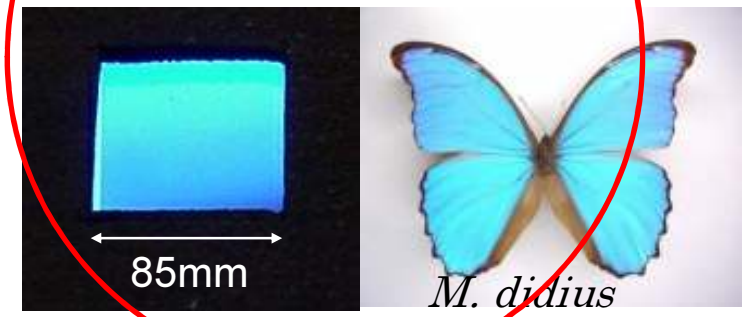
Wide Applications of the Mystery of a Brilliant Butterfly

23rd Japanese-German Symposium
@ Frankfurt, 2018.4.21

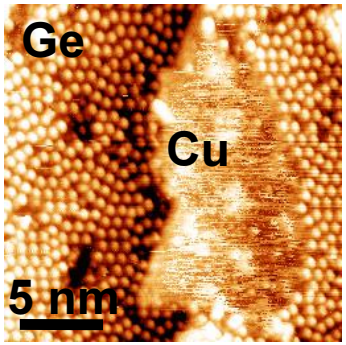
Akira SAITO 1) Osaka Univ. 2) SPring-8

Photon-Nanomatter Interaction

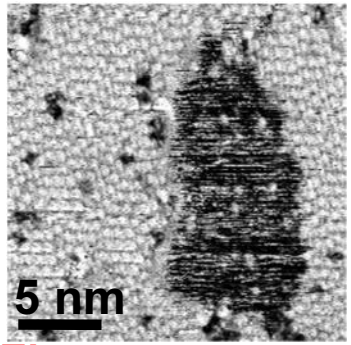
Morpho Butterfly's Mystery
→ Applications



Elemental Analysis
w/ Atomic Resolution



Topograph



Element contrast

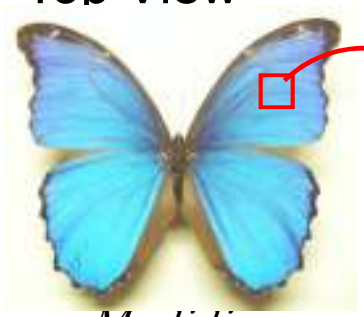
STM + Brilliant X-ray

Outline 1. Principles
2. Developments for Applications

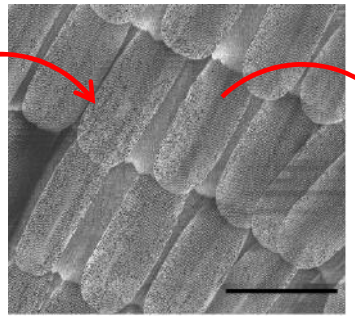
Principles of *Morpho*-type coloration

Blue but Pigment-Free & High Reflectivity. → *Interference Effect* of Periodic Structure.

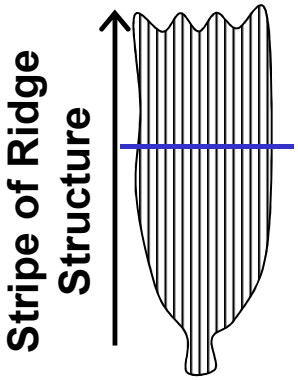
Top View



M. didius

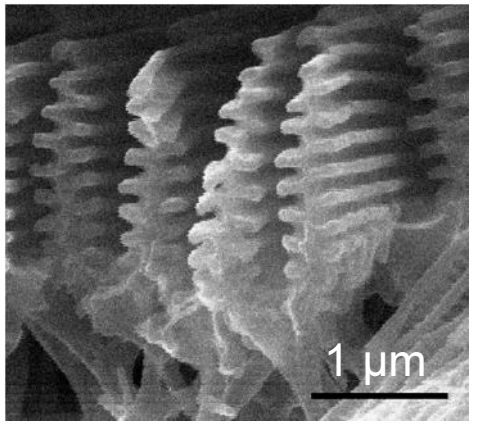


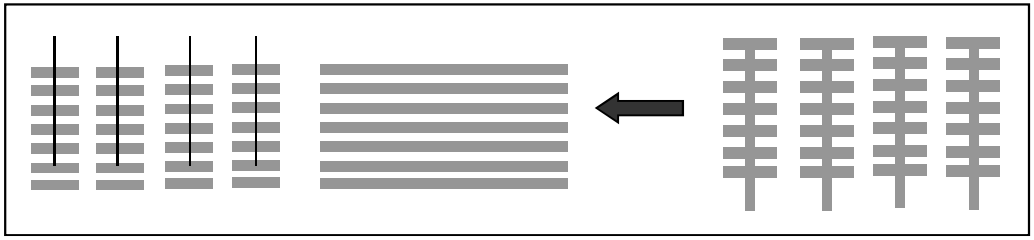
100μm



Cross sectional Side View

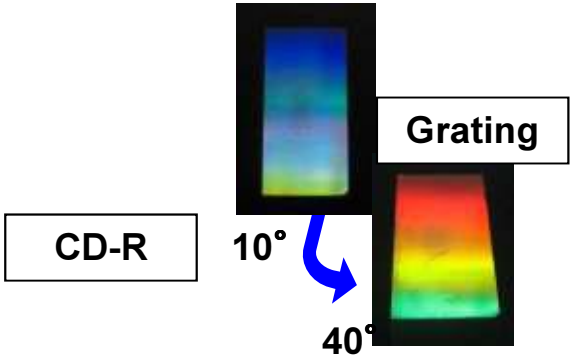
n=1.0
vs
n=1.6

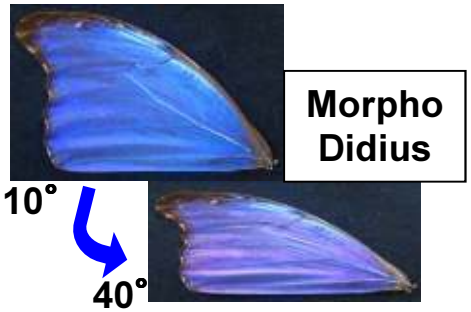




grating model or layered model

However, a mysterious feature…





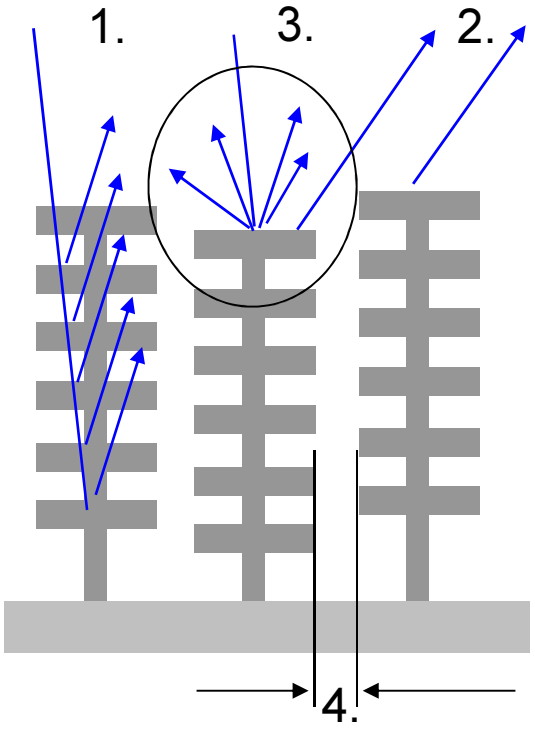
"Interference, but Single color & Wide angle." Why?

Discrete Multilayer

Side View

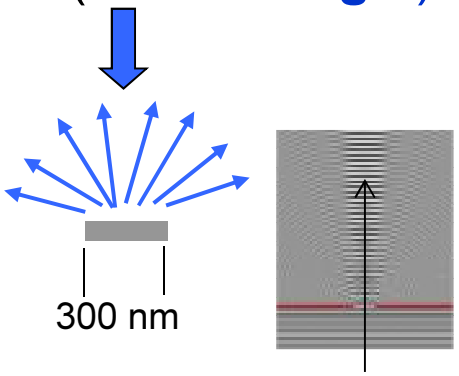
5 principles

1. Ordered structure makes Blue by interference



2. Disordered structure prevents the rainbow color.

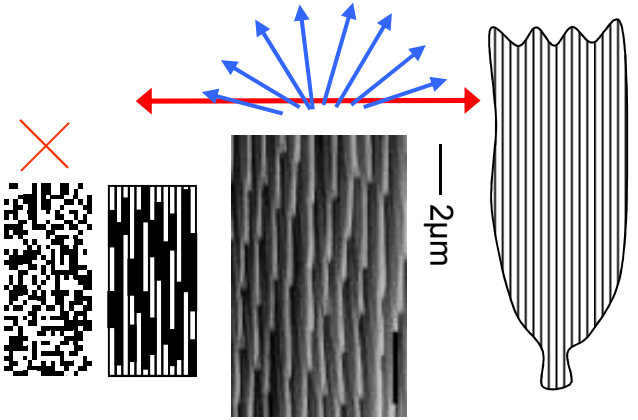
3. Small width diffracts the Blue (in **wide angle**)



4. Small gap makes **high reflectivity** **(high density)**

5. Anisotropy makes **high reflectivity**

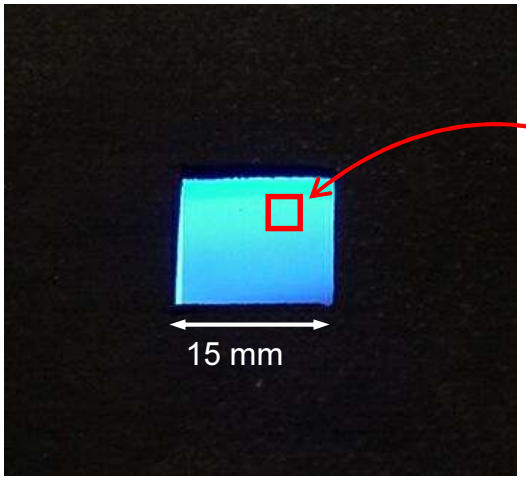
Top View



S. Kinoshita et al.
Proc. R. Soc. Lond. B269, 1417 (2002).

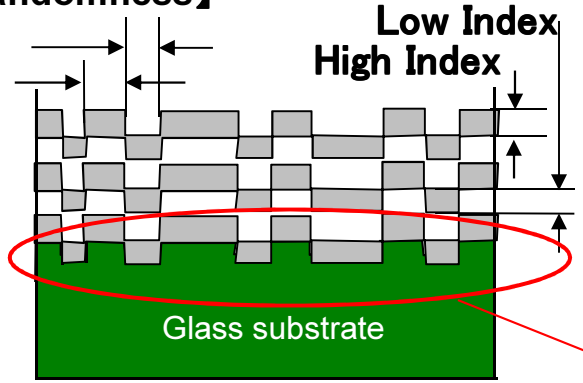
How to Prove it ?

Pigment free

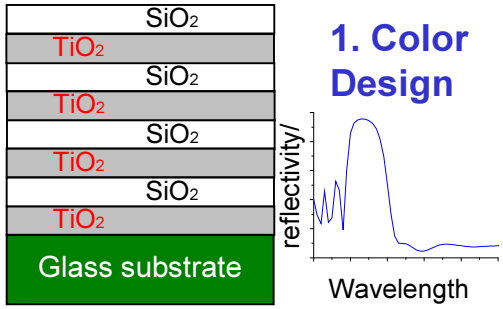


Reproduction of *Morpho*-blue (High Reflect., Blue in Wide Angle, 1-dim Anisotropy)

Width & Gap【~300 nm w/ randomness】

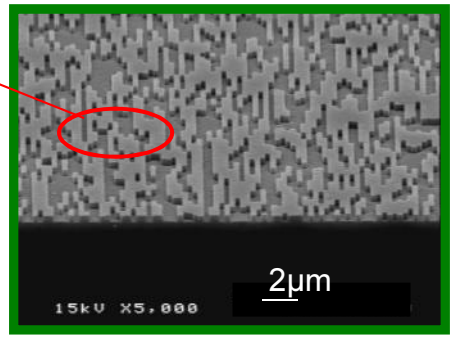


n=1.5 vs n=2.5



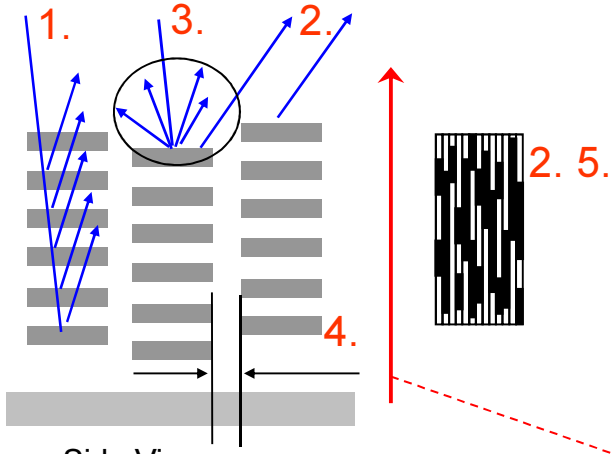
1. Color Design

+



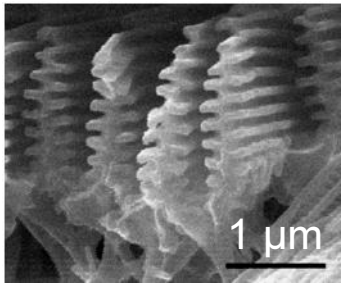
Process

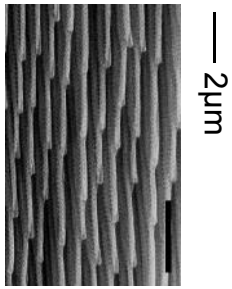
2. 3. 4. 5. Semiconductor Technology



A. Saito, S. Yoshioka, S. Kinoshita, Proc. SPIE, 5526, 188 (2004).

Morpho butterfly





1. Order = Multilayer interference.

Controlled Disorder

2. Disorder prevents Multi-color.

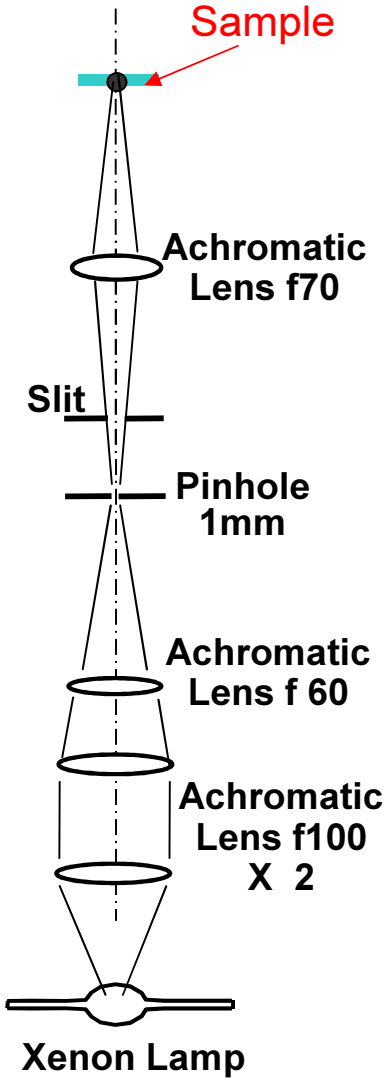
3. diffracted from small width.

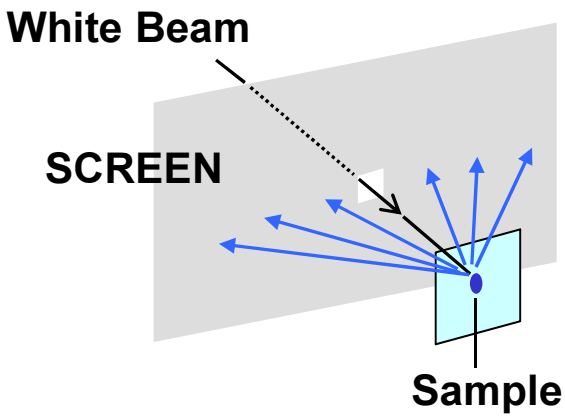
4. Small gap ➔ high reflectivity

5. Anisotropic pattern.

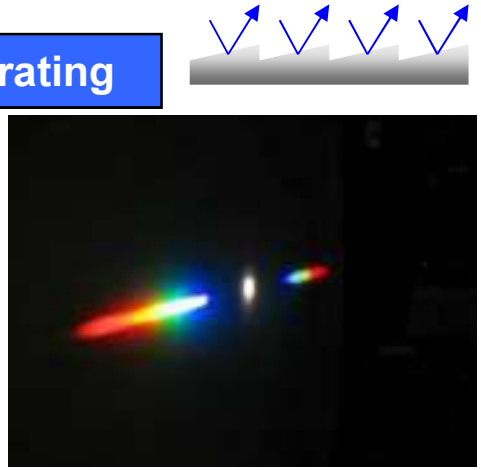
Optical Measurement 1. ~ Reflective Patterns ~

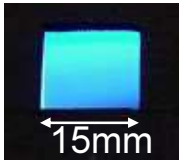
Set up





Grating

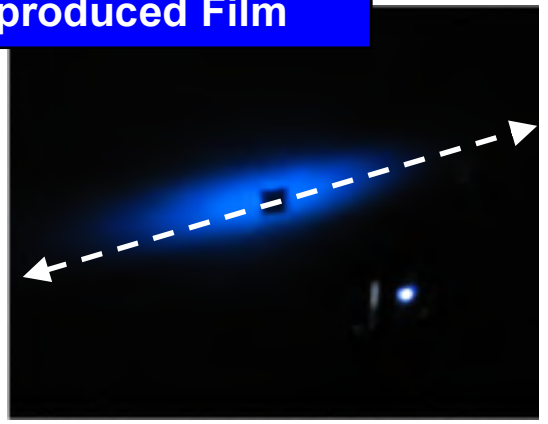




Morpho Didius

Scan Direction

Reproduced Film



Bright Single Blue & Anisotropy

Possible Industrial Applications

http://www.web-poster-data.com/zsa014.html

Decoration Films

https://watch.burnworks.com/article/170623203011/

Cosmetics (Powder)

https://www.wovensquare.com/collections/eye-shadow

https://www.groupon.com/latest-deals/gg-opi-brights-mini-nail-polish-set

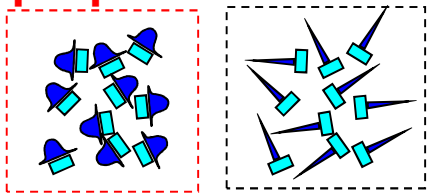
Posters Paints,..

Displays

Advantages of Morpho

- High Efficiency (Reflectivity)
  - ➔ Power saving (ex. Back Light saved)
- Single color in Wide Angle

New properties old



Security

Sign Board, Logo

Advantages of the Structural Color

1) Long lifetime (fadeless).
2) Thin & Light.
3) Pigment Free (Ecological)
   - ➔saving Chemicals.

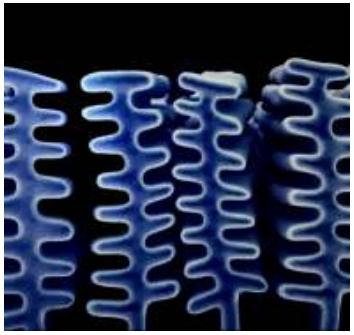
For Industrial Applications, DEATH VALLEYS…

1. Mass-Production, 2. RGB, 3. Control, 4. disorder, 5., ….

Recent info:

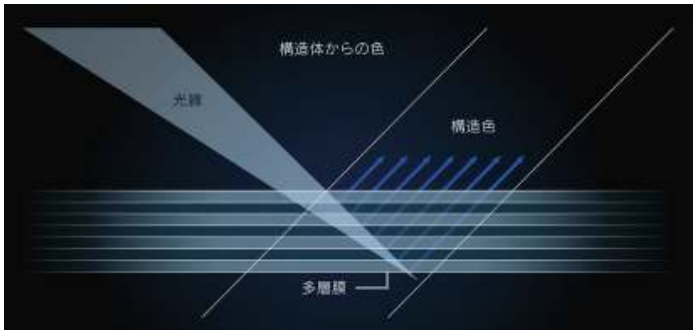
April 6, 2018 News, Toyota LEXUS

https://lexus.jp/models/lc/features/sesb/

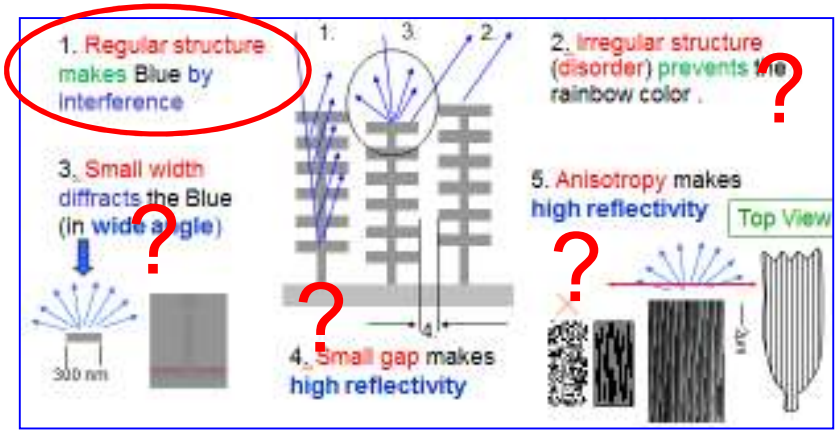


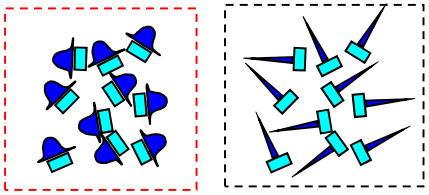
Thay say, Morpho butterfly is the model.

However, neither "Disorder" nor "Diffraction" nor "Anisotropy" could be found.



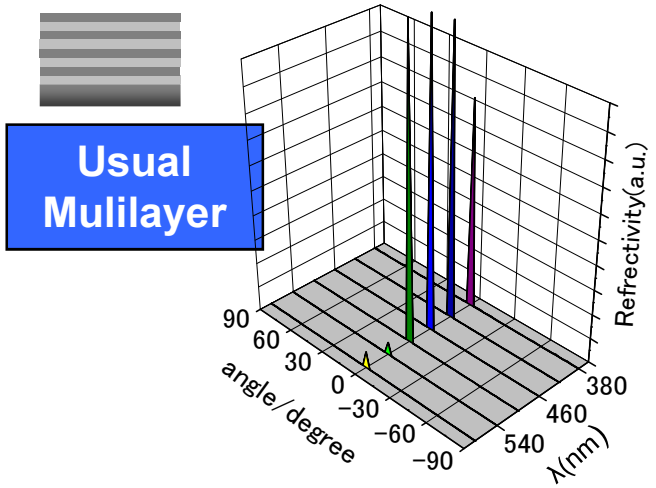
https://lexus.jp/models/lc/features/sesb/



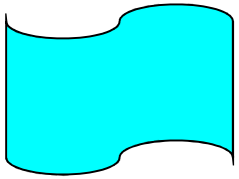


Looks Blue in
Wide Angle

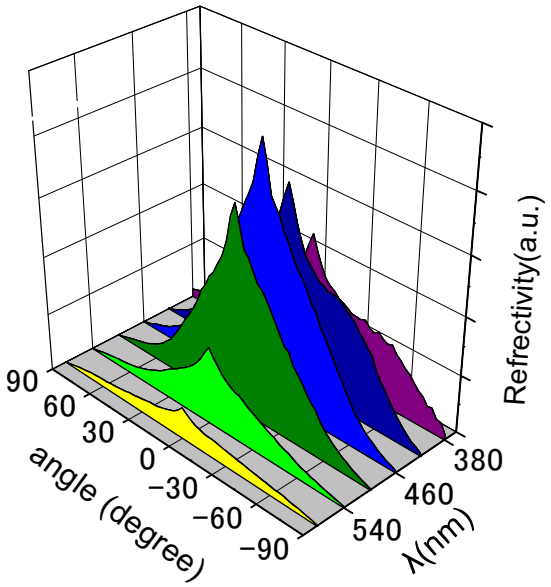
many powders in
random position

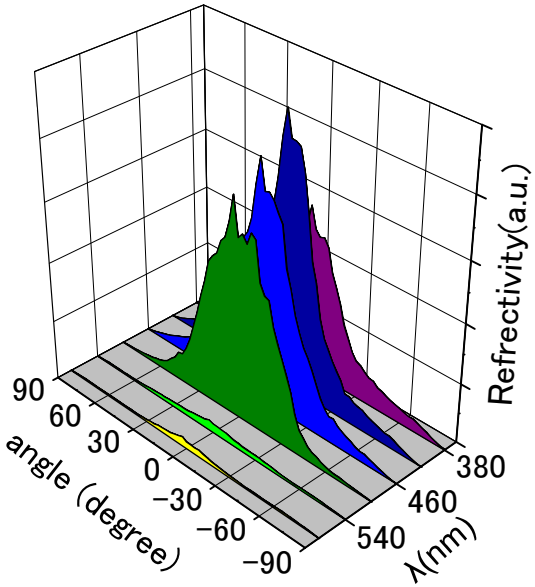


However,
How about the Hue ? (glares?)
How about the reflective Angular property ?
Reflectivity (~ 70% in total) ?
Especially for a single film?



Such data
are needed ➔





Past Several Artificial "*Morpho*"

https://minkara.carview.co.jp/userid/343721/blog/21351444/

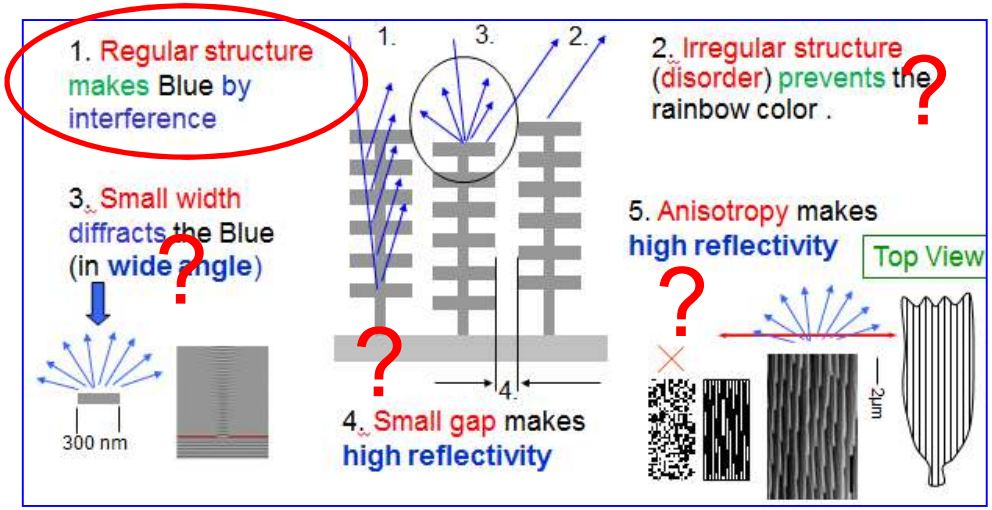
TOPPAN

OUR STORY 企業情報 製品・サー

https://www.toppan.co.jp/news/2016/08/newsrelease0809.html

Structural Color ? ➔ Yes

Single Color ? ➔ Yes / No



Bio(*Morpho*)-mimetics ?

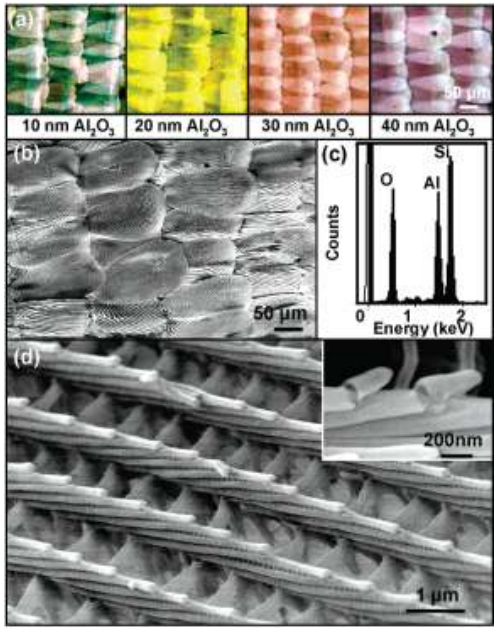
Structure & Principle ➔ No

Property (reflective Angle & reflectivity) ➔ ?

Template = Morpho

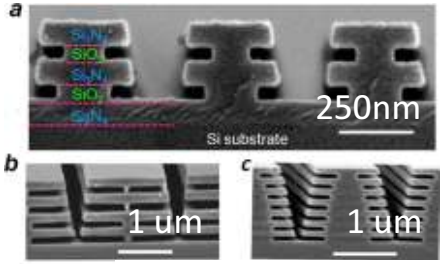
Nano Lett. 2006, 6 (10) 2325 J. Huang et al.,
Opt. Commun. 2011 *284, 2376;* 2013 *291, 416* Feng Liu et al.

ALD (Al_2O_3) coat ➔ Mold removed = Inverse Structure (Hollow)
➔ Color control by thickness.

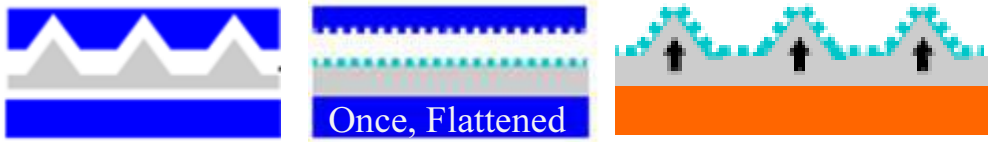


Fabrication Lack of disorder ?

JVST 2012, *B 30(6)* 061802 Mukti Aryal et al.
Multilayer (CVD)/ Si ➔ Photo Litho. ➔ Wet Chem. Etch. ➔ Tree.

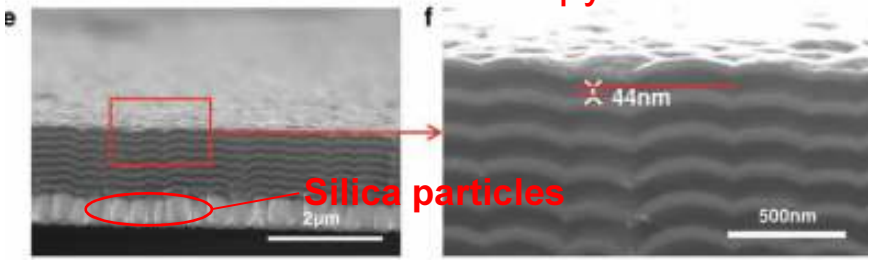


Opt. Mat. EXPRESS 4(9) 2014, *1895* N. Schneider et al.
Shape-memory polymer gives hierarchical structure (NanoImprint + Emboss)

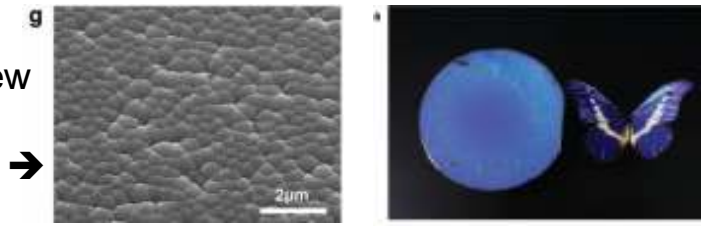


Adv. Mater. 2012 *24*, 2375 *K. Chung* et al.
Anisotropy ?

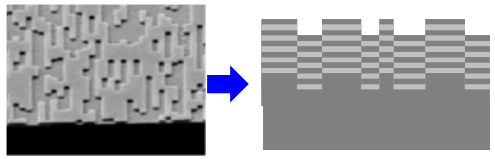
➔ *Sci. Rep.* 2017, *46037* *B. Song* et al.



← Side View
Top View ➔



What is necessary for Applications ?



Disorder + Anisotropy

Electro
-forming

1. Mass-production

Nano-imprint

UV

duplicate

Throughput x 1000

Rasin

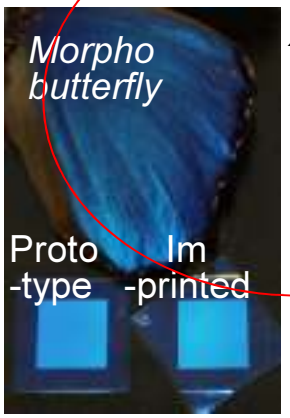
Glass

Quartz

Glass

Quartz

2. Large area



A.Saito et al., Proc. SPIE 6327 (2006) 1- 9.
A.Saito et al., JVST. B24 (2006) 3248-3251.

A.Saito et al.,
Proc. SPIE 9429 (2015).

7. Substrate-Free

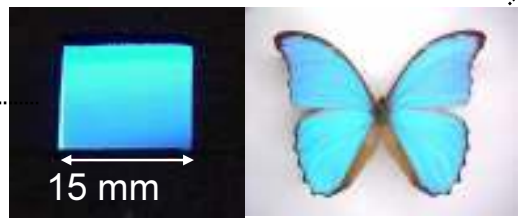
Film

Logo,
Display, etc.

Powder

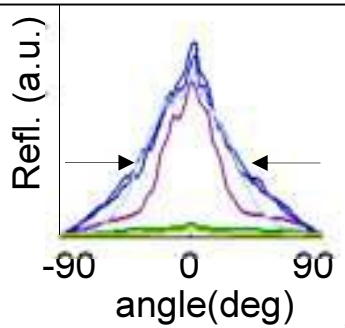
Cosmetic

Done w/ success



Done w/ success

3.Control:Angular distribution



A.Saito et al.,
Proc.SPIE
6767 (2007)
1-8.

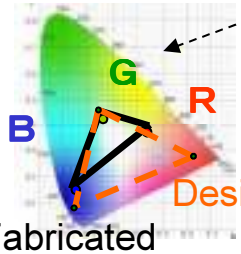
Patented 2008.9.27
(applied in 2003)

Done w/ success

4. RGB

A.Saito et al., J. Surf. Sci.
Soc. Jpn. 28 (2007) 414-420.

5. Control :
Color phase

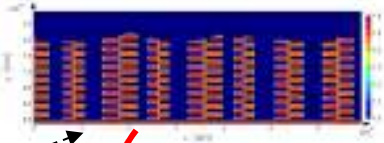


Fabricated

A.Saito et al., Proc.SPIE 7205 (2009) 1

FDTD

5. Simulation



A.Saito et al.,
J. Nanosci. Nano technol. (2011)

"Biomimetic Photonics"
(TAYLOR & FRANCIS , 2012)

Design

6. Basic Physics

Optical Role of disorder

Mass-Production by Nano-Imprint

Main Process

1) Patterning

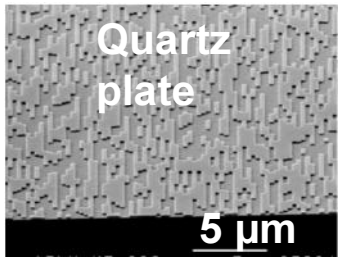
by Lithography
& Dry Etching
(most expensive)

2) Deposition

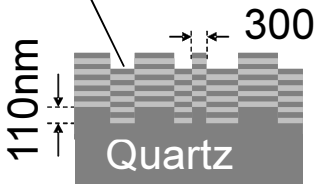
Glass substrate

Wet Process
(under Progress)

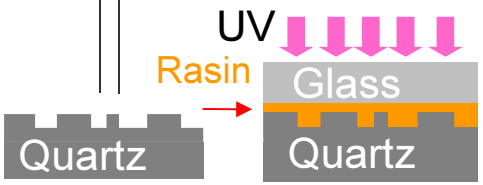
Conventional Process



Multilayer Deposition:
TiO_2 (~40nm) + SiO_2 (~75 nm)



New Process

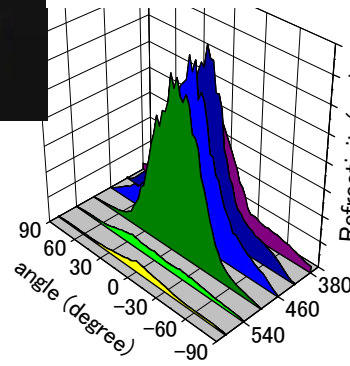


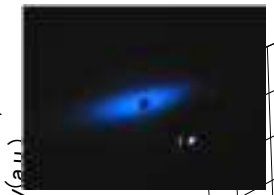
Replication

Deposition

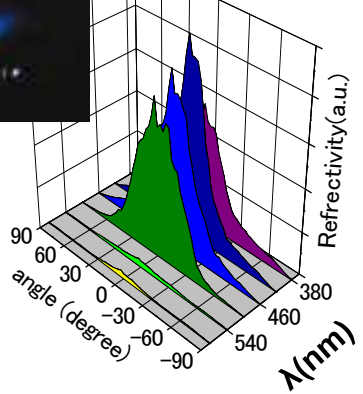
x 1000 throughput

Prototype



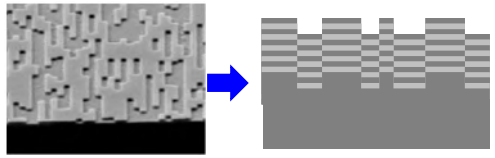


Imprinted



Principal properties
➔ reproduced by
the imprinted film, too

What is necessary for Applications ?



Disorder + Anisotropy

Electro
-forming

1. Mass-production

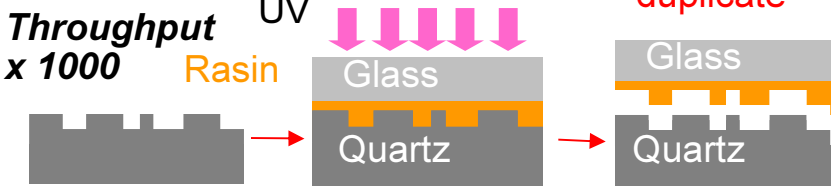
Nano-imprint

UV

duplicate

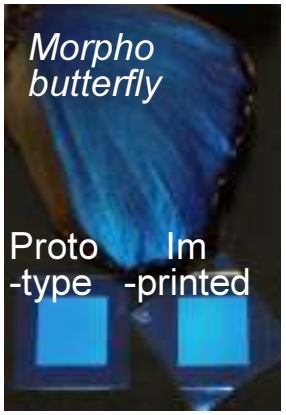
Throughput x 1000

Rasin

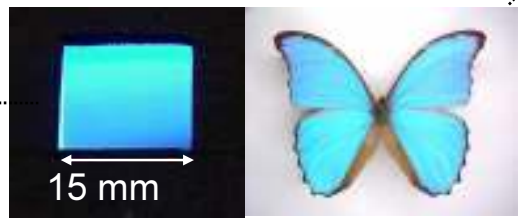


A.Saito et al., Proc. SPIE 6327 (2006) 1- 9.
A.Saito et al., JVST. B24 (2006) 3248-3251.

2. Large area

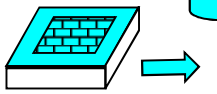


Done w/ success



A.Saito et al.,
Proc. SPIE 9429 (2015).

7. Substrate-Free



Film

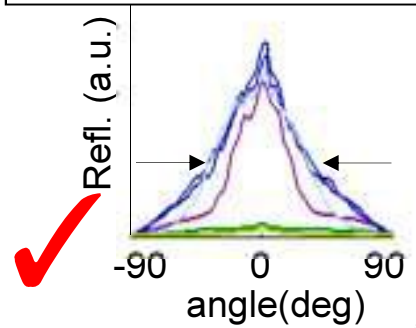
Logo,
Display, etc.

Powder

Cosmetic

Done w/ success

3.Control:Angular distribution



A.Saito et al.,
Proc.SPIE
6767 (2007)
1-8.

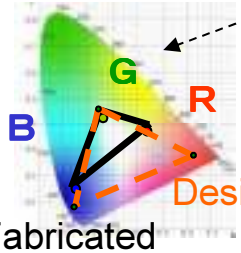
Patented 2008.9.27
(applied in 2003)

Done w/ success

4. RGB

A.Saito et al., J. Surf. Sci. Soc. Jpn. 28 (2007) 414-420.

5. Control :
Color phase

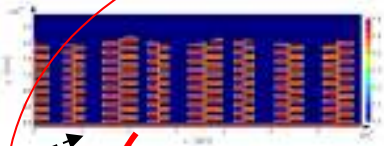


Fabricated

A.Saito et al., Proc.SPIE 7205 (2009) 1

5. Simulation

FDTD



A.Saito et al., J. Nanosci. Nano technol. (2011)

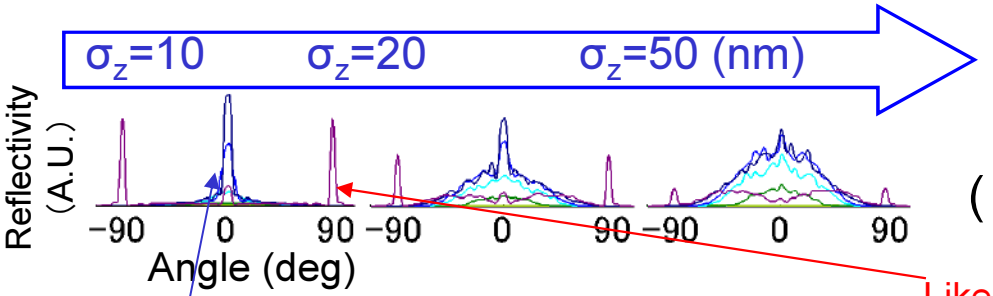
Design

"Biomimetic Photonics" (TAYLOR & FRANCIS , 2012)

6. Basic Physics

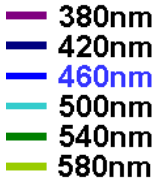
Optical Role of disorder

The optical Role of Disorder in STRUCTURE



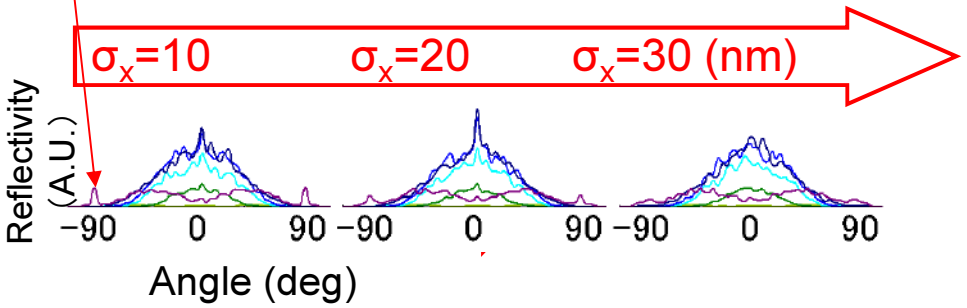
Role ➡ **Wide angle, Anti-grating**

(※σ_x =0nm, M =50)



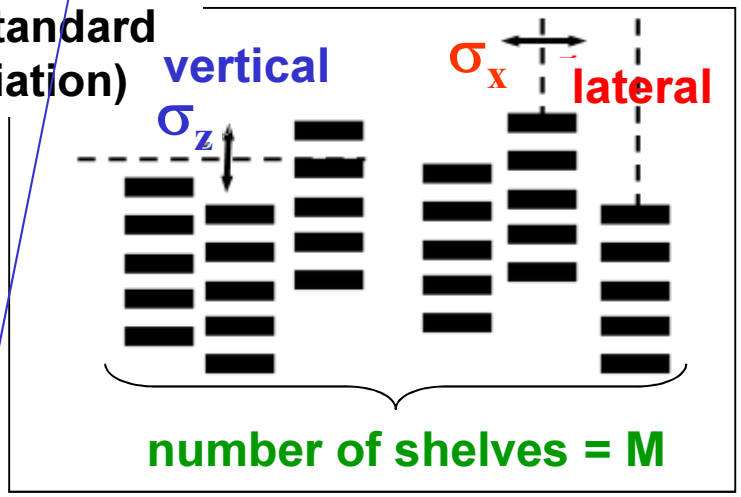
Like a GRATING

σ_z=50nm

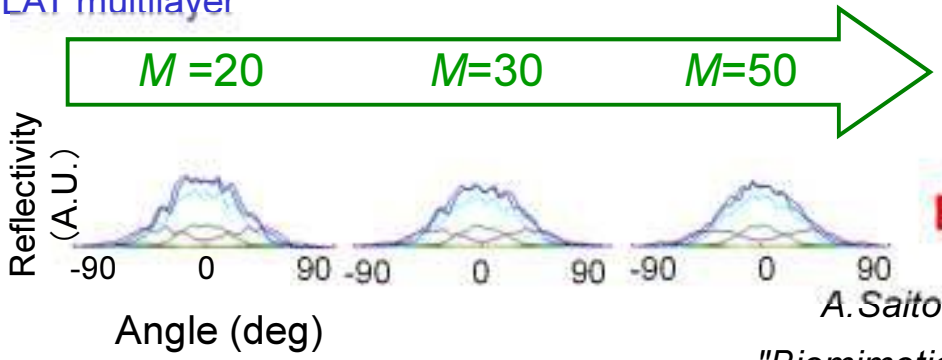


Role ➡ **Anti-grating**

(σ: Standard deviation)



Like a FLAT multilayer

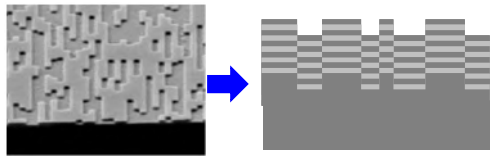


Role ➡ **Activation of Function**

A.Saito et al., J. Nanosci. Nanotechnol. 11 (2011) 2785.

"Biomimetic Photonics" (TAYLOR & FRANCIS , 2012)

What is necessary for Applications ?



Disorder + Anisotropy

Electro -forming

1. Mass-production

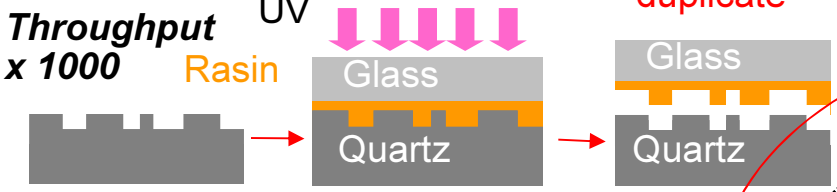
Nano-imprint

UV

duplicate

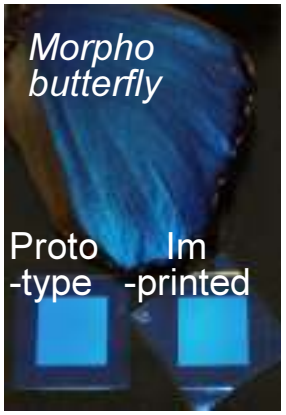
Throughput x 1000

Rasin

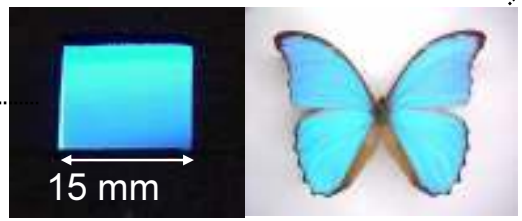


A.Saito et al., Proc. SPIE 6327 (2006) 1- 9.
A.Saito et al., JVST. B24 (2006) 3248-3251.

2. Large area

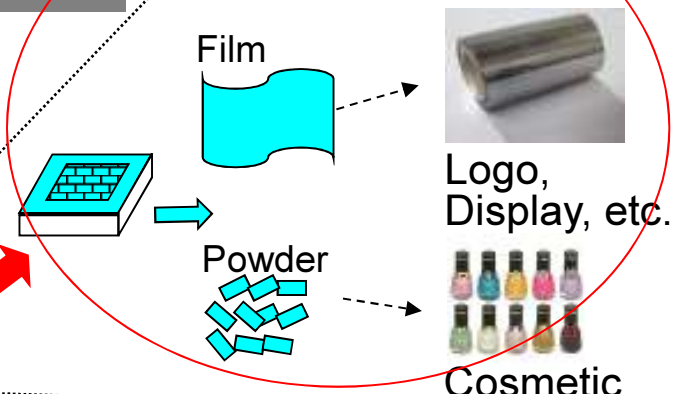


Done w/ success



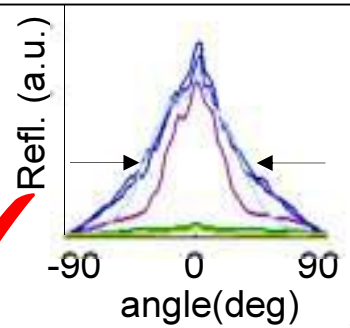
A.Saito et al., Proc. SPIE 9429 (2015).

7. Substrate-Free



Done w/ success

3.Control:Angular distribution



A.Saito et al., Proc.SPIE 6767 (2007) 1-8.

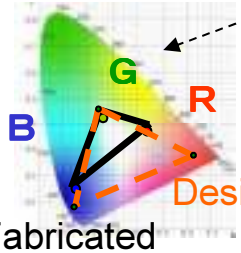
Patented 2008.9.27
(applied in 2003)

Done w/ success

4. RGB

A.Saito et al., J. Surf. Sci. Soc. Jpn. 28 (2007) 414-420.

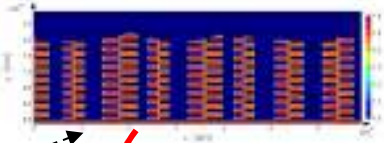
5. Control : Color phase



A.Saito et al., Proc.SPIE 7205 (2009) 1

FDTD

5. Simulation



A.Saito et al., J. Nanosci. Nanotechnol. (2011)

"Biomimetic Photonics" (TAYLOR & FRANCIS , 2012)

Design

6. Basic Physics

Optical Role of disorder

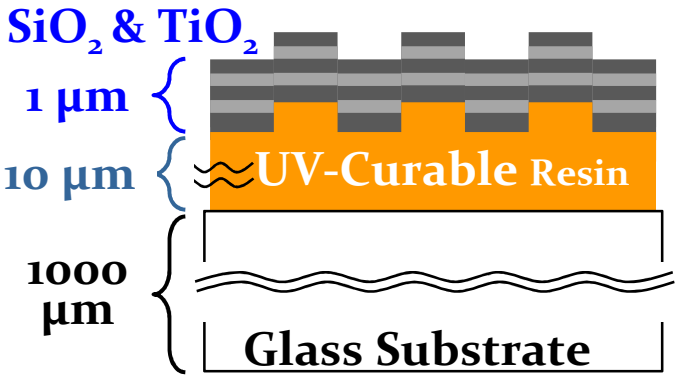
Why & How the Substrate-Free materials?

☞ For Wide Applications

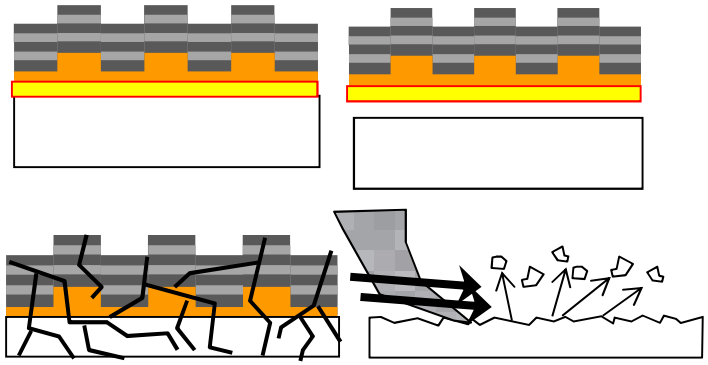
Flexible Film,
using Simple Process

▸ on a Free-Shape Materials

Mass produced *Morpho*-plate

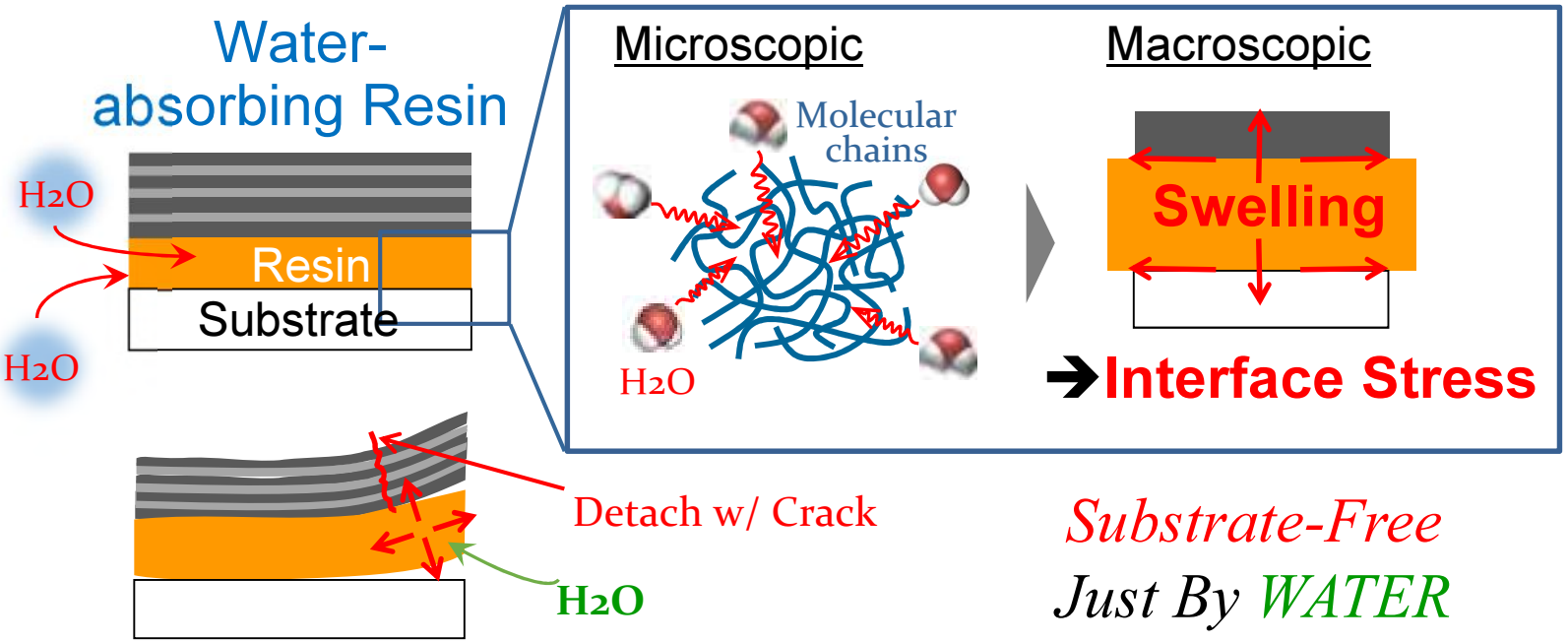


w/out additional Process
ex. ~~Sacrifice layer~~ ➔



w/out substrate pieces :
~~Break , Scratch~~, etc. (giving contaminant)

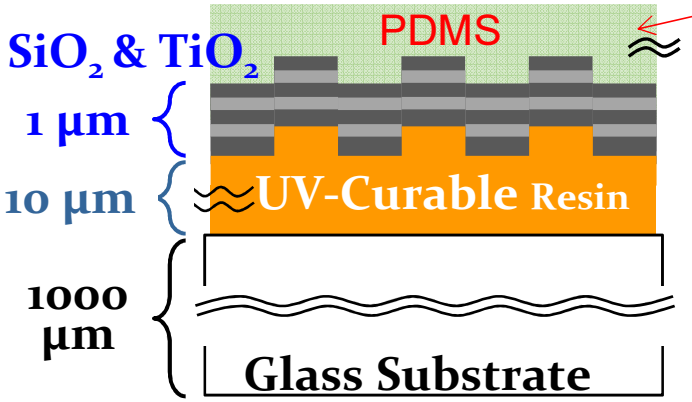
How to fabricate the Substrate-Free materials?



A.Saito et al., Proc.SPIE 9429 (2015).

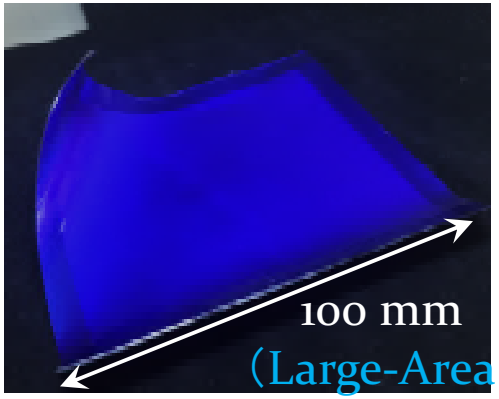
Substrate-Free
Just By WATER

Mass produced *Morpho*-plate + Cover by PDMS



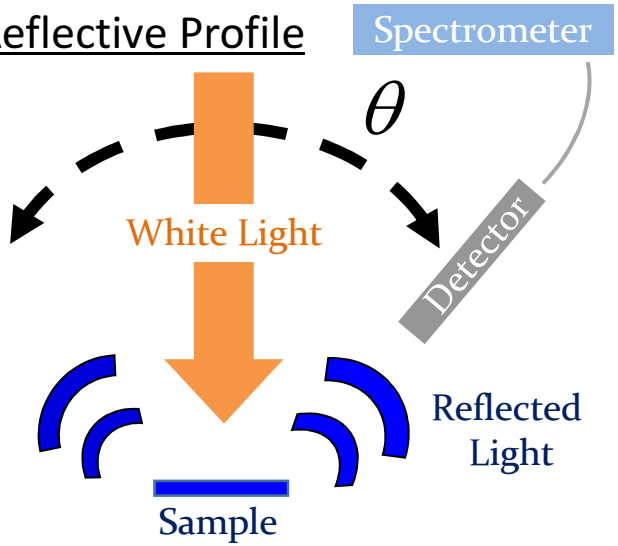
Detach

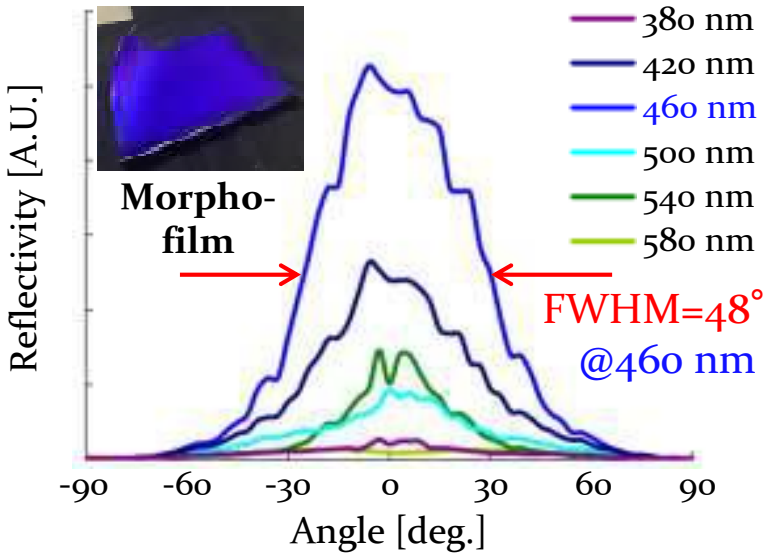
Flexible Film

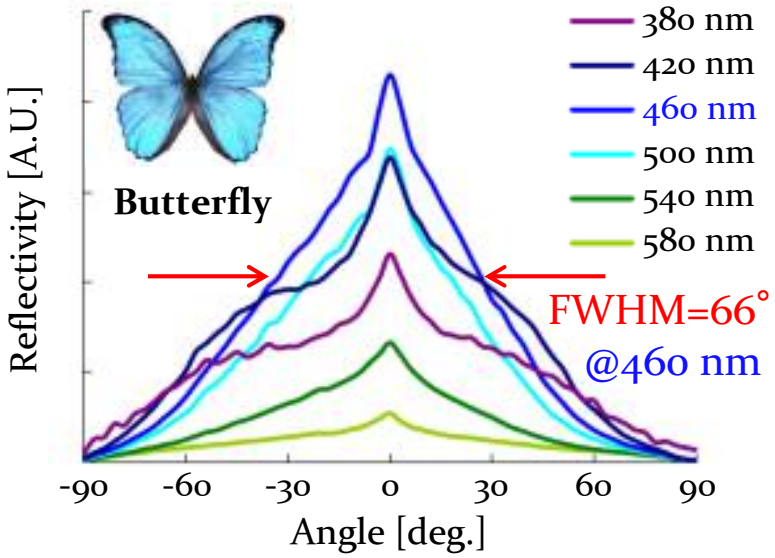


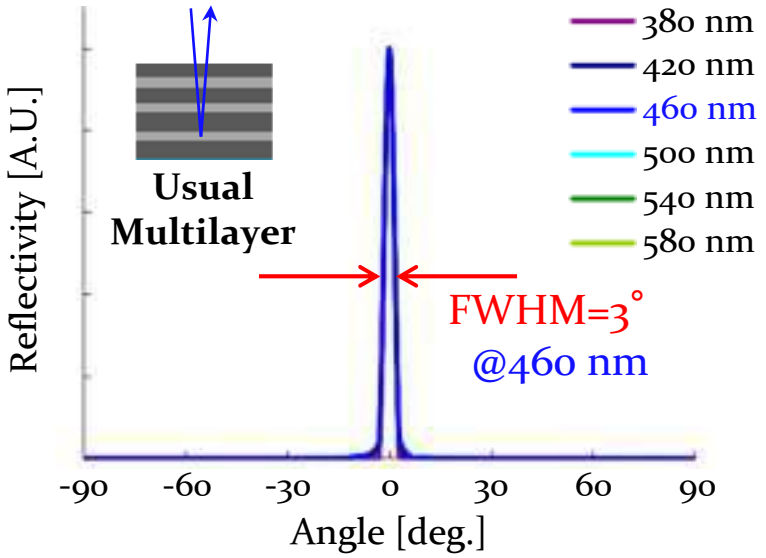
How about the Optical Properties?

▸Angular Reflective Profile









Almost Successfully Fabricated

Acknowledgement

M.Yonezawa, T.Shibuya, K.Ishibashi , J.Ohga : students
Y. Kuwahara : Prof.
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Y. Hirai : Nano-Imprint
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S. Matsui
Hyogo Univ.

S. Yoshioka & S. Kinoshita : Analysis @ start
Tokyo Univ. of Sci. , Osaka Univ.

Grant (Loréal Prize, 2004)
Kakenhi (Government):
seeds（2002~2003）,
basic（2006~2008, 2009~2012, 2014~）
JST : innovation（2008~2009）
Cosmetology Foundations
5 companies (finished)