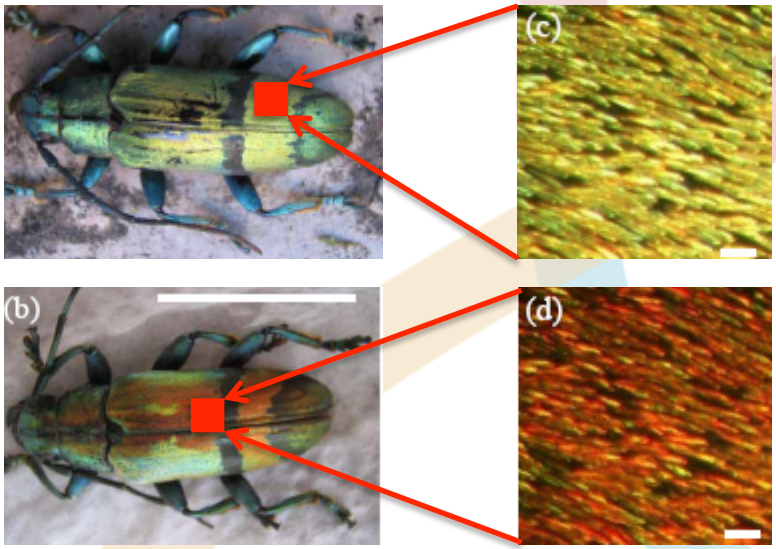
- by humidity effect

Photonic Crystals 1D
Morpho butterfly



http://cdn.iopscience.com/images/0957-4484/27/12/122001/Full/nanoaa13e1f8_lr.jpg

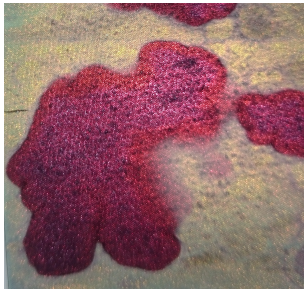
Photonic Crystals 3D
beetle Tmesisternus isabellae



F. Liu, B. Q. Dong, X. H. Liu, Y. M. Zheng, J. Zi, "Structural color change in longhorn beetles Tmesisternus isabellae," Opt. Express **17,** 16183-16191 (2009);
https://www.osapublishing.org/oe/abstract.cfm?uri=oe-17-18-16183

- at our lab:

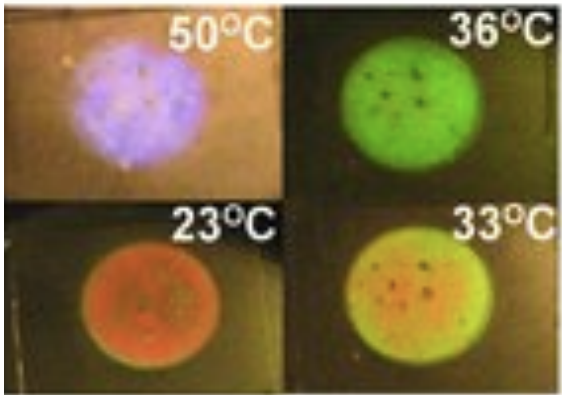
- wet



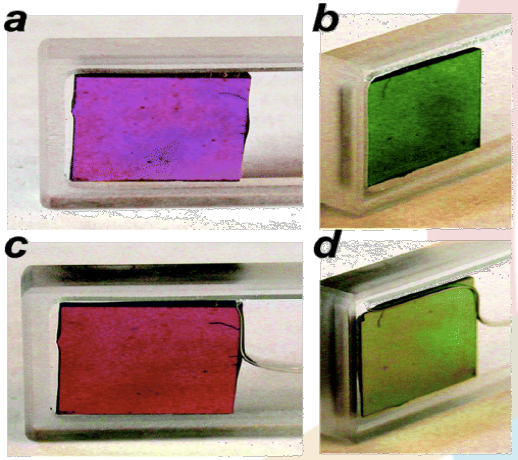
- drying

Sensors made of Photonic crystals

- by temperature effect



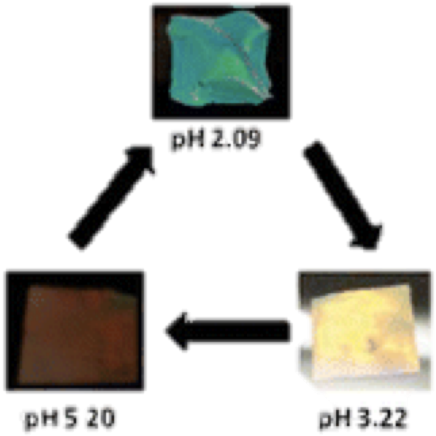
- by chemical effect



In air

In ethanol

- by pH effect



- others:
  - .ionic species
  - .pressure
  - .biomolecules

doi:10.3390/s130404192 **DOI:** 10.1021/nl061580m **DOI:** 10.1002/adma.201202459

Lab preparation soap-free emulsion polymerization

Monodispersed composite latex spheres of poly-(styrene-methyl methacrylate-acrylic acid) (P(St-MMA-AA)) were synthesized by soap-free emulsion polymerization in a three-necked flask equipped with a reflux condenser and a mechanical stirrer.

The mixture was stirred at 70 °C in N_2 atmosphere for 5 h to obtain a homogeneous particle diameter of ~170 to 250 nm.

Results and Discussion

P(St-MMA-AA) NANOSPHERE SYNTHESIS

Table 1 – Different reaction conditions tested (control reaction in bold).

	Temperature (°C)	Stirring (rpm)	Size (nm)
P(St-MMA-AA)	90	300	~170
	80	**300**	**~190**
	70	300	~210
	60	300	~250
	80	400	~190
	80	200	~170

Nanosphere size was confirmed by Scanning Transmission Electron Microscope (STEM).

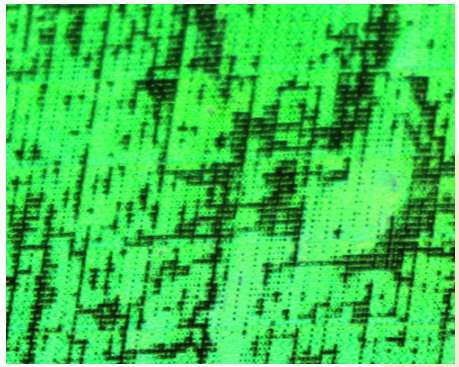
Results and Discussion

DEPOSITION METHODS – Gravitational sedimentation

Substrate: commercial black polyamide 6.6 plain fabric, with 61.5g/m^2, 67 warp and 47 weft yarns, 5.6 Tex and 3 Tex respectively.

Dilution

1:20



Fabric was placed in a Petri dished filled with PCs suspension, which was dried in the oven at 40ºC.

Results and Discussion

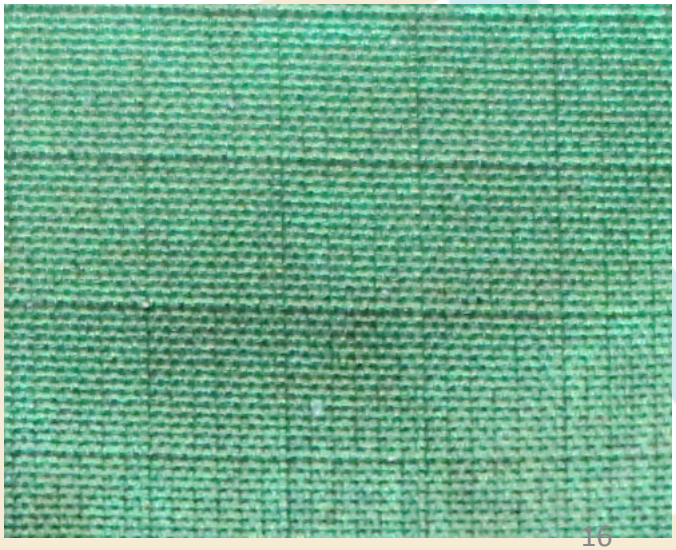
DEPOSITION METHODS – Dip-drawing

Initially tests were performed with a diluted solution:

- to get a good structural color the fabric has to be dipped and dried several times;
- not viable for industrialization processes;
- higher energy costs.

Optimize solution/method:

- One dip, plus dry (40ºC);
- Saves time and energy.



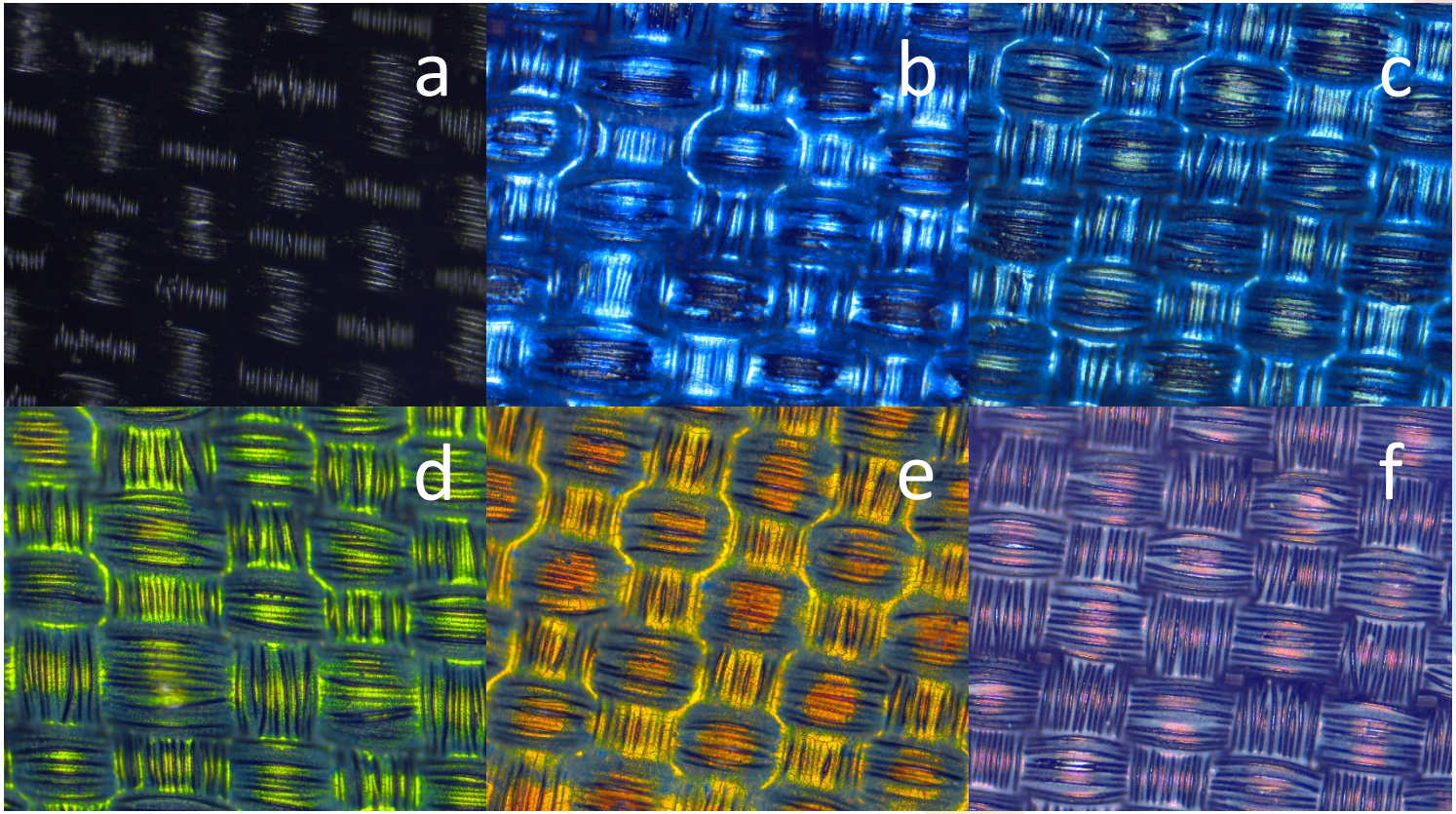
Results and Discussion

DEPOSITION METHODS – Dip-drawing

Due to the small size variations obtained during the synthesis repetitions for each temperature and each stirring speed it was possible to obtain different shades of colors.

Results and Discussion

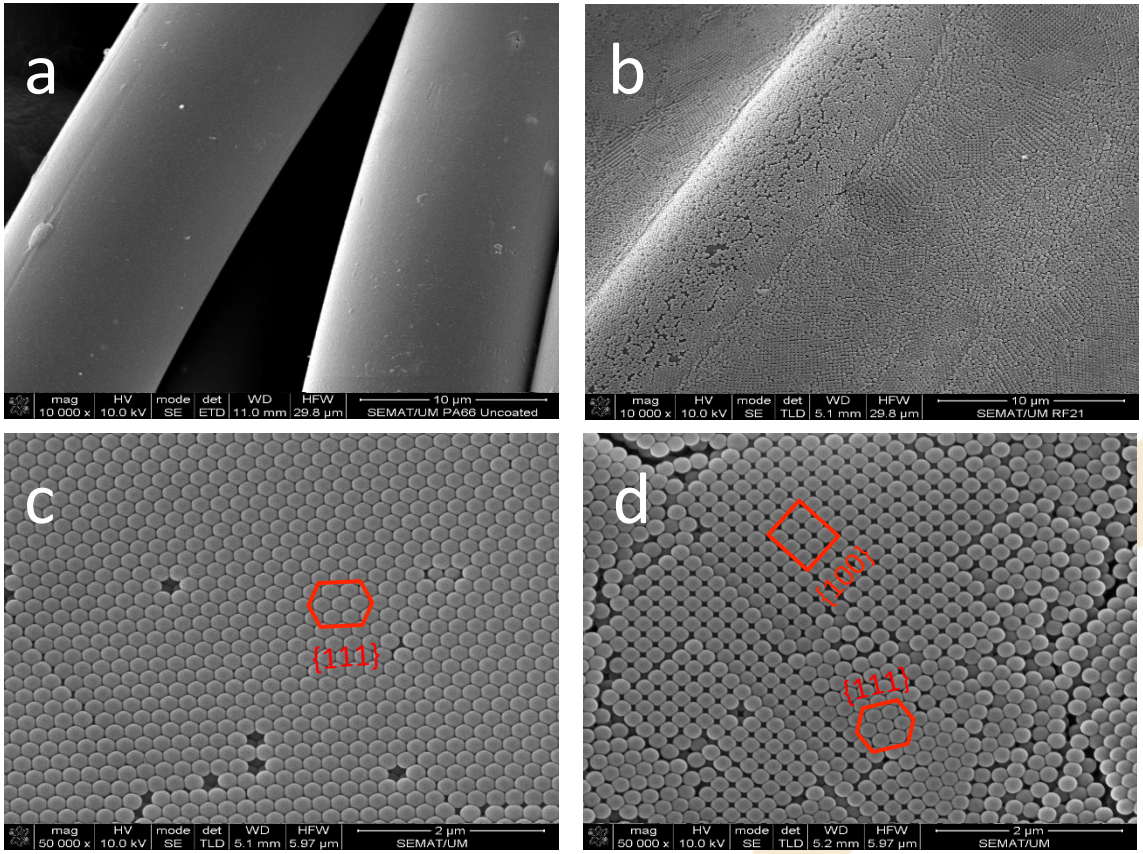
OPTICAL MICROSCOPY



a) PA Uncoated and coated with P(St-MMA-AA) particles b) 170 nm, c) 190 nm, d) 210 nm, e) 230 nm e f) 250 nm (100x magnification).

Results and Discussion

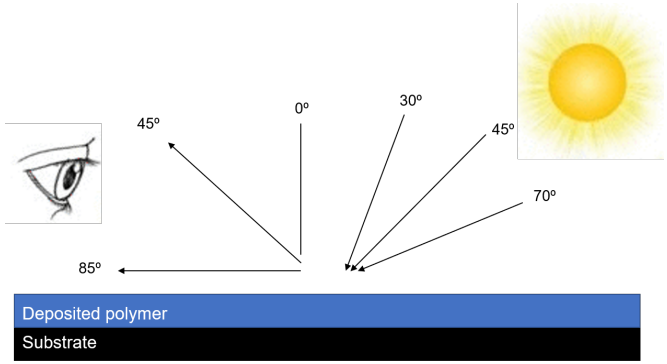
Scanning Electron Microscopy



SEM micrographs of coated PA fabrics. Hexagonally packed centre ({111}) structure is predominant, square arrangement ({100}) appears in out-of-plane surfaces.

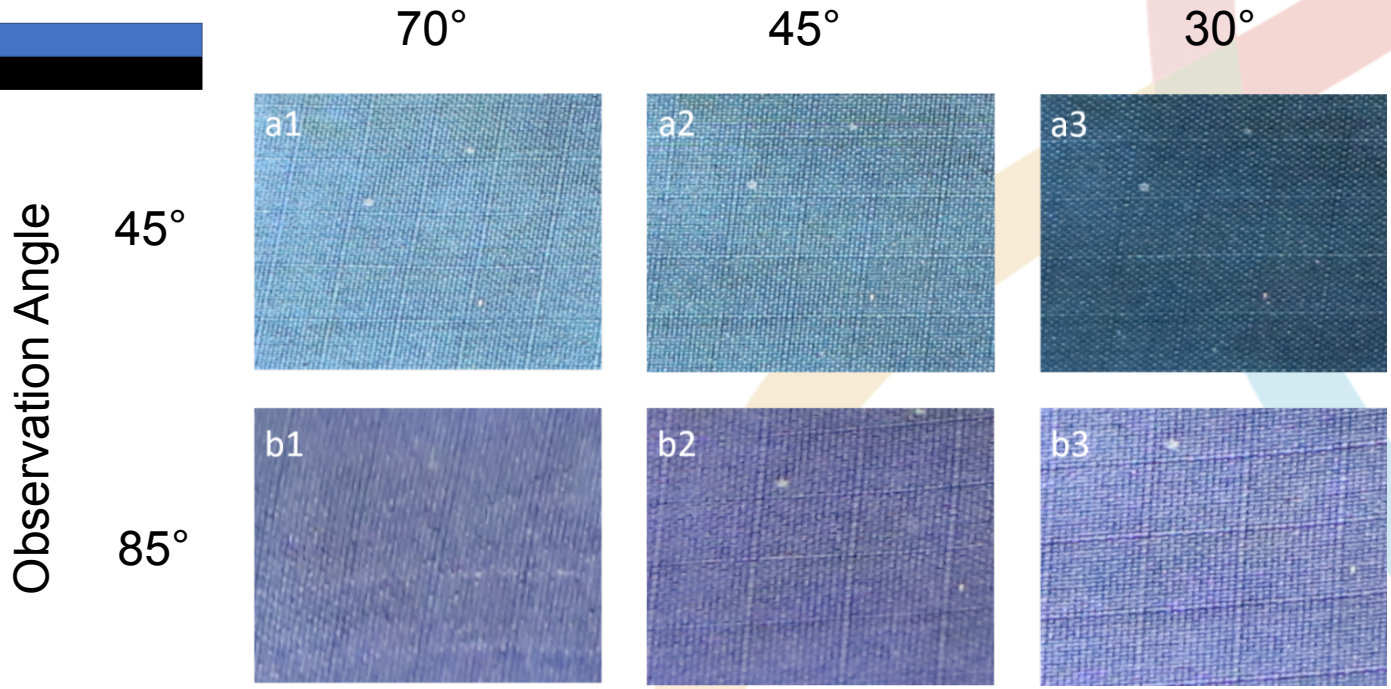
Results and Discussion

IRIDESCENCE EFFECT



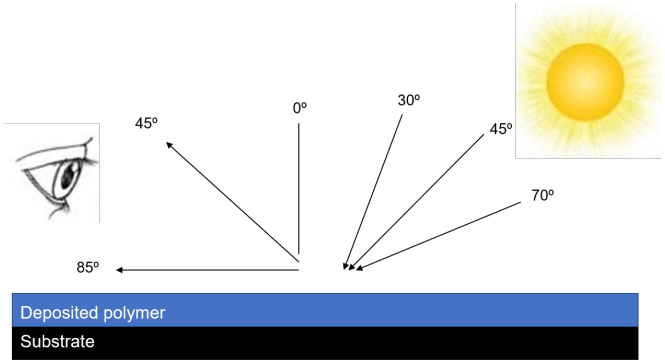
185 nm nanospheres

Light Incidence Angle



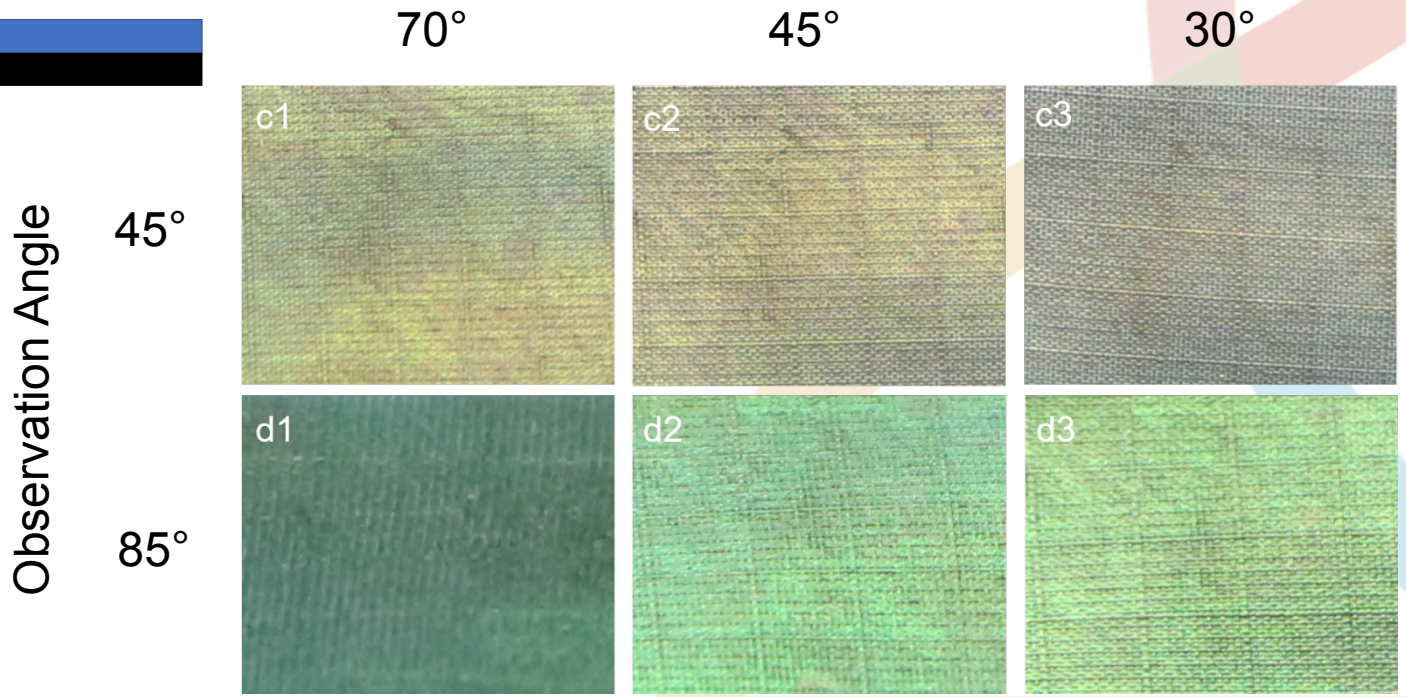
Results and Discussion

IRIDESCENCE EFFECT



230 nm nanospheres

Light Incidence Angle

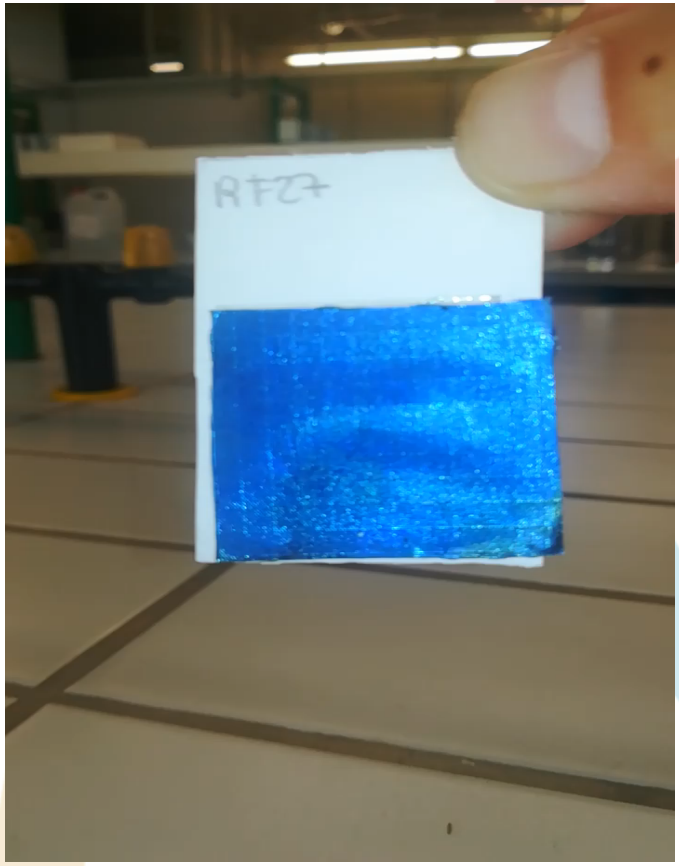


Results and Discussion

SPECULAR GLOSS

Specular gloss (UG) measurements for uncoated and coated PA fabrics, at 20°, 60° and 85°.

	20°	60°	85°
Uncoated	0.1	0.4	1.1
~190 nm nanospheres	0.3	1.9	3.6



Conclusion

- ✓ Synthesis of P(St-MMA-AA) nanospheres with different sizes by controlling the reaction parameters
- ✓ Different colors obtained by deposition of PCs onto PA 6.6 fabric:
  - Mainly hexagonally packed center structure
  - Uniform distribution of nanospheres onto fabric surface
  - Good structural color, gloss and iridescence
- ✓ Reduced amount of water used in fabric coloration

(new tool with applications in protective clothing)

PCs high light fastness

Eco-friendly coloration of fabrics

Nowadays challenges

- Can we give to the Nanophotonic crystals colour?

  YES, WE CAN -> We have done it!

- Can we “work” with several layers of color?

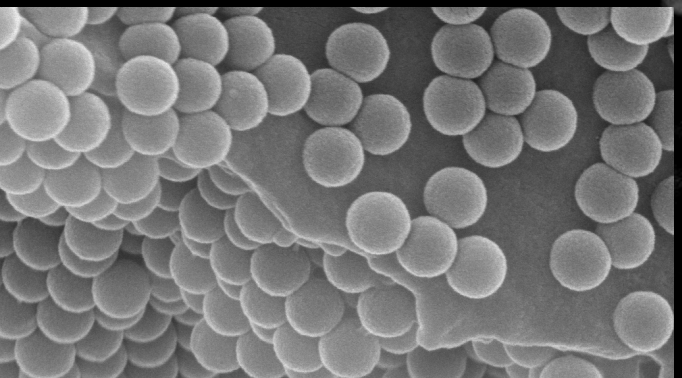
  YES, WE CAN

Nowadays challenges

Nowadays challenges

- How to improve washing durability?

A study is going on to improve washing fastness, without loosing the handle properties, applying mixture of biopolymers.



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Thank you for your attention

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