Universidade do Minho
Escola de Engenharia

CENTRO DE CIÊNCIA E TECNOLOGIA TÊXTIL

2022 AUXDEFENSE
3rd WORLD CONFERENCE ON ADVANCED MATERIALS FOR DEFENSE

Structural color for enhanced camouflage textiles (ID 231)

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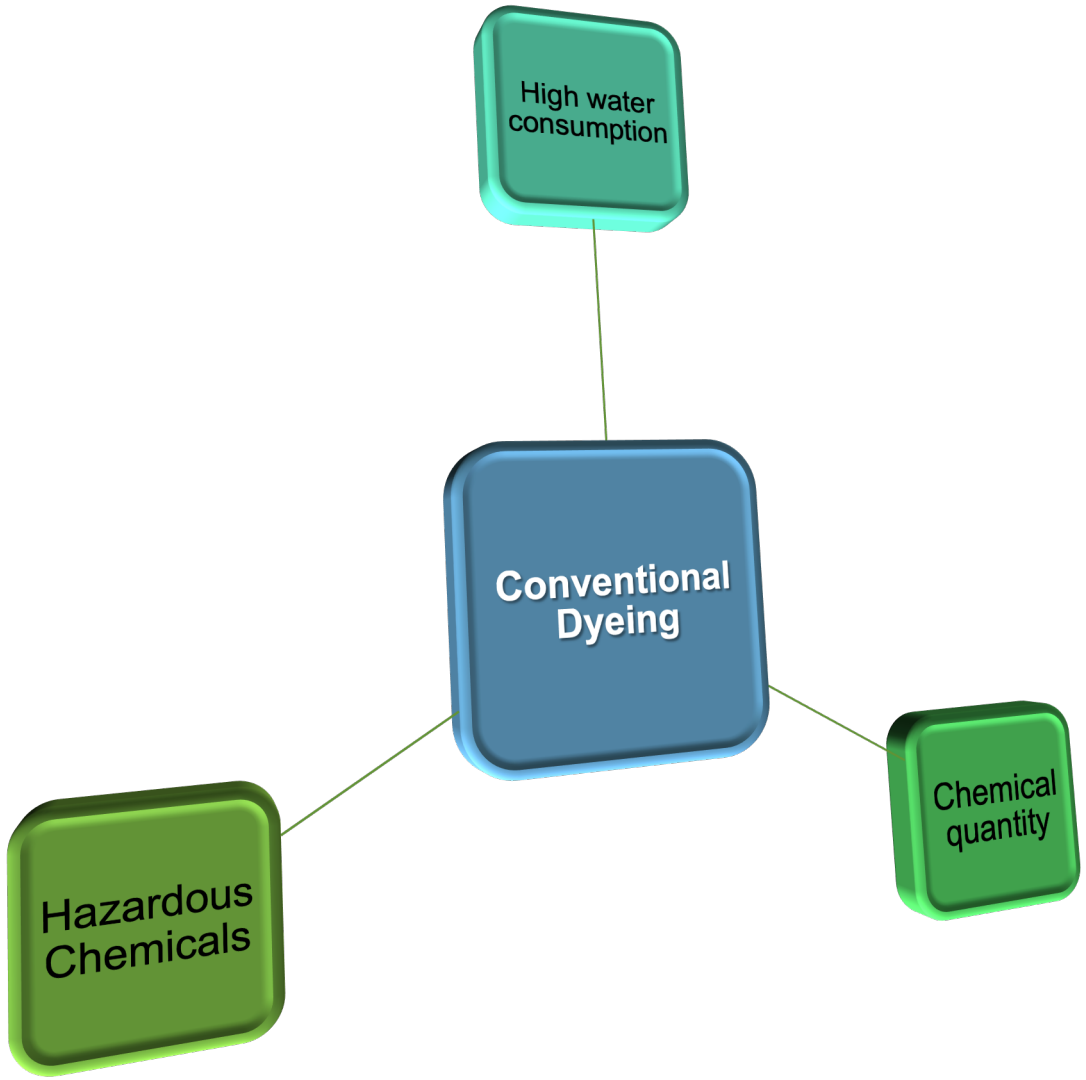
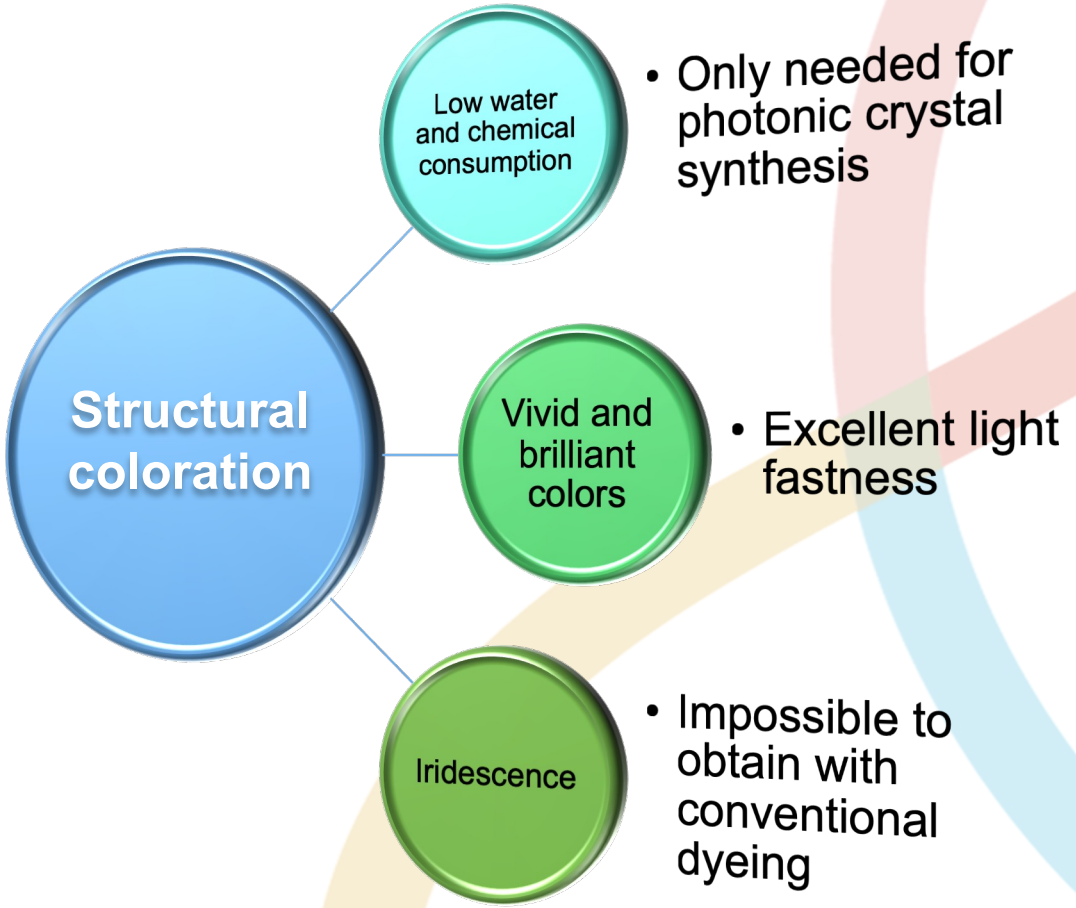
University of Minho, Guimarães, Portugal

Guimarães, July 2022

Why Structural Color?



Vs



Why Structural Color?

1 Pattern = 1 Color

www.vecteezy.com

Introduction

STRUCTURAL COLOR

Found in nature in animals, insects, fruits, plants and algae;

10.1038/srep04718

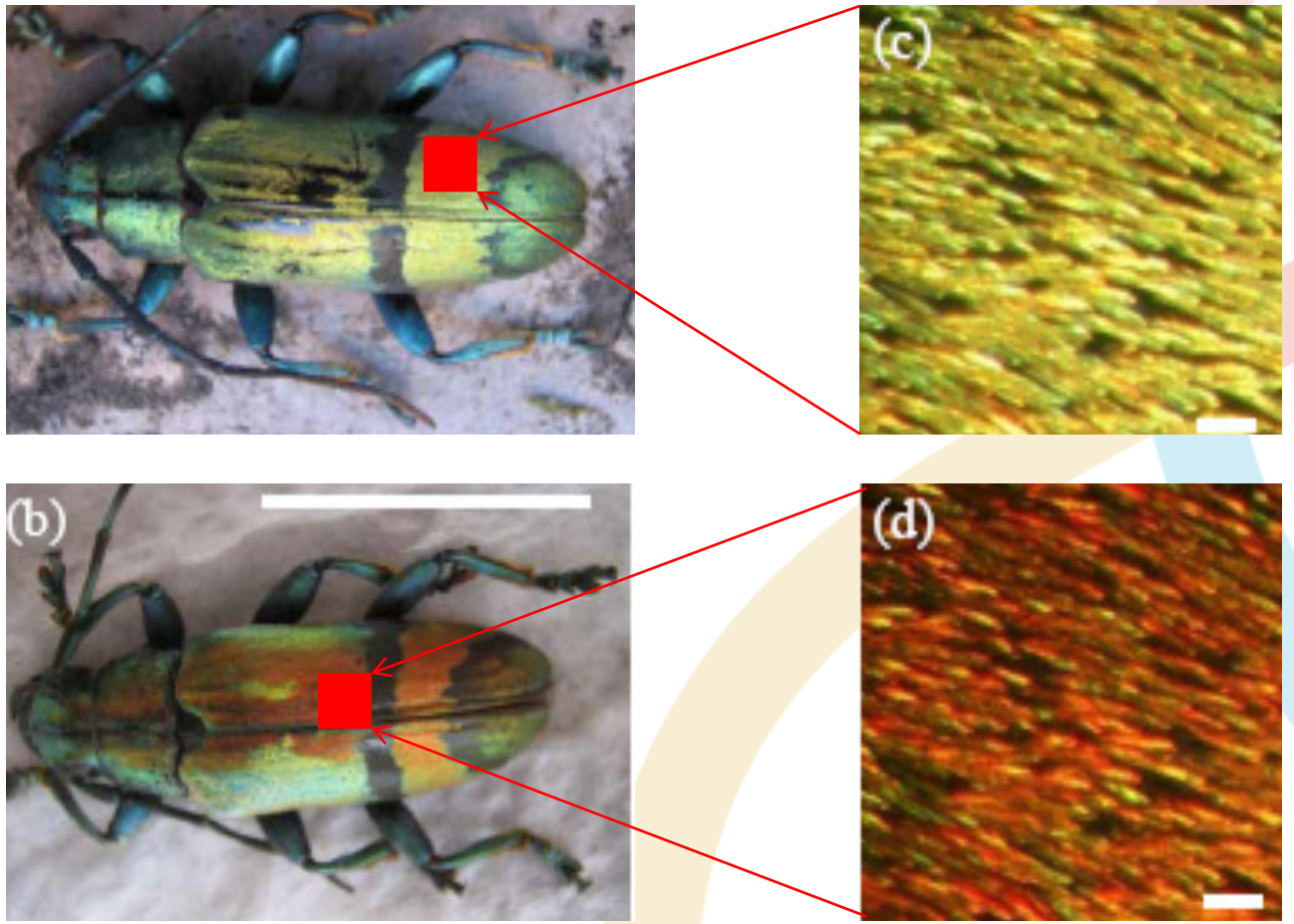
Introduction

STRUCTURAL COLOR

Found in nature in animals, insects, fruits, plants and algae;

Camouflage, signaling and communication;

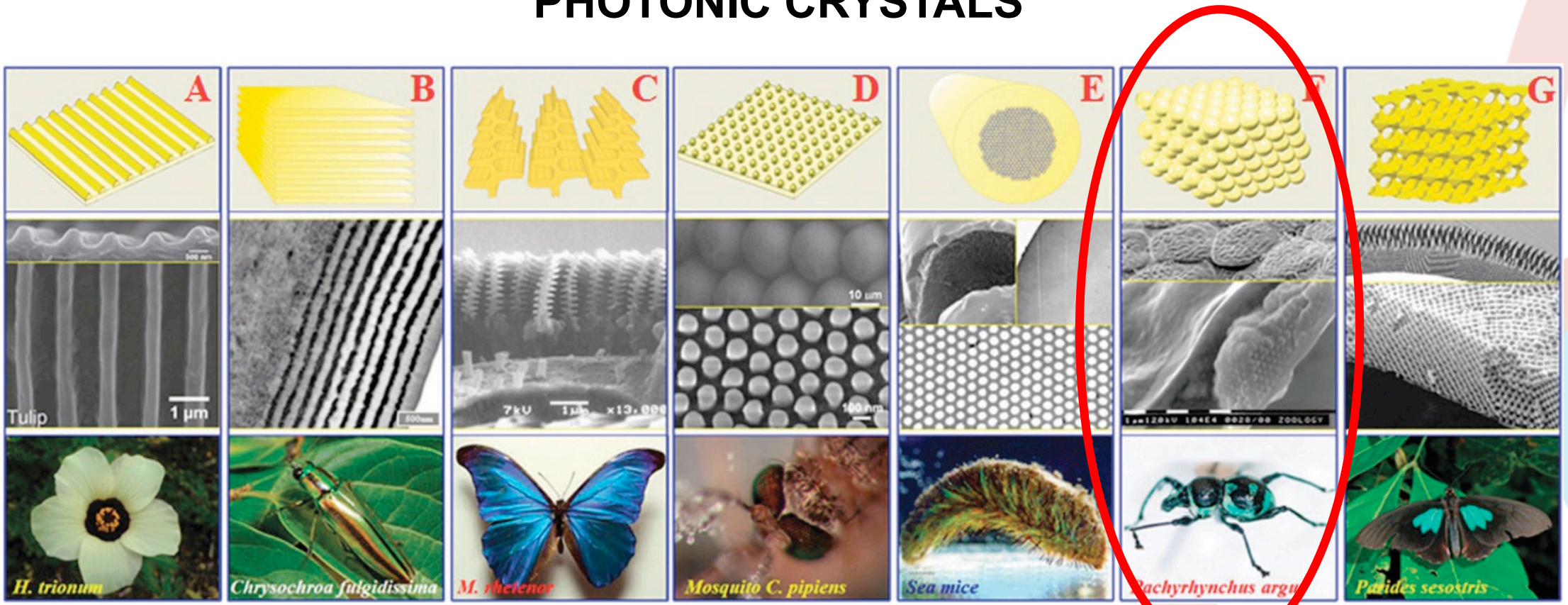
Obtained through photonic crystals (PCs).



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);

Introduction

PHOTONIC CRYSTALS



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

10.1039/c2cs15267c

Introduction

PHOTONIC CRYSTALS

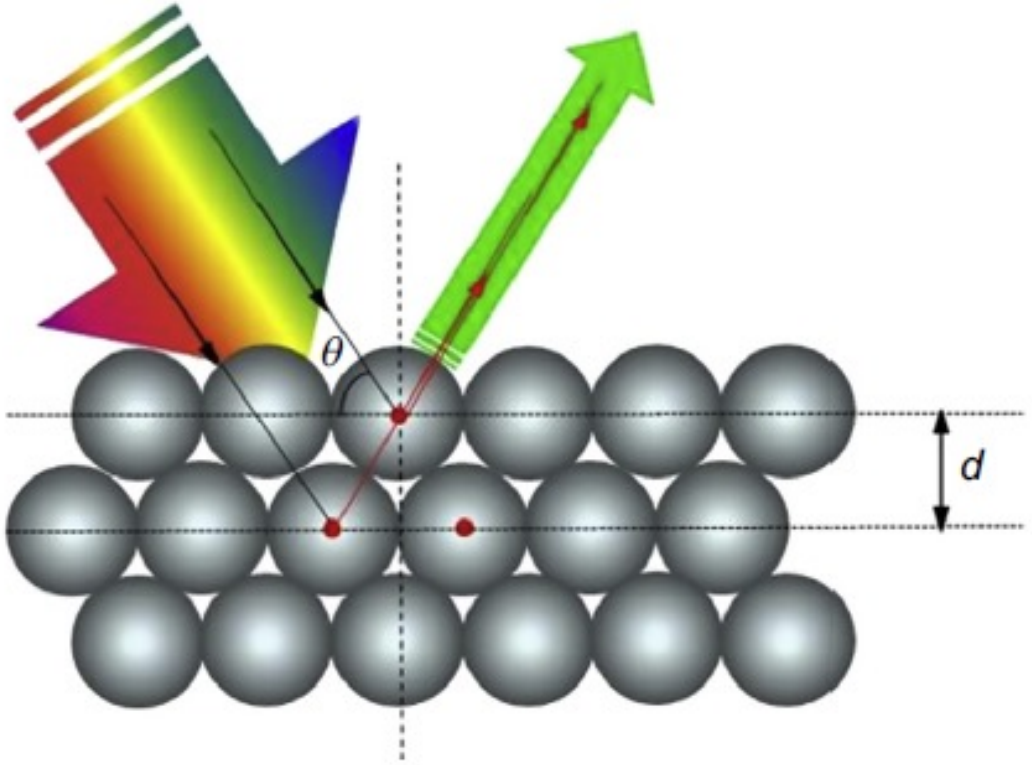
- Dielectric materials
- Highly periodic structure
- Spatially ordered lattices
- Capable of controlling the propagation of light due to the photonic band gap (PBG)

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

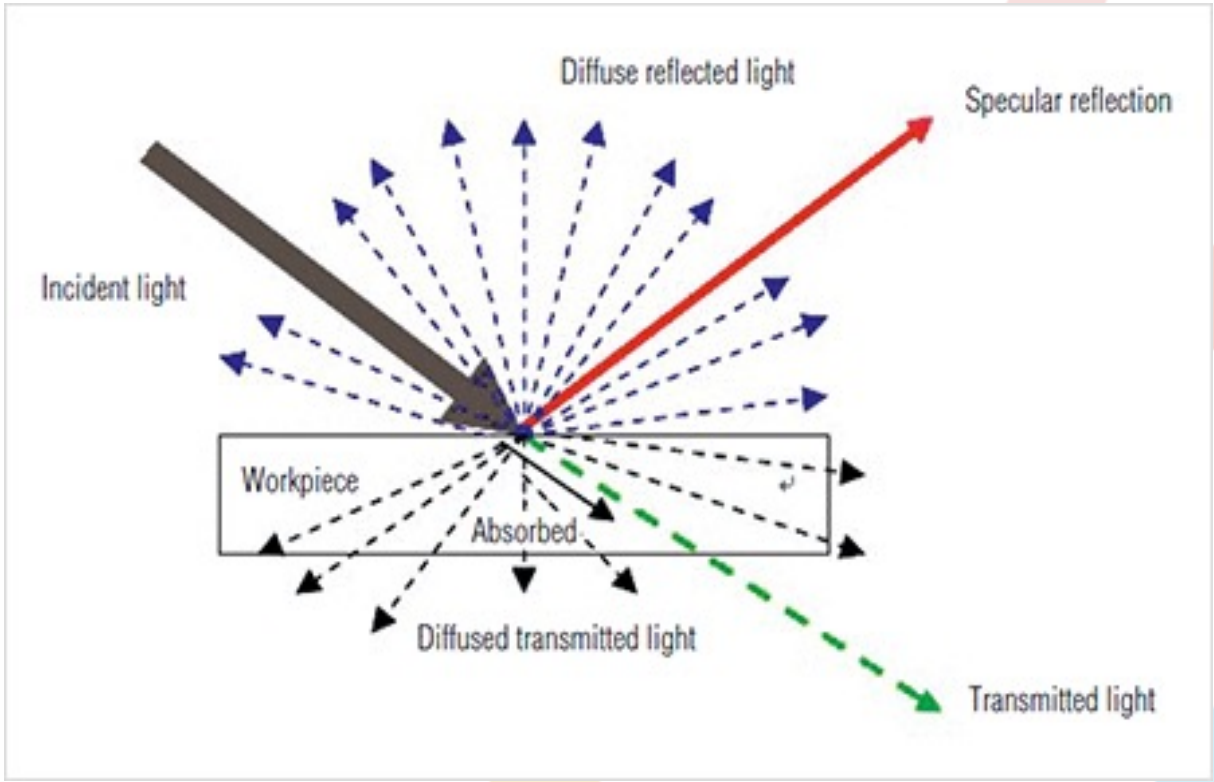
https://imgur.com/gallery/DpCkOpH

Introduction

LIGHT AND COLOR



Bragg's diffraction law (3D photonic crystals)



Conventional dyed substrate

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

Introduction

SUBSTRATE

- Smooth, flat and compact surface
- Low moisture property
- High dimensional stability
- Good resistance to heat
- Black color

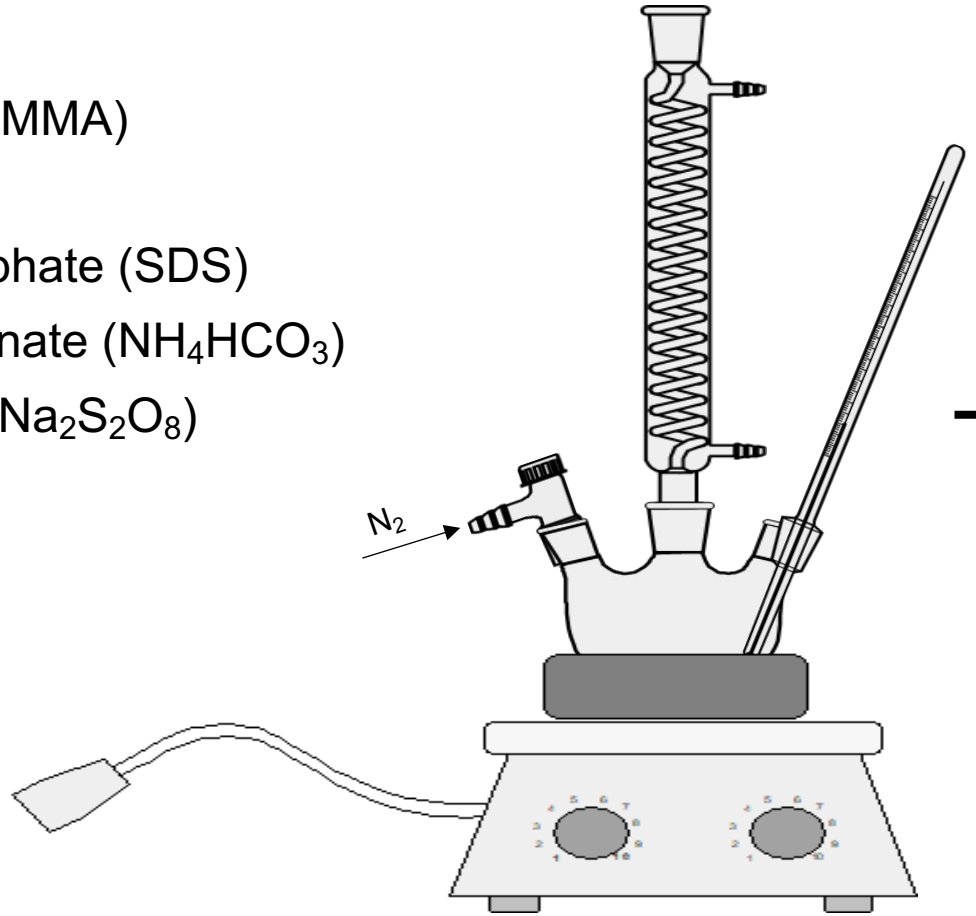
Synthetic fibers

Enhances the chroma produced by structural color

PCs synthesis

Synthesis and production of photonic crystals (PCs) controlling particle size

- Styrene (St)
- Methylmetacrylate (MMA)
- Acrylic acid (AA)
- Sodium dodecylsulphate (SDS)
- Ammonium bicarbonate (NH_4HCO_3)
- Sodium persulfate ($Na_2S_2O_8$)
- Water



P(St-MMA-AA)

PCs synthesis

Synthesis and production of photonic crystals (PCs) controlling particle size

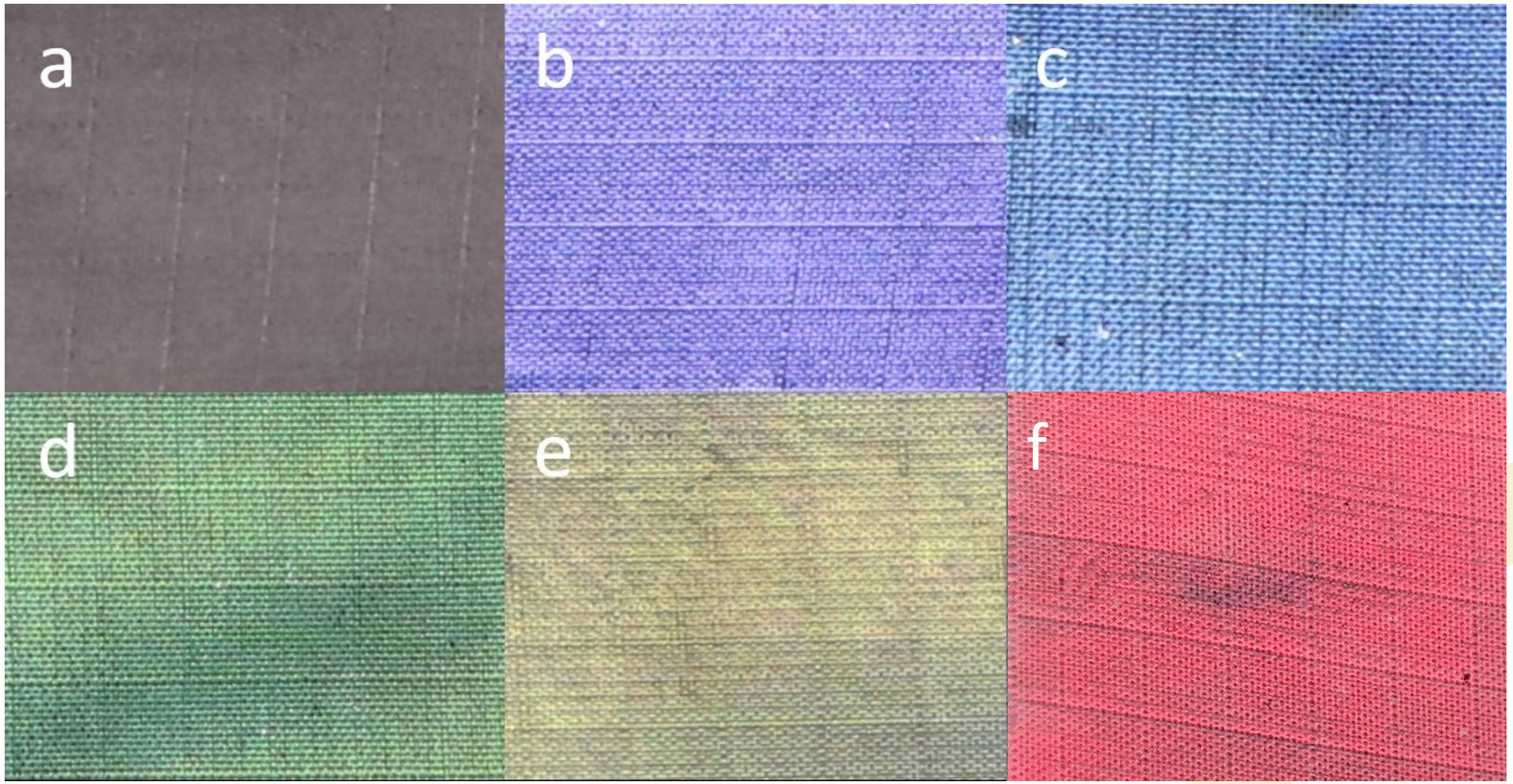
	Temperature (ºC)	Stirring (rpm)	Size (nm)
P(St-MMA-AA)	90	300	170 ±3.9
	80	300	190 ±4.5
	70	300	210 ±2.8
	65	300	230 ±3.4
	60	300	250 ±5.1
	80	400	190 ±4.5
	80	200	170 ±4.9

10.1111/cote.12452

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

PCs onto textiles

PCs were deposited onto polyamide (PA) fabric (3x3 cm) by dip-drawing

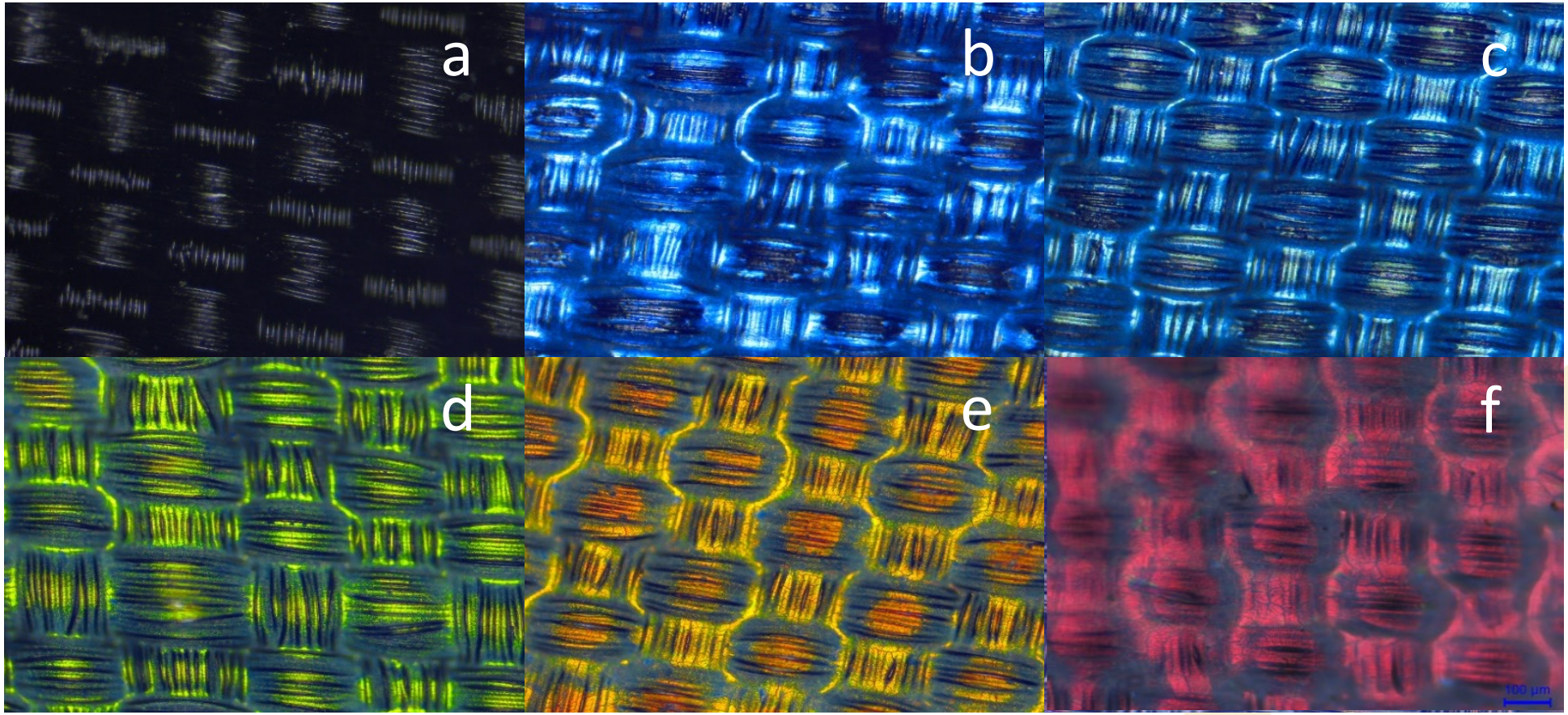


10.1111/cote.12452

Photograph of (a) uncoated PA fabric and PA fabric coated with different size P(St-MMA-AA) nanospheres *ca.* (b) 170 nm, (c) 190 nm, (d) 210 nm, (e) 230 nm and (f) 250 nm, by dip-drawing method (1 Dip dried at 40 ºC).

PCs onto textiles

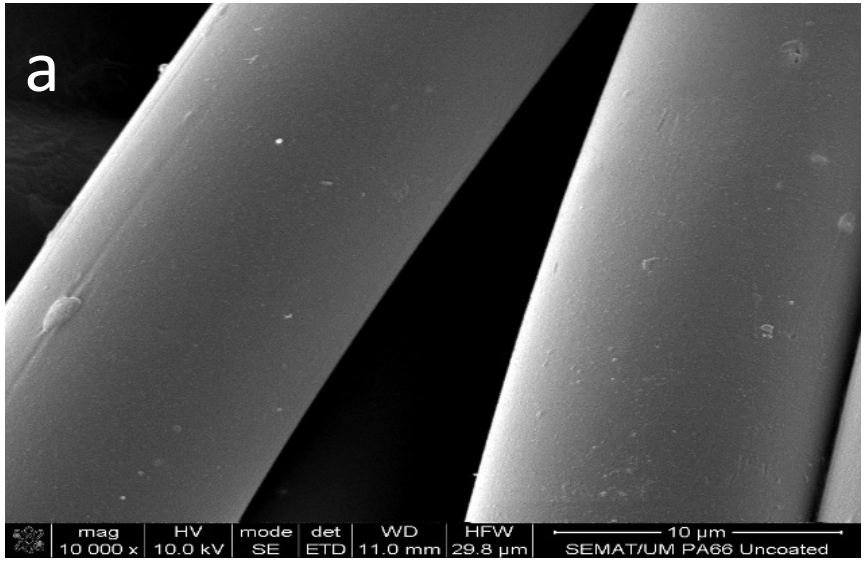
Optical Microscopy

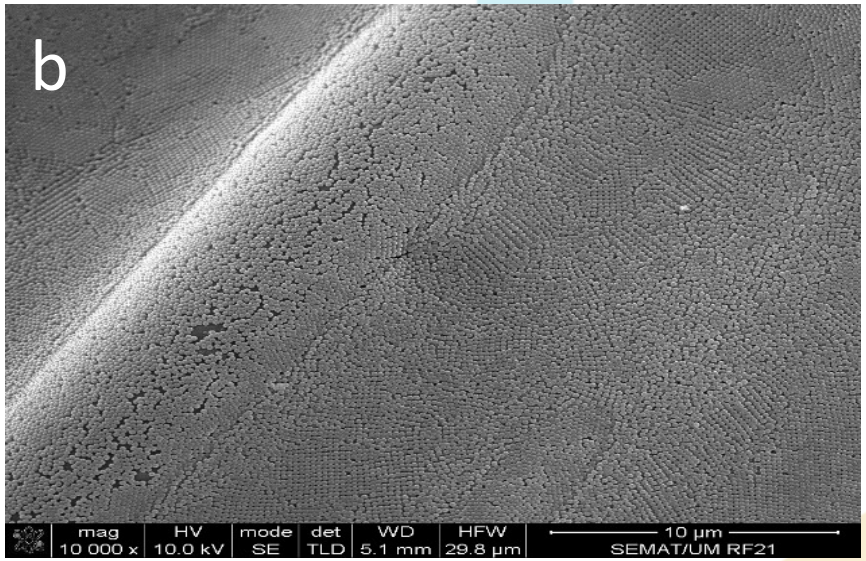


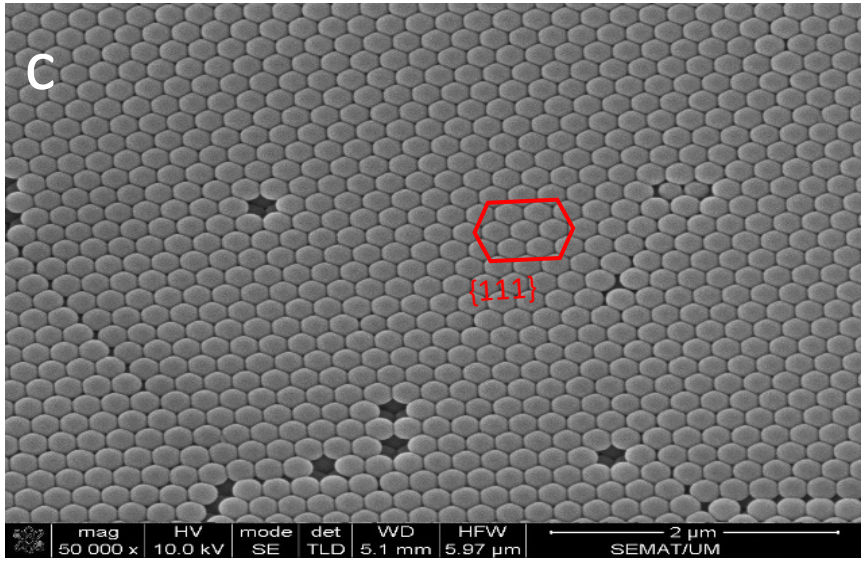
Optical microscope images of (a) uncoated PA fabric and PA fabric coated with different size P(St-MMA-AA) nanospheres *ca*. (b) 170 nm, (c) 190 nm, (d) 210 nm, (e) 230 nm and (f) 250 nm (100x magnification).

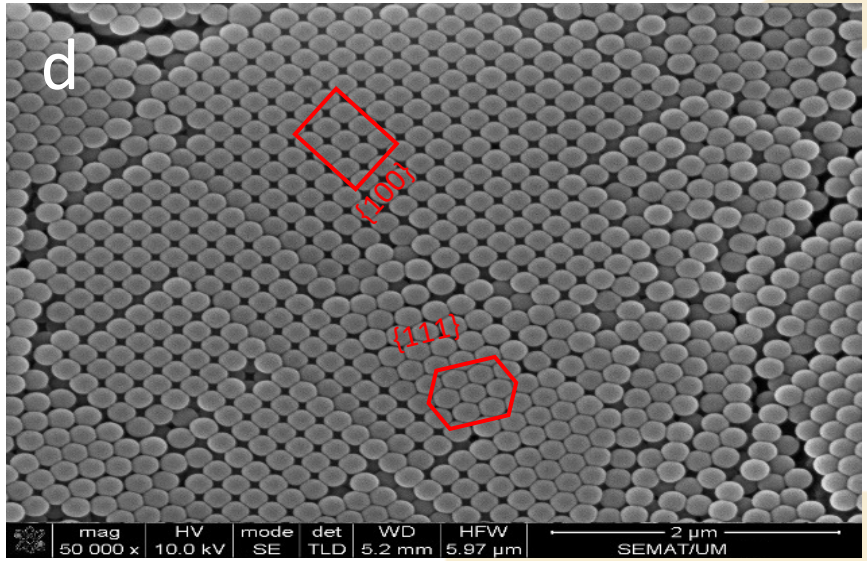
PCs onto textiles

Electronic Microcospy (SEM)



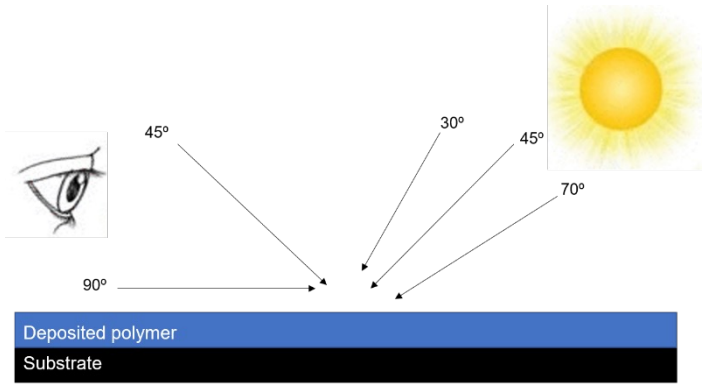


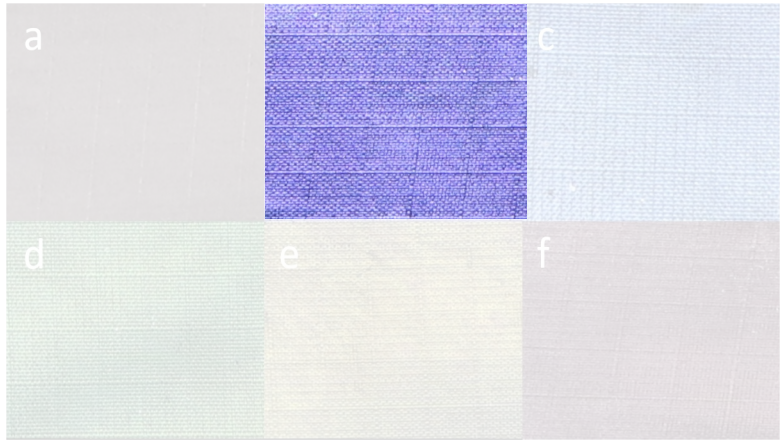




10.1111/cote.12452

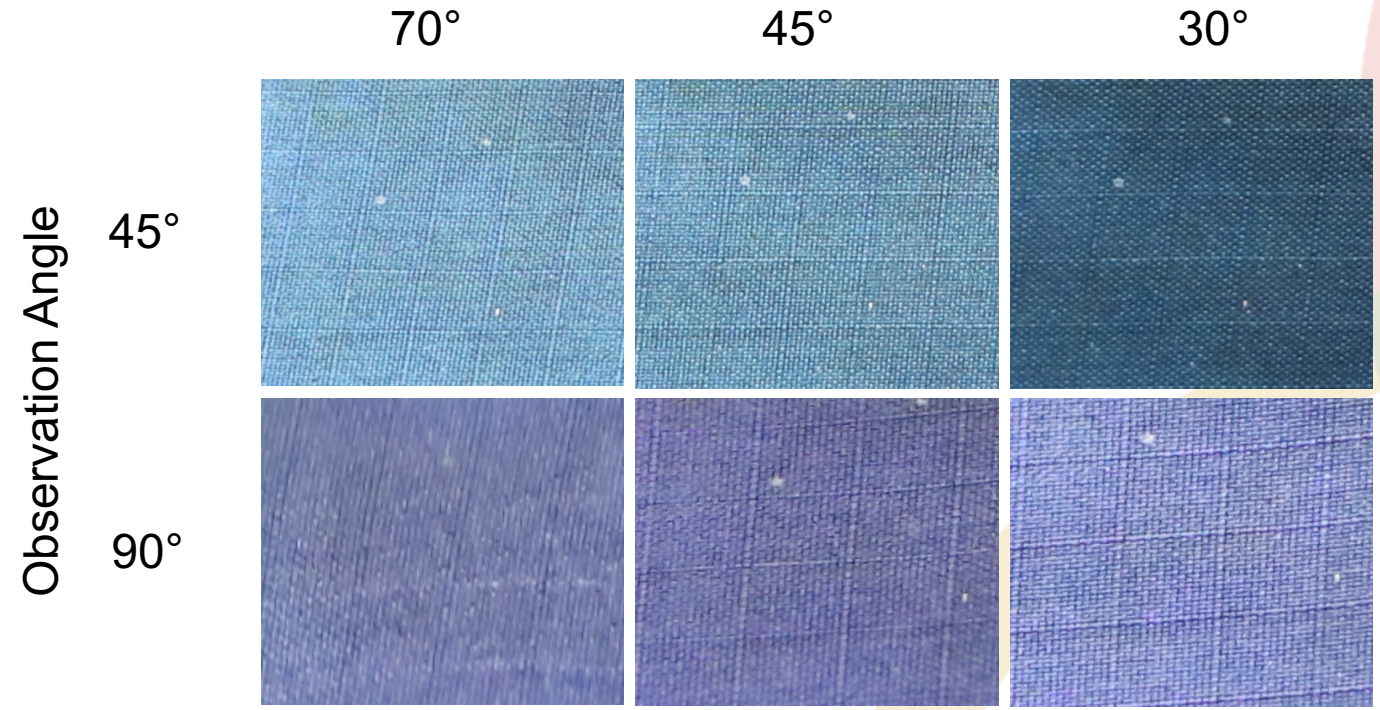
Iridescence Effect



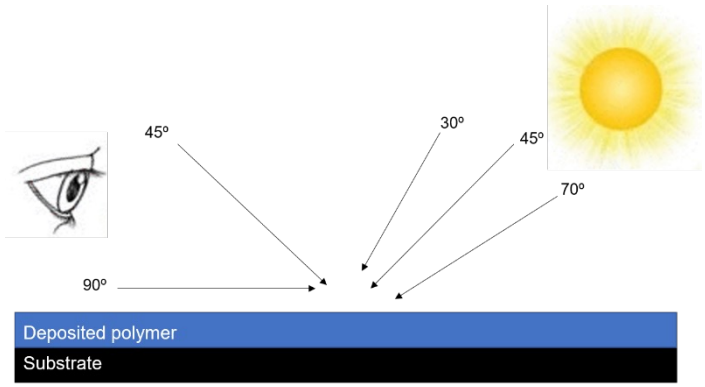


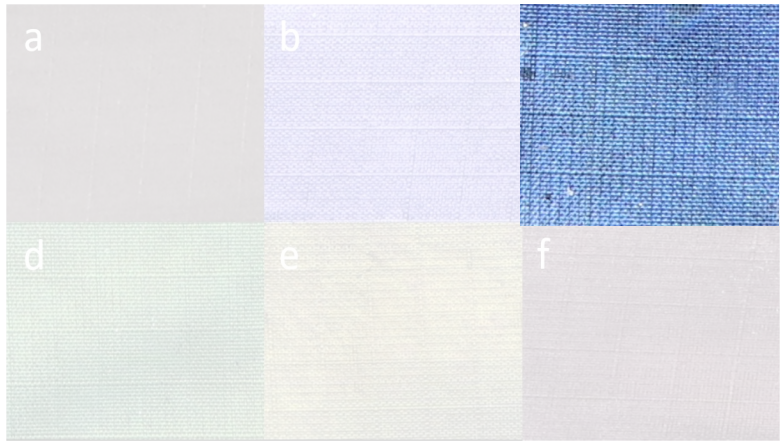
Light Incidence Angle

Observation Angle



Iridescence Effect





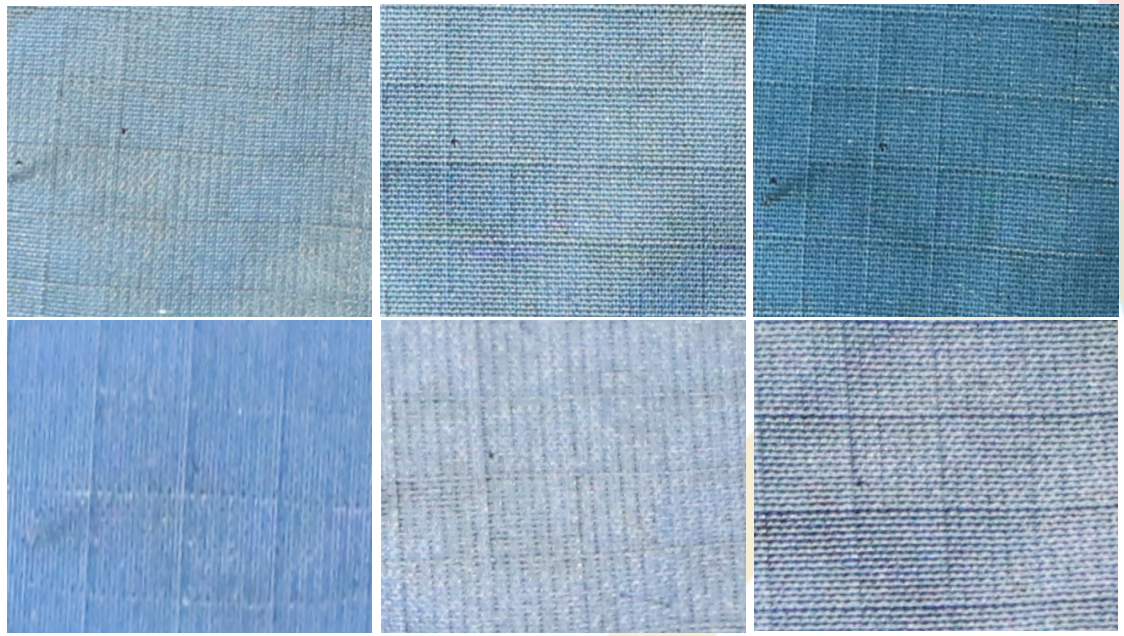
Light Incidence Angle

70° 45° 30°

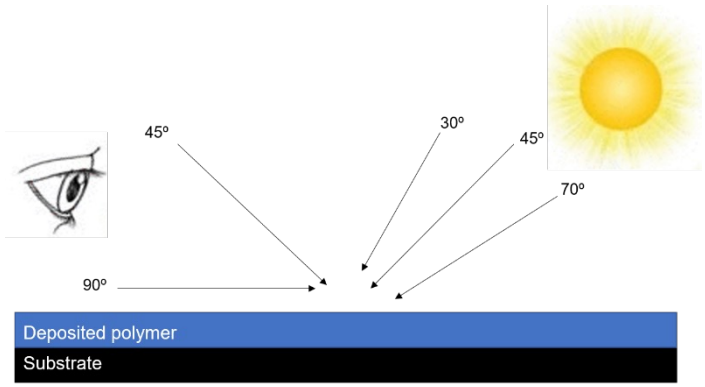
Observation Angle

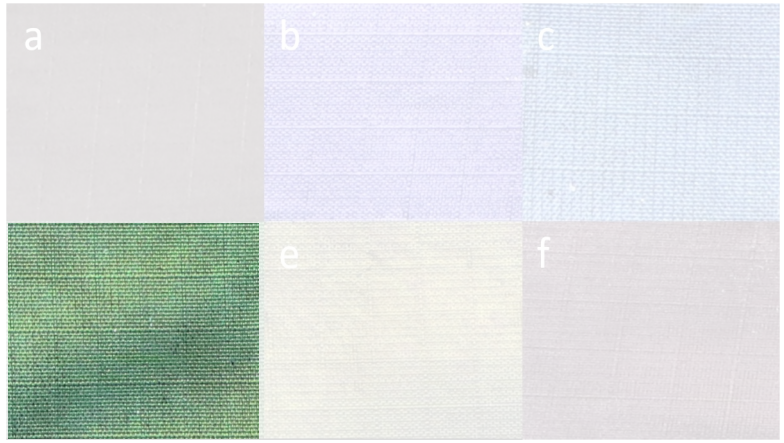
45°

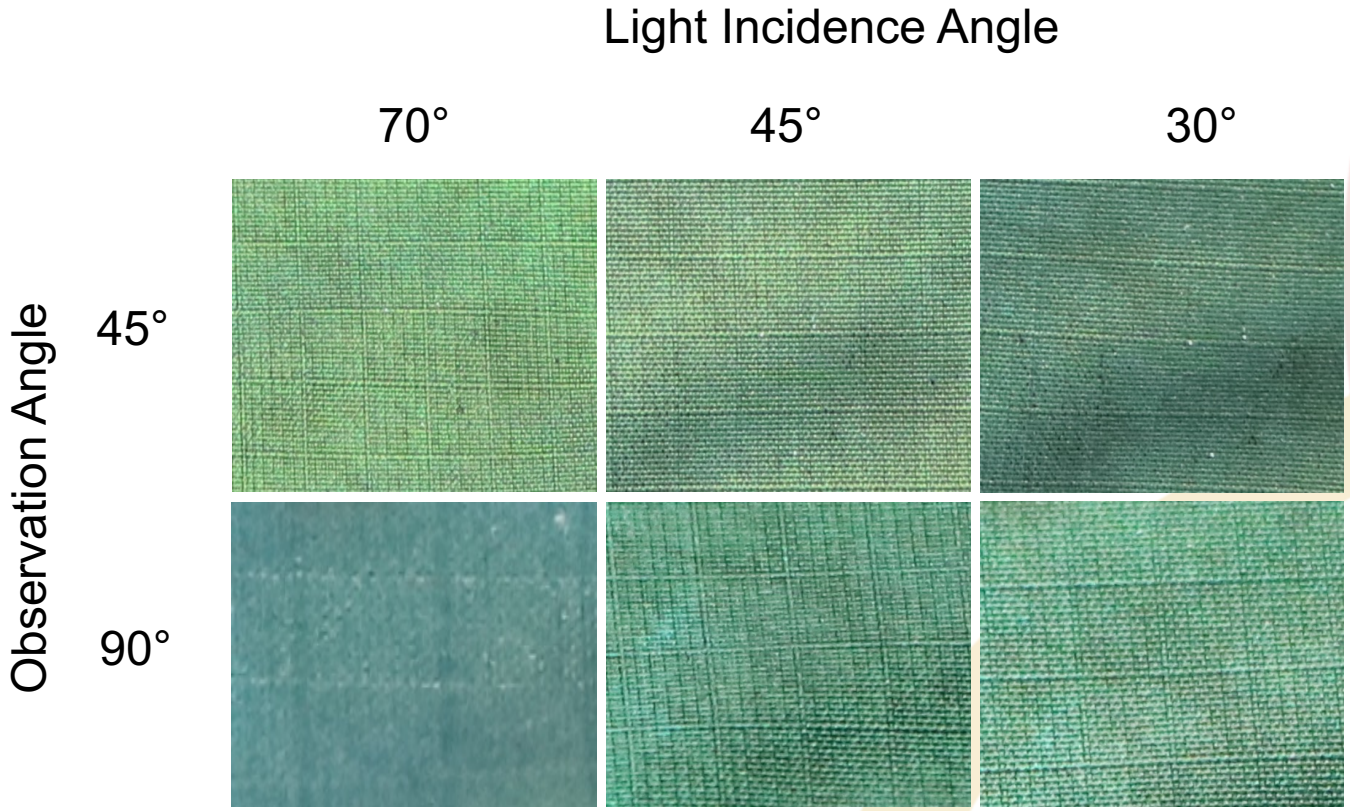
90°



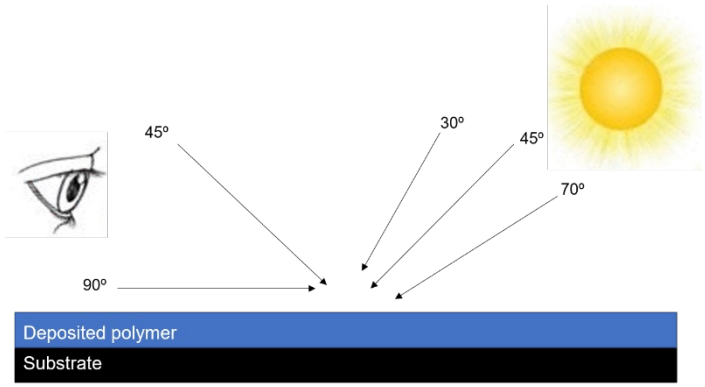
Iridescence Effect

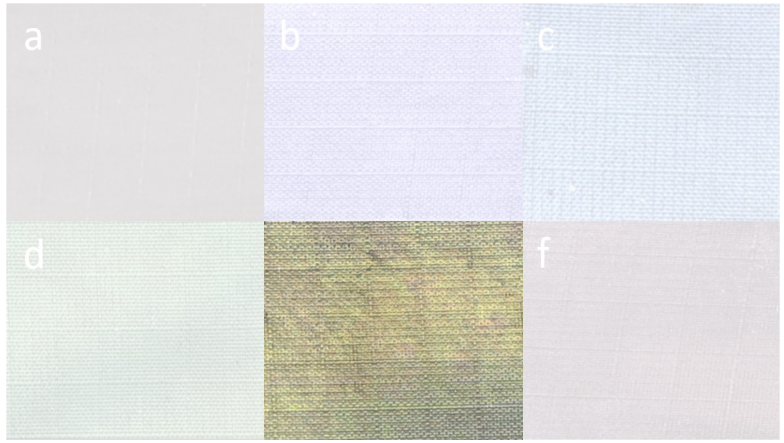






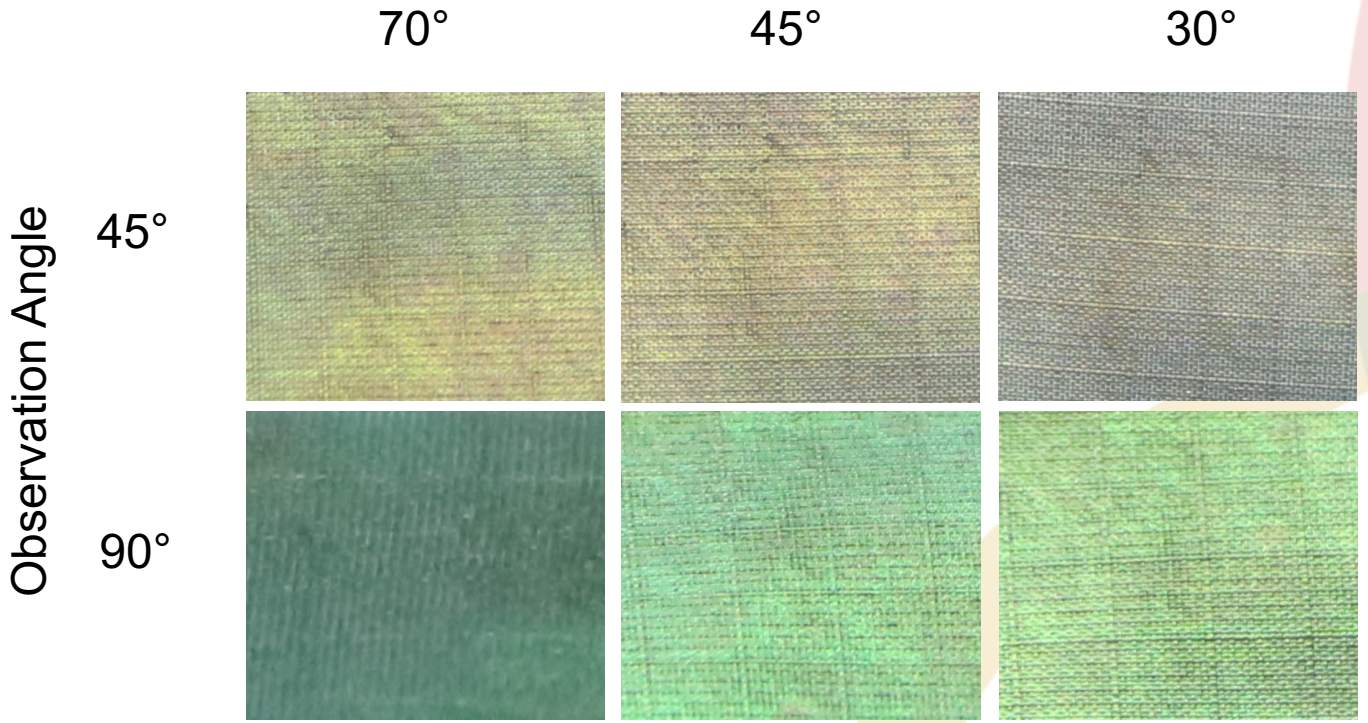
Iridescence Effect



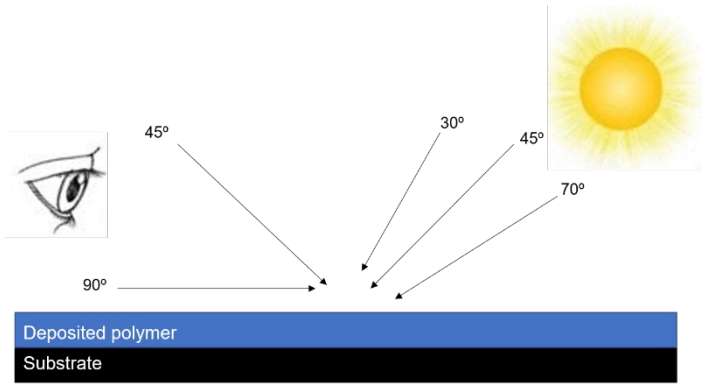


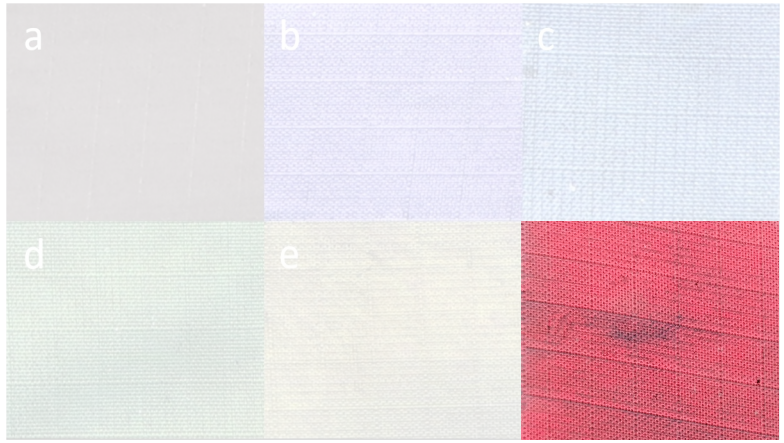
Light Incidence Angle

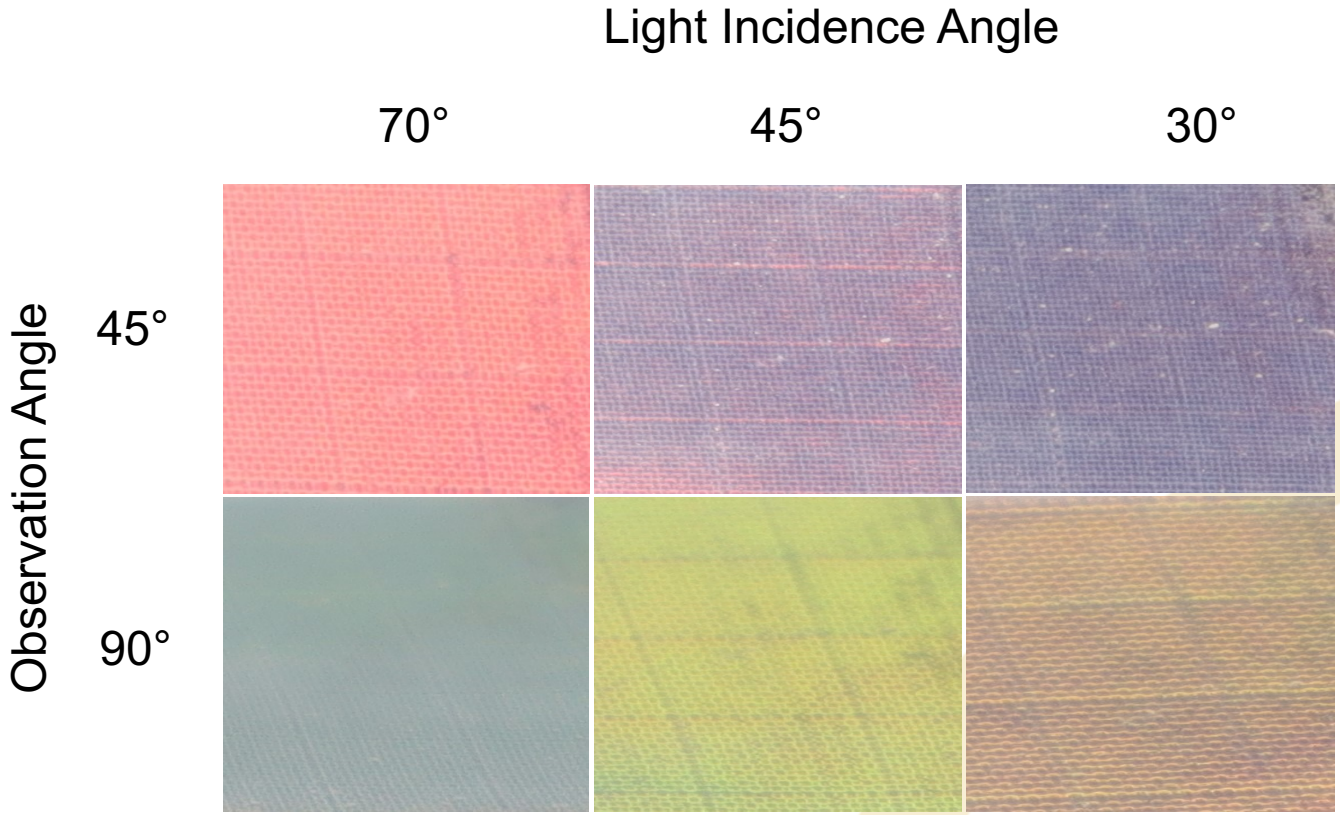
Observation Angle



Iridescence Effect







Iridescence Effect

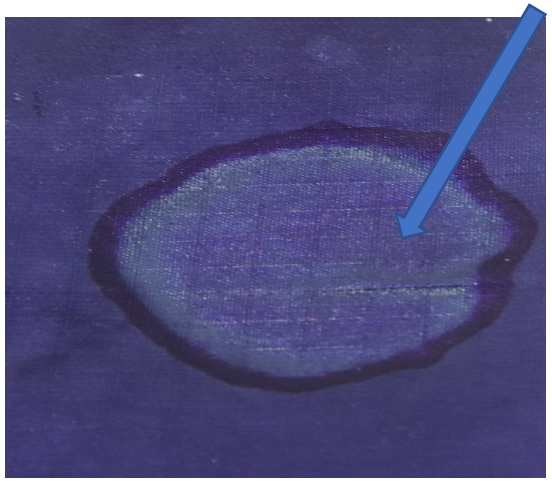
Sample placed inside a light chamber with a 45º incidence light angle

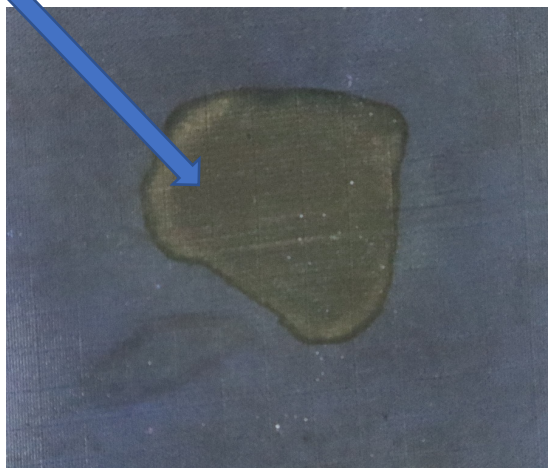
Observation angle of 90º (camera view) – yellowish color

Observation angle of 45º (photograph) – reddish color

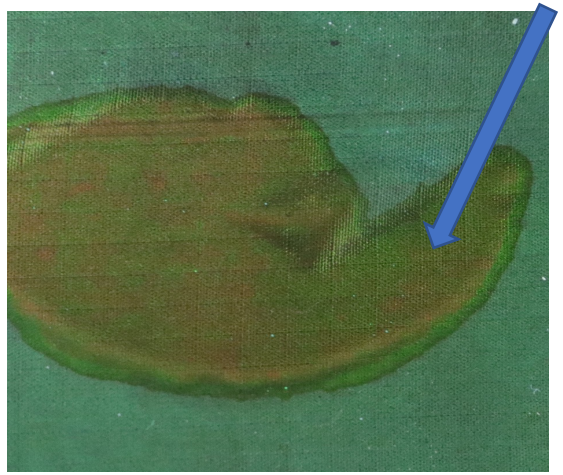
PCs as sensors

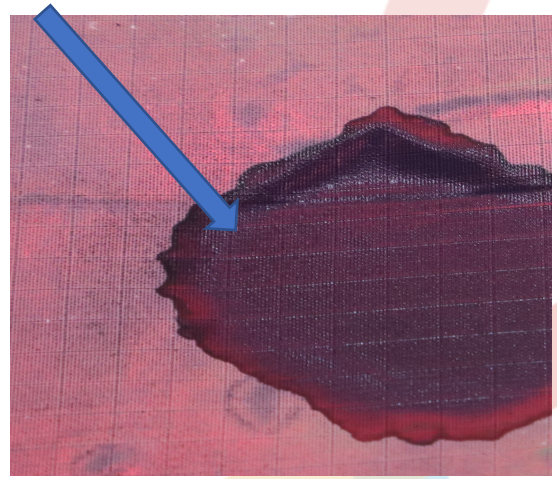
Wet



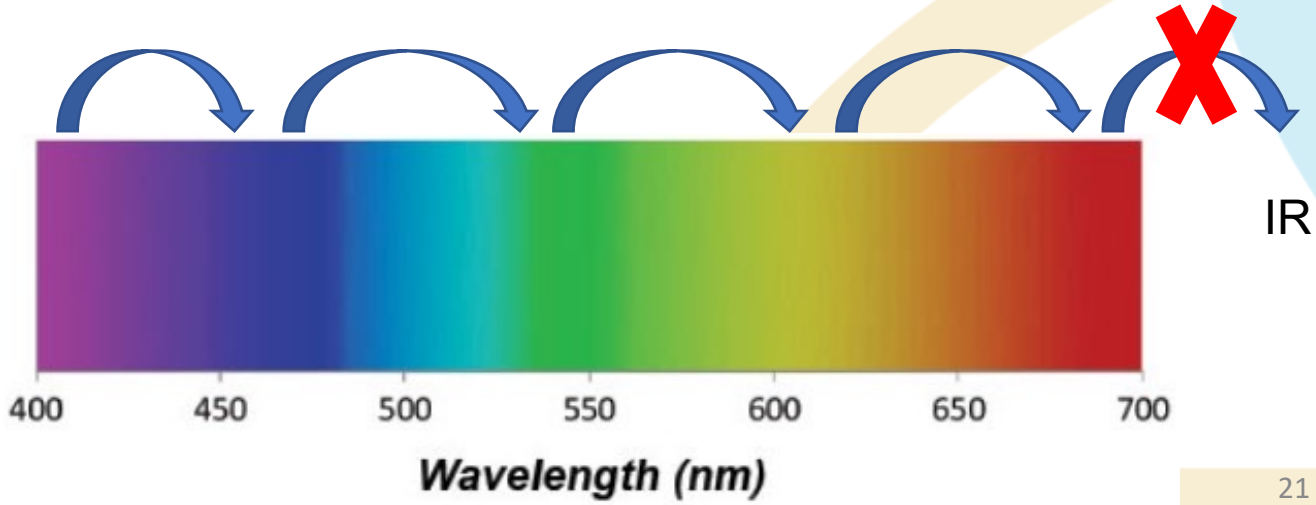


Wet





Water (or humidity) swells PCs structure thus a red shift will occur

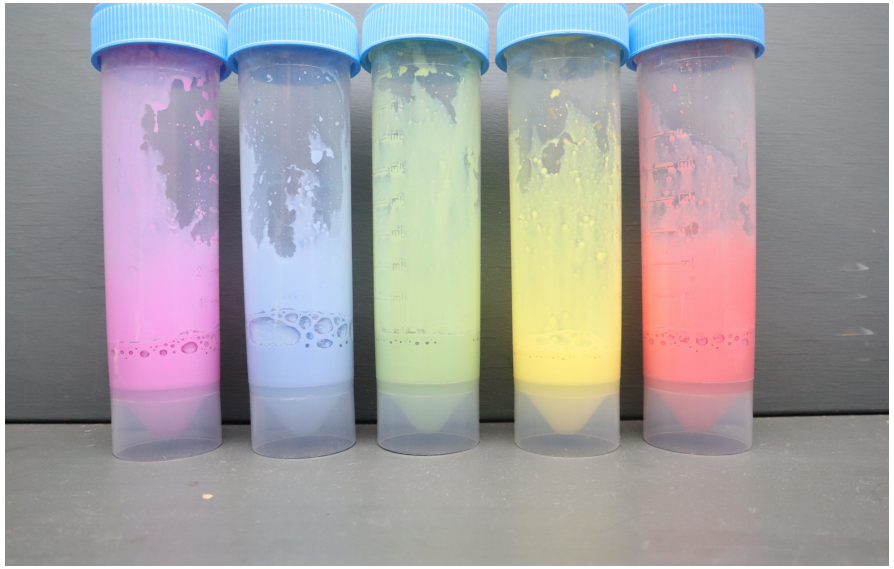


Current Work

PCs dyeing and substrate color

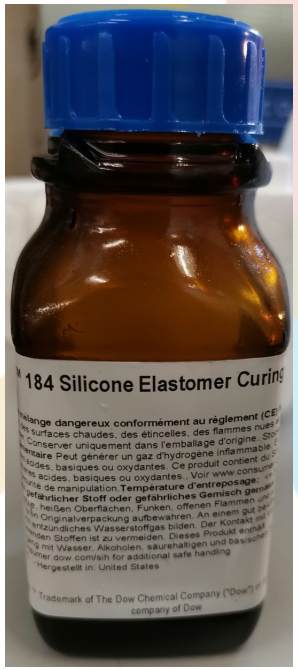
Pristine
Green PCs

2% wt
Disperse Dye



Green PCs@Disperse dye

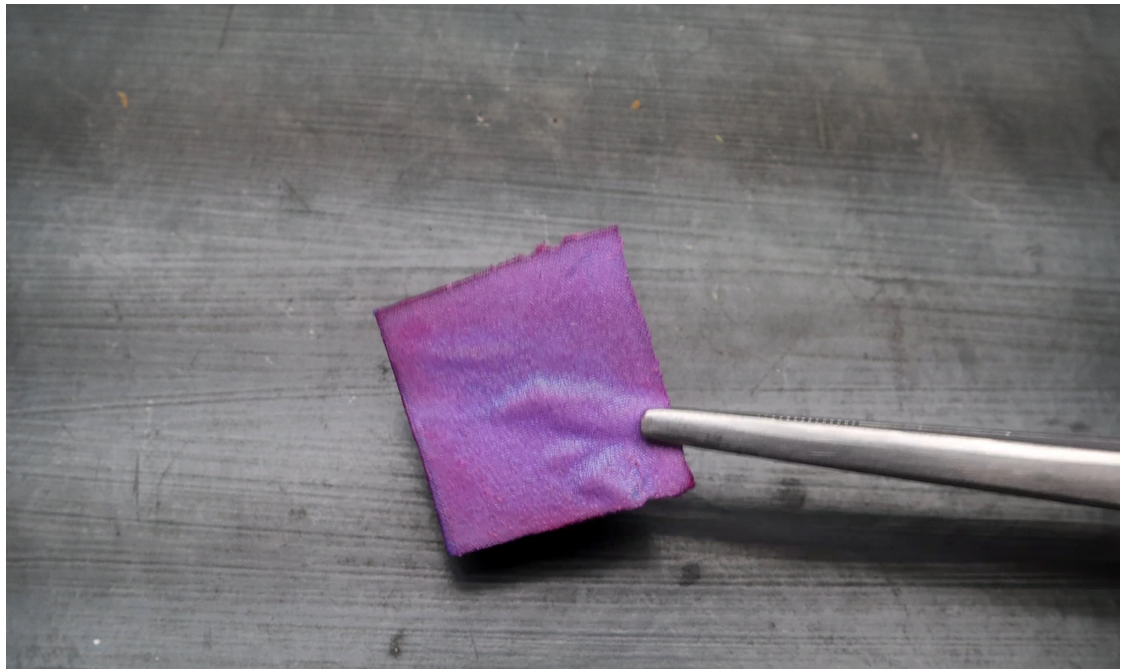
Washing Fastness



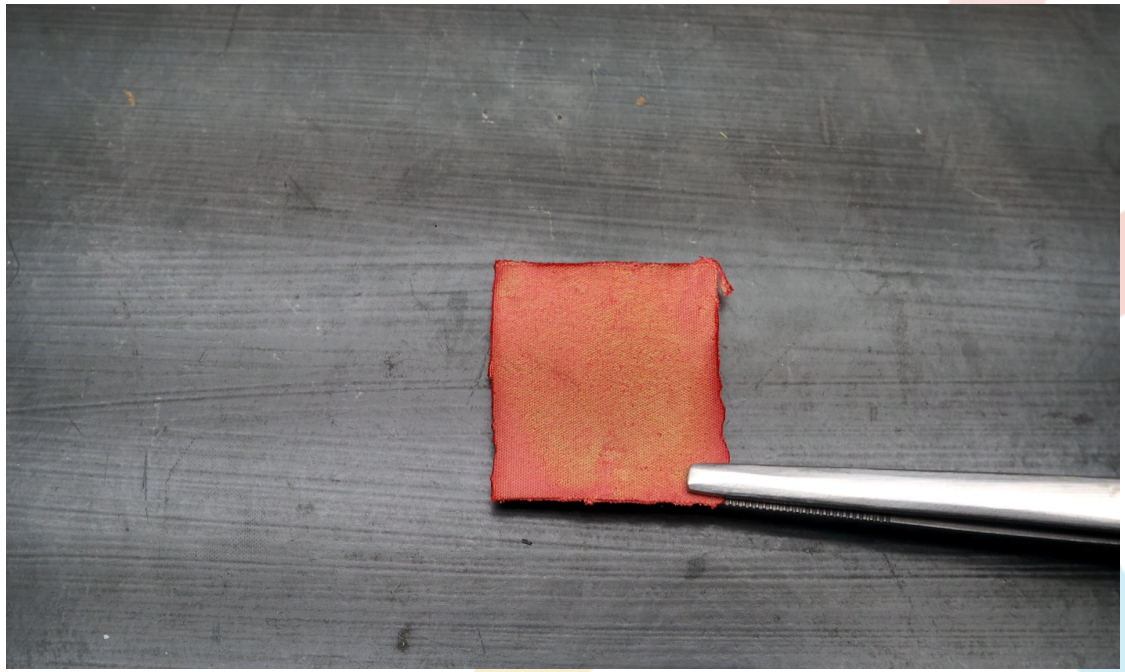
Sylgard 184 (PDMS)

Iridescence in dyed PCs

Green PCs@Violet Dye, Blue Substrate



Green PCs@Red Dye, Red Substrate



Conclusions

- Consumption of water and chemicals can be highly decreased vs conventional dyeing
- Photonic crystals can be tuned (mix similar to paints) to obtain the desired color
- Photonic crystals can also be dyed in order to enhance/decrease the “special” effects
- Structural coloration has a great potential to be applied in camouflage garments

Acknowledgements

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FCT Fundação para a Ciência e a Tecnologia
(SFRH/BD/145269/2019)

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Guimarães, July 2022