

8 June 2013 : The Use of Nano Technology in our Daily Life and Nature (EDB Hong Kong)

一些大自然與日常物品的納米科技 Nanotechnology in nature and common daily items



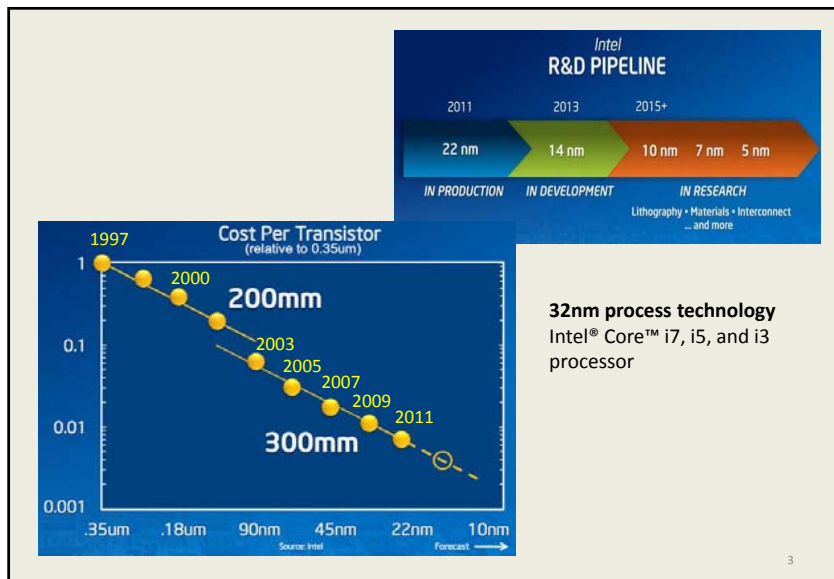
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高科技: 從微米電子到納米電子

From microelectronics to nanoelectronics

- 提起細小或微小，我們常常想到微電子元件的尺寸。Intel 的微處理器元件的尺寸從1971年的 $10\ \mu\text{m}$ 縮小到1997年的 $0.35\ \mu\text{m}$
- 到2009 年的 $32\ \text{nm}$, 2011年的 $22\ \text{nm}$.
- 1微米($1\ \mu\text{m}$)是百萬分之一米 ($1 \times 10^{-6}\ \text{m}$), $1\ \mu\text{m} = 1000\ \text{納米}(\text{nm})$.
 $10\ \text{nm}-100\ \text{nm}$ 是納米尺寸.
- 從 $10\ \mu\text{m}$ 縮小到 $32\ \text{nm}$, 器件的尺寸縮小超過 300倍, 密度提高 10萬倍.
- 器件縮小, 其速度加快, 價格下降.
- 微米/納米的尺寸半導體器件是用微光刻技术加工得到:
極(遠)紫外光, 掩模版, 光刻膠

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我們以下討論一些常見的普通物品的納米科技

- 在小尺寸範圍, 粘滯力主導, 慣性力可以忽略 **viscous force**
- 蝴蝶鱗片與飛蛾眼睛 **butterfly scale and moth eye**
反射結構和色彩, 抗反射和隱形
- 荷葉(出淤泥而不染)效應 **lotus effect**
疏水表面與自潔效應
- 蜘蛛絲上的露珠 **dew drops on spider silk**
- 彩繪玻璃(納米金 固體溶液, 膠體金溶液) **stained glass**
表面等離子激元的光吸收
光熱醫療

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物體的物理特性取決於物體的形狀和尺寸大小

Dependence of physical properties on size and shape

頻率與尺寸的關係

大尺寸 → 低頻 → 慢 large size → low frequency/slow

小尺寸 → 高頻 → 快 small size → high frequency/fast

大小合適

On being the right size

(J. B.S. Haldane 1926)

圖取自

Halliday, Resnick & Walker,
Fundamental of Physics, 6th ed.
Wiley, New York, 2001



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On Being the Right Size - J. B. S. Haldane (1926)

- You can drop a *mouse* down a **thousand-yard mine shaft**; and, on arriving at the bottom, it gets a slight shock and walks away, provided that the ground is fairly soft. A *rat* is killed, a *man* is broken, a *horse* splashes.

Terminal speed 終端速度: <http://ocw.mit.edu/courses/physics/8-01-physics-i-classical-mechanics-fall-1999/video-lectures/lecture-12/>

- For the resistance presented to movement by the air is proportional to the surface of the moving object. Divide an animal's length, breadth, and height each by ten; its weight is reduced to a thousandth, but its surface only to a hundredth. So the resistance to falling in the case of the small animal is relatively ten times greater than the driving force.
- An insect, therefore, is not afraid of **gravity**; it can fall without danger, and can cling to the ceiling with remarkably little trouble.
- But there is a force which is as formidable to an insect as gravitation to a mammal. This is **surface tension**.

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Some Terminal Speeds in Air 終端速度

Object	Terminal Speed		95% Distance* (m)
	(m/s)	mph	
16-lb shot	145	324	2500
Sky diver (typical)	60	134	430
Baseball	42	94	210
Tennis ball	31	69	115
Basketball	20	45	47
Ping-Pong Ball	9	20	10
Raindrop ($r = 1.5\text{mm}$)	7	16	6
Parachutist (typical)	5	11	3

* 95% Distance is the distance through which the body must fall from rest to reach 95% of its terminal speed.

Source: Adapted from P.J. Brancazio, *Sport Science*, Simon & Schuster, New York, 1984 in Halliday & Resnick's *Fundamentals of Physics, Third Edition*, John Wiley & Sons, 1988.

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On Being the Right Size - J. B. S. Haldane (1926)

- A man coming out of a bath carries with him a film of water of about one-fiftieth of an inch (0.5 mm) in thickness. This weighs roughly a pound (454 grams).
- A wet mouse has to carry about its own weight of water.
- A wet fly has to lift many times its own weight and, as everyone knows, a fly once wetted by water or any other liquid is in a very serious position indeed.
- An **insect going for a drink** is in as great danger as a man leaning out over a precipice in search of food. If it once falls into the grip of the surface tension of the water – that is to say, gets wet – it is likely to remain so until it drowns.

- 大小合適：特征長度，我們身的高低，手的大小，腿的長短

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物體的物理特性 取決於物體的形狀和尺寸大小

• 伽利略平方立方法則 (1638)

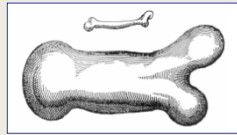
Galileo's square-cube law

面積 = (長度)², A = L²

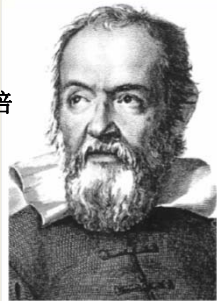
體積 = (長度)³, V = L³

重量 = (密度)(體積) g = ρL³g

(g = 重力加速度)



尺寸增大2倍
支撐結構的橫截面積增大 2²倍
重量(體積)增大 2³倍
重量截面比(應力) = 2倍
支撐結構的應力增大2倍。



取自Wikipedia

大動物的骨骼在比例上要更粗，以免折斷。

尺寸收縮 n倍，面積縮小 n²倍，體積縮小 n³倍，面積體積比 = n。
小動物的面積體積比相對地大

大動物(大物體)與小動物(小物體)的差異

體能，失熱與食量，代謝率與心跳率
受制於體重或受困於水

電影中的巨型怪獸(金剛，哥斯拉)，沒有可能存在。

格列佛遊記(大小人國遊記)
Gulliver's Travels 1726
不可能話對
體溫與食量



極小(?)的物體
會有什麼樣的性能?

取自G Barnes1989, Physics and Size in Biological Systems

	Height 身高	Mass 體重
Gulliver	1.80 m	75 kg
Lilliputian 小人國人	0.15 m	75 × (0.15/1.8) ³ = 0.043 kg
Brobddingnag大人國人	18 m	75 × (10) ³ = 75,000 kg = 75 tons

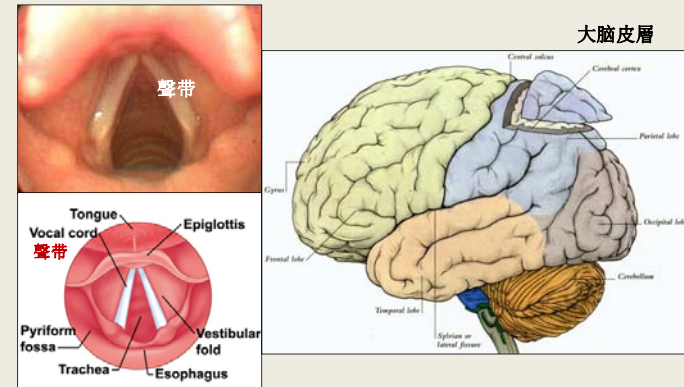
Can they talk to one another? 他們能對話嗎?

Vocal cords as vibrating strings, frequency f is inversely proportional to the square of its linear dimension l: f ∝ 1/l².

Gulliver	20 - 18 kHz	100 Hz	1000 Hz	10 kHz
Lilliputian	(l _G /l _L) ²	14.4 kHz	144 kHz	1,400 kHz
Brobddingnag	(l _G /l _B) ²	1 Hz	10 Hz	1000 Hz

Philip Morrison: Gulliver's Laws: The Physics of Large and Small (1968)

Vocal chord, brain (cerebral cortex) 聲帶與大腦



Communication by speech 用語言溝通

It takes about 1 second for us to say the word 'Brobdingnagian', speaking at 160 Hz, it means 160 wavelengths have entered our ears.

Slow & long Brobdingnagian speech 緩慢而漫長的談話

- When a Brobdingnagian says the same word at 1.6 Hz, it takes her/him 100 times longer, i.e. 100 seconds = 1 min 40 sec. We need to be very patient to hear him speak.

Fast & short Lilliputian speech 快速而簡略的談話

- Speaking at a frequency 144 times ours, a Lilliputian needs only 1/144 s \approx 7 ms to say our one second word.
- If a Lilliputian were to do a hour lecture, it would take her/him just 25 seconds. Do you think you would have understood anything she/he said?

Brain size and wisdom 腦的大小與智慧

The cerebral cortex, 2 - 3 mm thick, covering our brain like a skin can be treated as an area. The mental capacity thus scales as the square of the characteristic length of the cerebral cortex.

$$C_L = C_G (\ell_L / \ell_G)^2 = C_G (0.15 / 1.8)^2 = 0.0069 C_G$$

- The intelligence of a Lilliputian gentleman is less than 0.7% of that of Gulliver. 微小的大腦
- So even if Gulliver could detect his frequency and handle the rapidity of the words, he would find his tiny companion had essentially nothing to say. 快速和無意義的空話
- The Brobdingnagians having cerebral cortex 100 times longer would be 100 times as intelligent as Gulliver! 巨大的大腦
- They would be saying extremely wise things, but in a very, very deep voice and extremely slowly. 低沉緩慢而明智的談話

Food for metabolism 維持新陳代謝之食物

納米尺度 Nano scale: 1 nm – 100 nm

是指在牛頓宏觀尺度(μm , mm, m, km) 與電子和原子量子尺度(< 0.1 nm)之間的尺度

- 千分之一米 (m) \rightarrow 毫米(mm),
- 千分之一毫米 (mm) \rightarrow 微米(μm),
- 千分之一微米 (μm) \rightarrow 納米(nm)

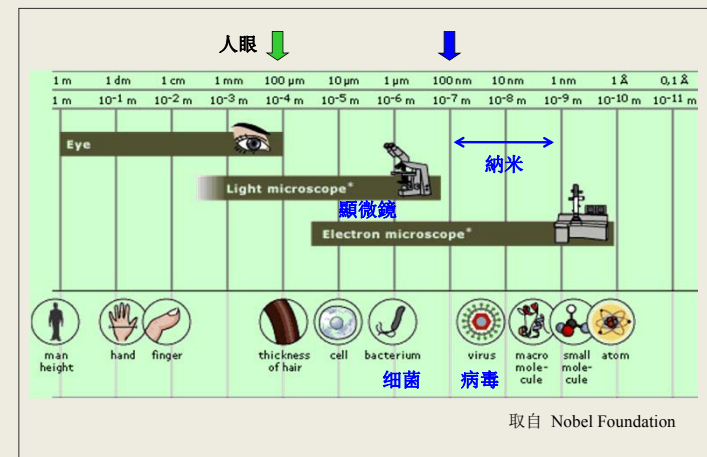
可見光的波長: 400 – 700 nm

我們的頭髮的直徑約為 0.1 mm, 或 100 μm , 放大一萬倍

- 頭髮直徑 : 1 m
- 可見光的波長 : 4 – 7 mm
- 納米尺寸 : < 1 mm



人眼和顯微鏡的分辨率



取自 Nobel Foundation

Bacteria and Viruses 細菌和病毒

細菌 Bacteria

EM Purcell, *Life at Low Reynolds Number* (1976)

Reynolds number, Re

$$Re = \frac{\text{inertial force}}{\text{viscous force}} = \frac{av\rho}{\eta}$$

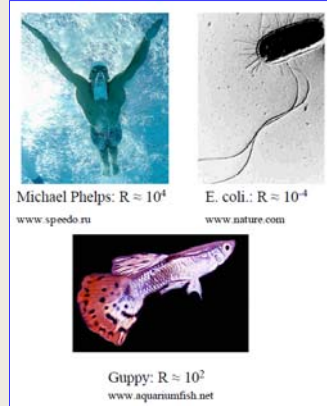
a : size (dimension)

v : speed

ρ : density

η : viscosity

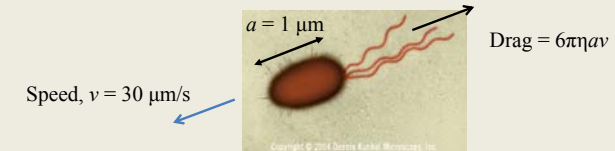
雷諾數：慣性力和粘滯力之比



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At $Re = 10^{-4}$, **viscous force** \gg **inertial force**

For **E. coli** (大腸杆菌), with $v = 30 \mu\text{m/s}$, $a = 1 \mu\text{m}$, the bacteria moves a distance of 0.007 nm in $0.2 \mu\text{s}$.



- To swim, the E. coli must produce a continuous force, reciprocal motion will not get them anywhere.
- It is better for E. coli to **move by diffusion**, local stirring is 100 times slower.
- Implication for micro-robots 微型机器人的運動受限制

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噬菌體病毒

Monitoring Viral Emergence

Bacteriophage

These bacteria-infesting viruses are the most abundant life-form on the planet, their number far exceeding that of stars in the universe. Trillions inhabit each of us.

Nathan Wolfe

T4 bacteriophage virus

200 nm long

Small, Small World 小小世界

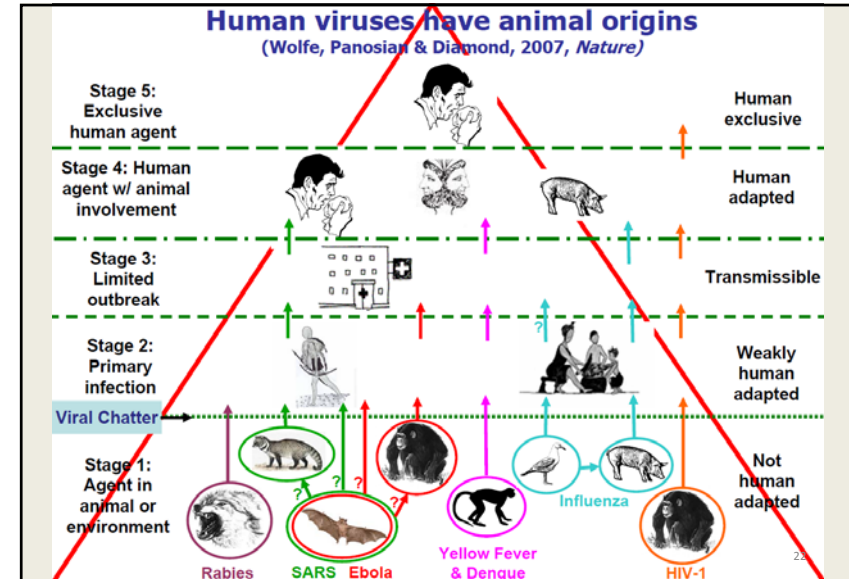
Nathan Wolfe, *National Geographic Magazine*, January 2013

- When we inhale, our nostrils capture millions of invisible particles: dust, pollen, sea spray, volcanic ash, plant spores. These specks in turn host a teeming community of **bacteria** and **viruses**.
- A few types may trigger allergies or asthma.
- **Far more rare** are inhaled **pathogens** that are themselves the agents of diseases, such as **SARS**, **tuberculosis**, and **influenza**.

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Diseases 疾病		Agent 病毒
AIDS	艾滋病	HIV
Dengue fever	登革热	Flavivirus: dengue virus
Hepatitis	肝炎	Hepadnavirus: Hepatitis virus
Influenza	流感	Myxovirus: Influenza virus
Measles	麻疹	Paramyxovirus: Morbillivirus
Mumps	腮腺炎	Paramyxovirus: Rubulavirus
Rotavirus	轮状病毒	Reoviridae: Rotavirus
Rubella	风疹	Togavirus: Rubivirus
Smallpox	天花	Poxvirus: variola virus
Yellow fever	黄热病	Flavivirus: Yellow fever virus

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H5N1 avian Flu virus

H5 N1

禽流感病毒

A computer simulated scanning electron microscope image of the avian flu virus.

Ying-Ta Wu
Academia Sinica, Taipei

Erasmus University Medical Center in the Netherlands and the University of Wisconsin (Madison)

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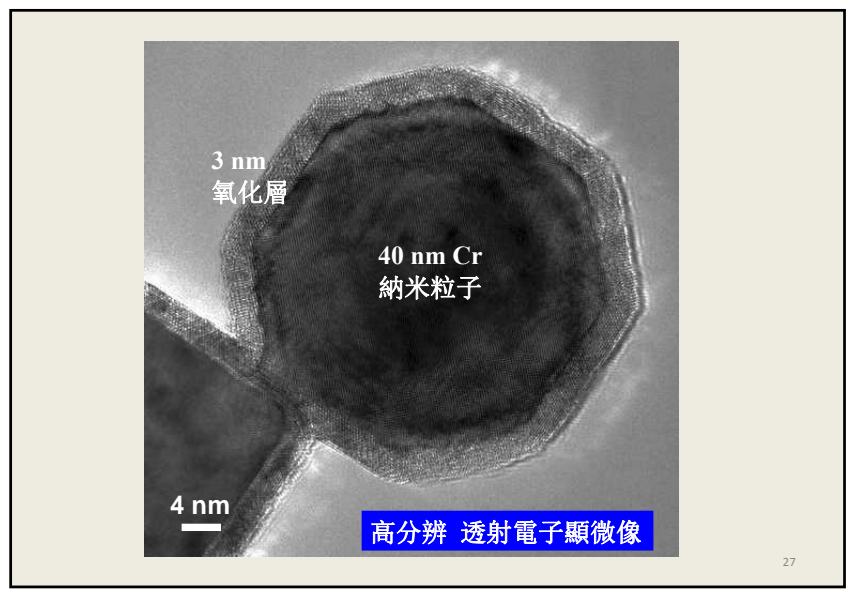
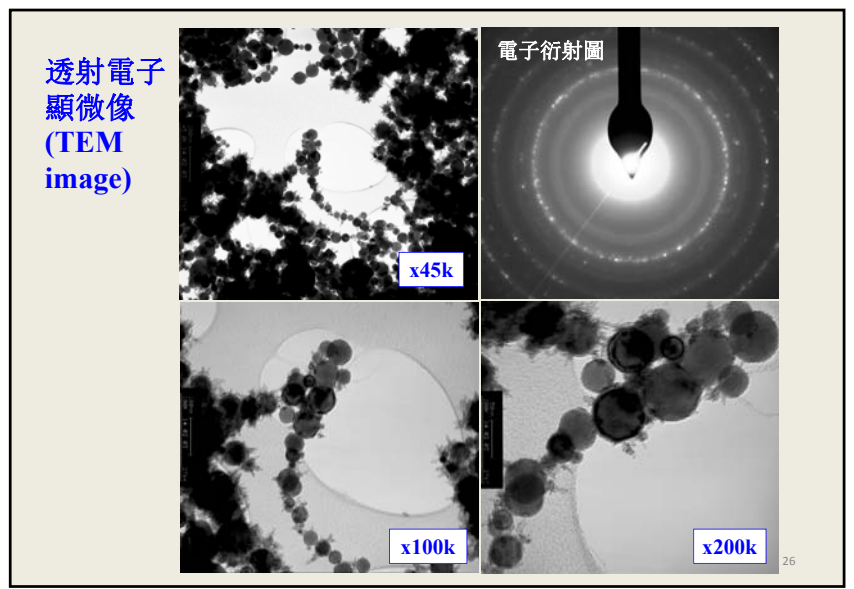
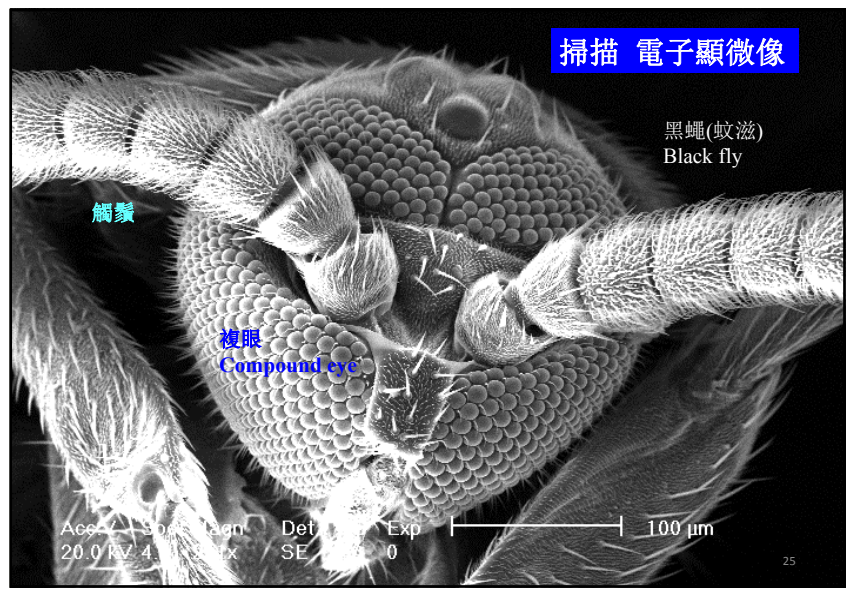
透射 電子顯微鏡 (TEM)

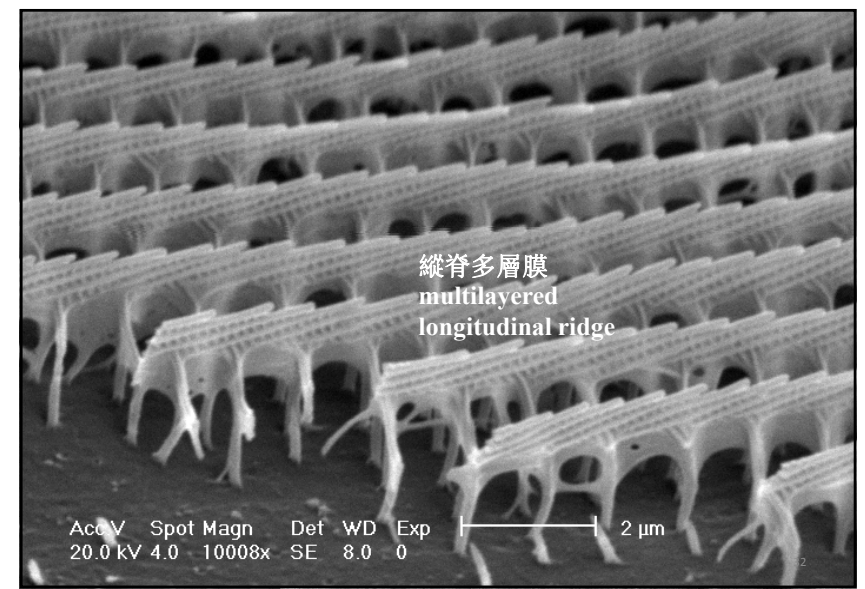
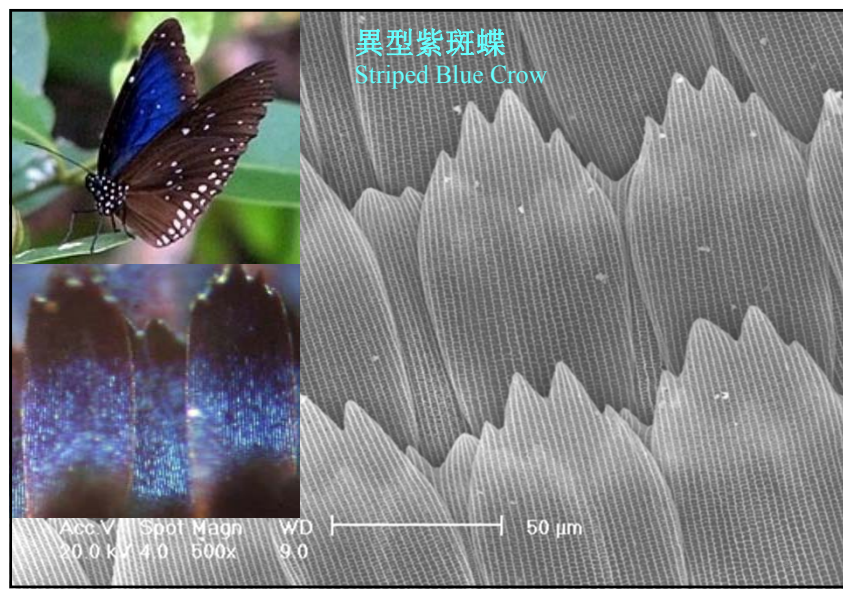
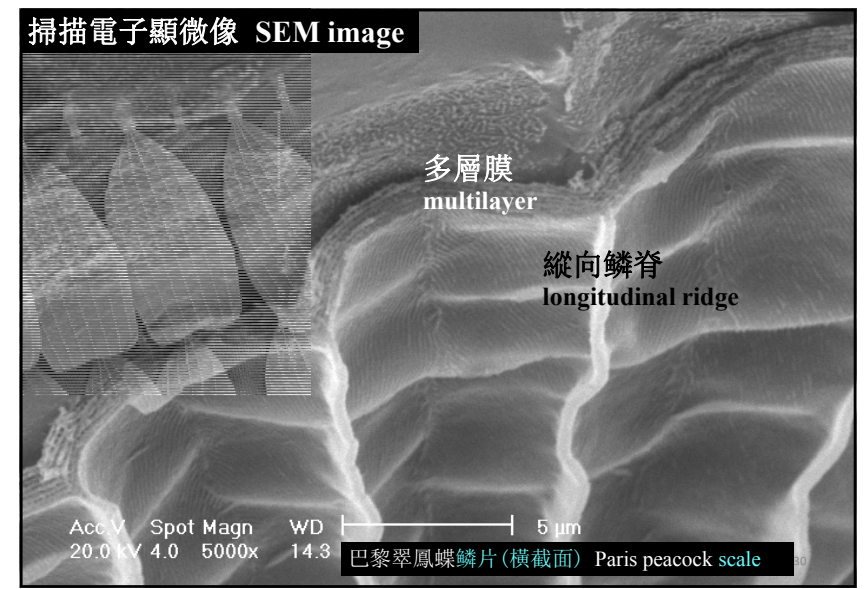
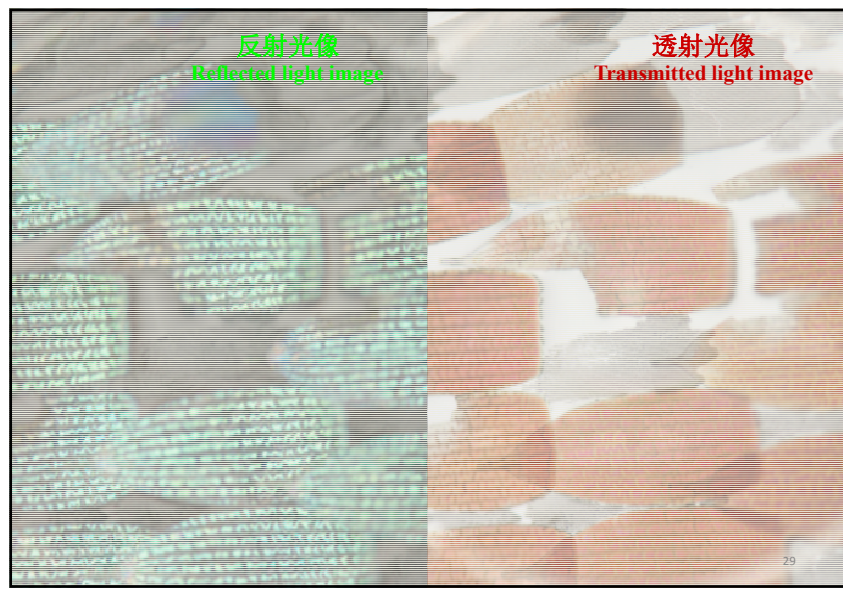
掃描 電子顯微鏡 (SEM)

樣品製備 面對的問題:
導電 conducting electrons
真空 high vacuum

SEM TEM

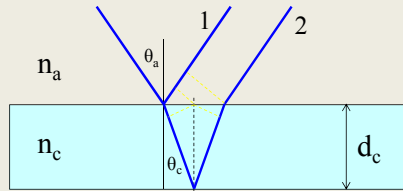
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Reflection from a thin oil film

最常見的和最為人熟悉的反射薄膜是
單層油膜



入射光線在高折射率(n_c)薄膜的折射效應為
 $n_a \sin \theta_a = n_c \sin \theta_c$

光線 1 位相轉變 $180^\circ \rightarrow$ 波長轉變 $\lambda_a/2 = \lambda/2$
光線 2 的光程差 = $2d_c \cos \theta_c$

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相長干涉 **constructive interference**

\rightarrow 看見增強的反射光

$$2d_c \cos \theta_c = \lambda_c / 2 = (\lambda / n_c) / 2$$

$$n_c d_c \cos \theta_c = \lambda / 4$$

考慮垂直入射, $\theta_c = 0$, $n_c d_c = \lambda / 4$

$n_c d_c$ = 膜的光學厚度 = 光波長的四分之一 ($\lambda/4$)

假如反射光為藍光 ($\lambda=480$ nm),

空氣膜的厚度 = 120 nm, 油膜 ($n=1.5$) 的厚度 = 80 nm.

當入射角增大, 反射光的波長減小 \rightarrow 色彩 **藍移**

當折射率增大, 反射光的波長增大 \rightarrow 色彩 **紅移**

多層膜: **幾丁質膜** **空氣膜** 交替組成

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光通信與眼睛 Eye for optical communication



複眼



眼耀 eye shine

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眼睛: 光信號探測器 **Light signal detector**

複眼

- 數以千計的小眼, 點彩 視力
- 可見光 紫外光 偏振光 視力
- 移動 敏感的 探測器
- 抗反射

色彩的用途

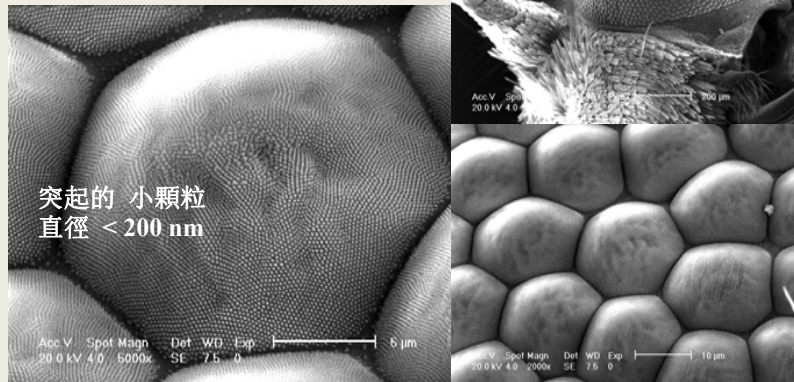
- 求偶
- 隱蔽
- 警告

反射多層膜的應用

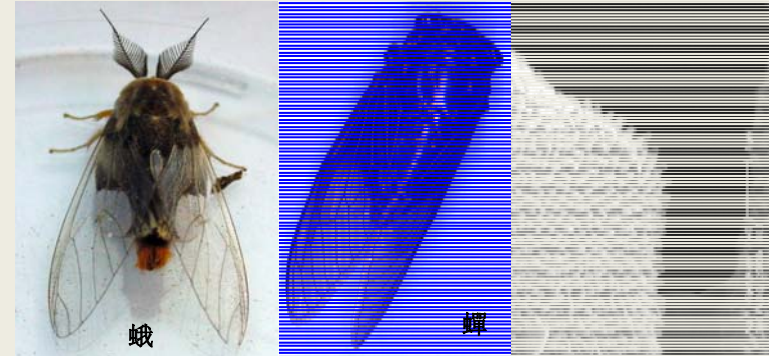
- 防偽: 錢幣, 商標
- 裝飾
- 顯示屏
- 節能
- 印刷

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抗反射的蛾眼結構 Antireflection moth eye structure



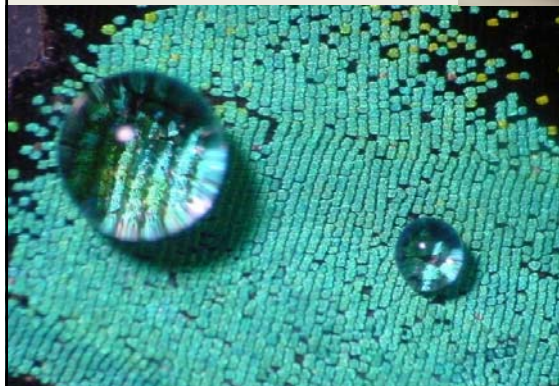
昆蟲的透明翅膀也是抗反射結構 Transparent wings of insects are also antireflection structures



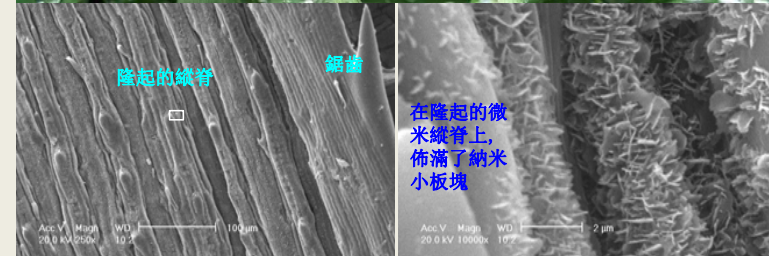
抗反射結構膜的應用: 太陽能電池, 隱形轟炸機
Applications: solar cells, stealth bomber

蝴蝶鱗片 Hydrophobic scales

擁有微米/納米兩個層級結構, 通常是疏水的, 水珠可以輕易滾動. 水珠也可以釘扎在鱗片表面上.



草葉的疏水表面 Hydrophobic surface of grass leaves



荷葉效應 Lotus effect

W. Barthlott & C. Neinhuis, *Planta* 202 (1997) 1-8.
H.J. Ensikat et al., Beilstein *J. Nanotechnol* 2 (2011) 152-161

突出的乳頭狀 表皮細胞

水珠 water drop

小水珠

水珠

水上 above water

水下 under water

自潔效應 self-cleaning

- 水珠在荷葉上，形成水珠。
- 水珠和荷葉的接觸角大，接觸面小
- 在微微傾斜的荷葉上水珠輕易滾動
- 滾動的水珠帶走塵粒

荷葉效應的演示：
<http://www.youtube.com/watch?v=LJtQ6dvcbOg> (3:48)
<http://www.youtube.com/watch?v=WeGnjXcEK78&feature=related> (0:31)

荷葉的表面結構

SEM image showing nano-tubules on papillose epidermal cells and space between cells.

乳突

Acc.V 20.0 kV Magn 4000x Det SE WD 19.2 Scale bar 5 μm

Magn 10000x Det SE WD 19.2 Scale bar 2 μm

荷葉表面分佈了隔離的微米乳突表皮細胞，形成凹凸不平的結構。納米小管覆蓋了葉的表面。所有的表皮結構都是疏水蠟質組成。

在荷葉上的水珠

Water drop on lotus leaf

(i) (ii) (iii)

Scale bars: (i) 10 μm, (ii) 2 μm, (iii) 0.4 μm

Microstructure of papillose epidermal cells covered with nanoscale epicuticular wax tubules on the surface

荷葉表面SEM像顯示在微米乳突表皮細胞的納米小管結構
(取自M. Nosonovsky and B. Bhushan, *Phil. Trans. R. Soc. A* 368 (2010) 4677)

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不同方法製備的荷葉樣品的 SEM 像

(a) (b) (c) (d) (e) (f)

Fig. 2 Lotus leaf (*Nelumbo macleod*) treated with 6 different preparation methods. (a): CP-drying preserves the papillae, but the epicuticular waxes are destroyed. (b): Air-drying causes severe shrinkage of the epidermal cells. (c): The fresh-hydrated sample (without metal coating) at ca 5°C shows little shrinkage after 10 minutes observation time. The waxes are intact, but sample drift retards high magnifications. (d): Glycerol-infiltration prevents shrinkage of the papillae: the waxes are intact, the surface is dry and untouched; sample without metal coating. (e): Low-temperature SEM image of the frozen-hydrated sample without metal coating. The waxes and papillae are intact, but the image contrast is poor due to charging of the non-conductive sample. (f): The freeze-dried sample with metal coating shows good preservation of the papillae and waxes and is suitable for high magnification (the inset shows the wax tubules).

(取自HJ Ensikat et al., *Microscopy: Science, Technology, Applications and Education*) 44

接觸面積 contact area

水珠在微米 / 納米凹凸不平粗化的蠟質固體表面

- 水珠和葉面全接觸 (Wenzel態: 液固接觸)
- 水珠和凸出的圓錐體頂部以及圓錐體之間的空氣接觸 (Cassie態: 液固, 液氣接觸)
- 水珠不接觸固體, 浮在蒸汽上, 在固體表面移動 (Leidenfrost 效應)

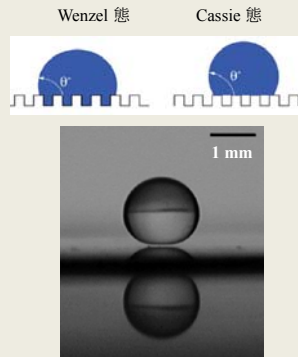
水珠和葉的接觸面積 : 2-4%

(Ensikat, Schulte, Koch & Barthlott, *Langmuir* 25 (2009) 13077)

葉面納米小管密度: 正面 200/10 μm^2 , 反面 63/10 μm^2

荷葉的氣孔在葉的正面, 而不是在反面

(Ensikat, Ditsche-Kuru & Barthlott, *Beilstein J. Nanotech-nol.* 2 (2011) 152)



Leidenfrost 水珠

(取自 Quere and Reyssat, *Phil. Trans. R. Soc. A* 366 (2008) 1539)

45

荷葉效應(Lotus effect)與疏水性(hydrophobicity)

當水潤濕固體表面時, 原本空氣和固體的界面被水和固體的界面所取代. 如果被濕潤的固體表面有較低的界面能, 水會在固體表面擴張. 水面和固體表面所成的角度稱為接觸角. 接觸角較小, 表明水傾向於在表面上散開, 這是親水表面; 接觸角較大, 表明水沒有在表面上散開, 表面相對地保持乾爽, 這是疏水表面.



荷葉的表面有超強的疏水性, 接觸角大於160度, 水極不容易潤濕荷葉表面. 雨水落在荷葉上, 會形成水珠. 水珠在荷葉上, 處於類Cassie態, 接觸面積很小, 灰塵和荷葉的接觸面積也 很小. 葉面受到輕微擾動, 水珠輕易滾動, 接觸塵粒, 並將塵粒帶走, 達到自動清洗的效果, 這就是荷葉效應, 即自潔效應.

46

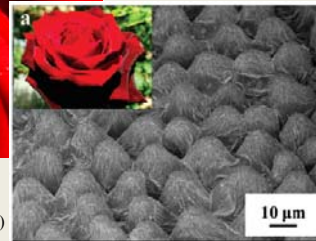
玫瑰花瓣效應 (rose petal effect)



從 Wikipedia 下載

在玫瑰花瓣上的水珠不滾動, 而釘扎在表面上. 水珠處於類Wenzel態. 可以倒掛在花瓣下.

花瓣表面佈滿了相連的微米圓錐體, 圓錐體的表面存在納米折疊.



取自 (L. Feng et al., *Langmuir* 24 (2008) 4114)

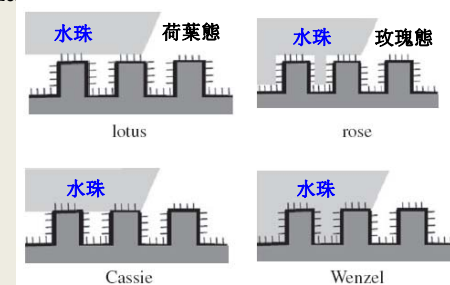
47

Micro-nano hierarchial roughness 微米納米兩層級的表面粗化微結構:

- 在微米結構上, 再有納米結構
- 水受壓後, 可以滲透進入微米結構之間的空間
- 水珠和微米/納米結構接觸與不接觸
- 可以有各種可能的接觸態,
- 下面展示了Cassie態, Wenzel態, 荷葉態, 玫瑰態

疏水性植物很多:

除了荷葉, 草葉, 花瓣, 還有芋頭 (*Colocasia esculenta*) 葉



除了微米/納米結構的結合之外, 還有什麼其他可能的結合?

(取自 B. Bhushan & M. Nosonovsky, *Phil. Trans. R. Soc. A* 368 (2010) 4713)

48

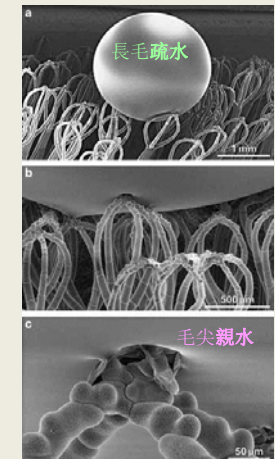


Air retaining surfaces in water 在水中保留空氣的疏水表面

水浮蓮和槐葉萍 葉的表面 有很多蠟質疏水長毛。 葉子浸在水中, 困在疏水毛之間的空氣, 給出銀色的反射。 水和葉的接觸面積很小, 接觸角大, 形成水珠。 小水珠釘扎在葉毛上, 大水珠相對容易滾動。

水浮蓮和槐葉萍葉面長毛疏水, 但毛尖親水, 能夠釘扎空氣和水的界面。 在動盪的水流中, 可以防止氣泡分離逃脫。 水浮蓮和槐葉萍表面的毛可以長時間保留表面空氣。

(取自 Barthlott et al., *Adv Materials* 22 (2010) 2325)



槐葉萍 *Salvinia molesta*

50

Superhydrophobic surfaces with hydrophilic pins for retention of air under water

槐葉萍(*Salvinia*)效應:

疏水表面上的親水釘在水裏保留表面空氣



疏水長毛 親水毛尖
(取自 Barthlott et al., *Adv Materials* 22 (2010) 2325)

- 釘扎空氣和水的界面, 防止氣泡分離逃脫。長時間保留表面空氣。
- 水和和固體界面之間的空氣, 可以減少阻力。
- 空氣保留表面, 可望應用在船殼, 流體輸送管的減阻。

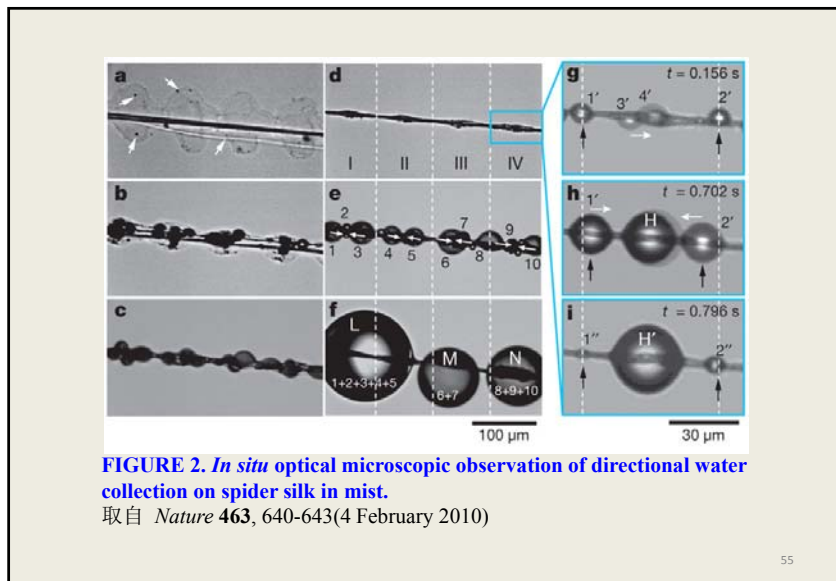
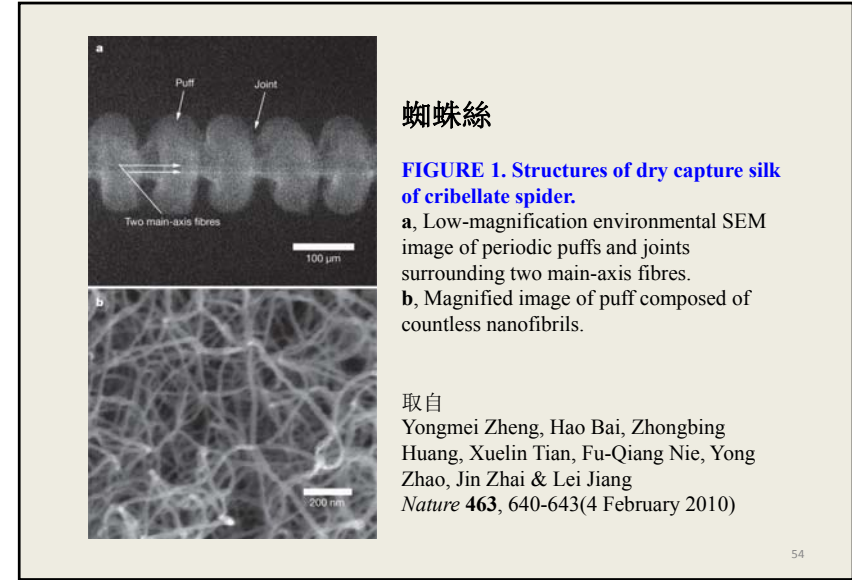
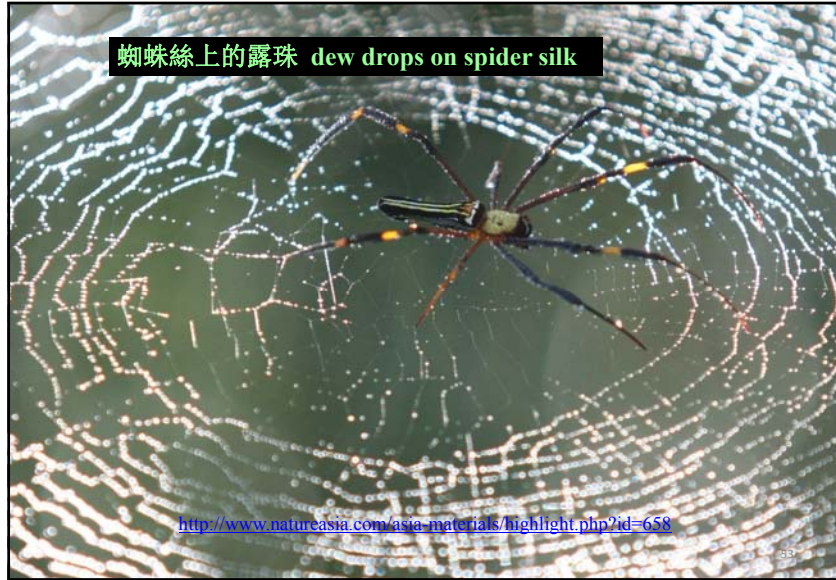
51



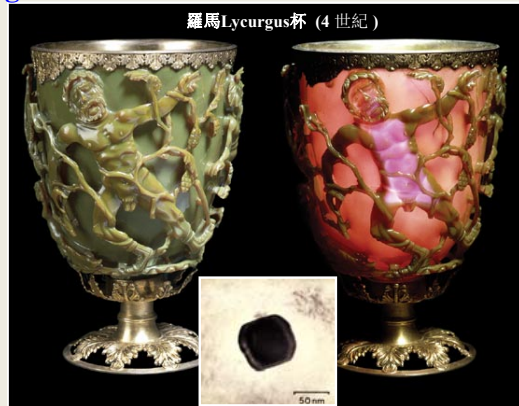
Emperor Penguin use air as a lubricant to cut drag and increase speed. Air is trapped in a fine, downy mesh (20 μm) and released as microbubbles so tiny that they form a lubricating coat on the feather surface.

NATIONAL GEOGRAPHIC MAGAZINE
Photograph by Paul Nicklen

Nov 2012



纳米金: 從羅馬手工藝到納米高科技
Nano-gold: from Roman handicraft to modern hi-tech



羅馬Lycurgus杯 (4世紀)

透射電子顯微像 顯示金銀納米粒子分散在玻璃內
 Barber & Freestone 1990

57

彩繪玻璃
Stained glass



Canterbury大教堂
 13世紀
 (從Wikipedia下載)

58

Metals Used to Impart Color to Glass 用來在玻璃加色的金屬

Cadmium Sulfide	硫化鎘	黃	Yellow
Gold Chloride	氯化金	紅	Red
Cobalt Oxide	氧化鈷	藍紫	Blue-Violet
Manganese Dioxide	二氧化錳	紫	Purple
Nickel Oxide	氧化鎳	紫	Violet
Sulfur	硫	琥珀黃	Yellow-Amber
Chromic Oxide	氧化鉻	翡翠綠	Emerald Green
Uranium Oxide	氧化鈾	熒光黃, 綠	Fluorescent Yellow, Green
Iron Oxide	氧化鐵	綠和棕	Greens and Browns
Selenium Oxide	氧化硒	紅	Reds
Carbon Oxides	碳氧化物	琥珀棕	Amber Brown
Antimony Oxides	氧化銻	白	White
Copper Compounds	銅化合物	藍, 綠, 紅	Blue, Green, Red
Tin Compounds	錫化合物	白	White
Lead Compounds	鉛化合物	黃	Yellow
Manganese Dioxide	二氧化錳	脫色劑	A "decoloring" agent
Sodium Nitrate	硝酸鈉		A "decoloring" agent

<http://geology.com/articles/color-in-glass.shtml>

59

金錫紫1685 (卡西斯紫 purple of Cassius)
金水瓷釉 (金珺瑯) (gold enamel):
粉彩瓷 (雍正)
(Famille Rose porcelain, 1723)



清雍正粉彩「蟠桃獻瑞」圖圓蓋盒。《大清雍正年制。直徑19.2 cm。(香港蘇富比圖片, 2011年春季拍賣會)



從博宝艺术网下載

清雍正 珊瑚紅地 粉彩 碗

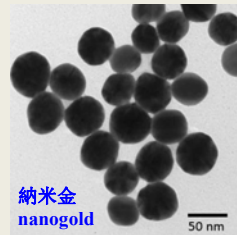
60

金的顏色 Colour of gold

黃色還是紅色 yellow or red



從 Wikipedia 下載



納米金
nanogold



取自

Gold Bulletin 2007 • 40/4, 267

61

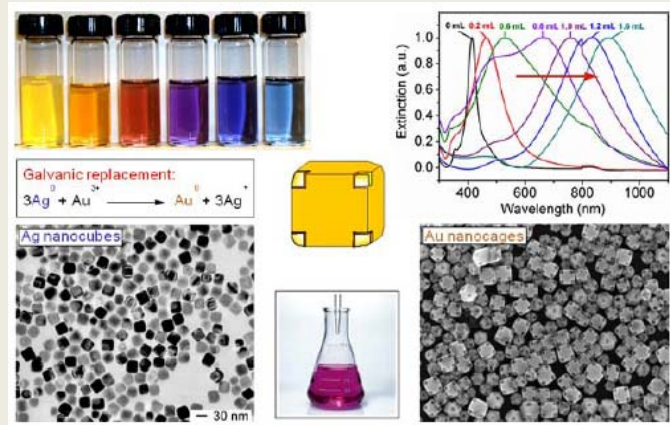
膠體溶液 Colloidal Solution

微小到看不見的粒子分散和懸浮在水或其他溶媒中所形成的溶液

- **Michael Faraday (1857)** 在水裏溶解微小金屬粒子, 獲得**寶石紅**金溶液 (ruby gold solution)
- **Thomas Graham (1861)** 稱之為**膠體**溶液 (colloidal solution)
- **Richard Zsigmondy (1898)** 證明**金錫紫**為膠體金溶液, 從而獲得1925年諾貝爾化學獎 (Nobel price for showing purple of Cassius is due to colloidal gold)
- **J. Turkevich (1951)** 使用透射電子顯微鏡 表明膠體金粒子的大小為 6 ± 2 nm. (TEM imaging of colloidal gold nanoparticles: 6 ± 2 nm)

62

用銀納米立方獲得金納米籠 gold nanocages from silver nanocubes



取自 <http://www.nano.wustl.edu/doc/labs/xia.pdf>

63

核殼結構: SiO₂/Au core-shell structure

二氧化硅核 (50 nm 直徑) - 金殼(5 nm 厚)

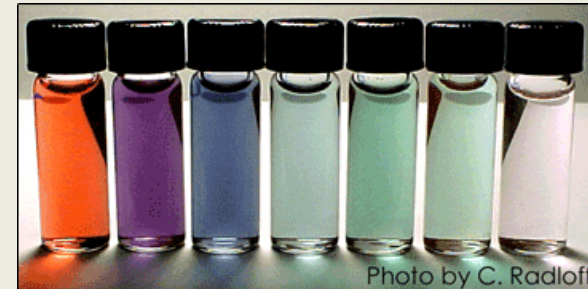
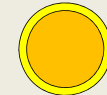


Photo by C. Radloff

Nanoengineered Photonics and Plasmonics

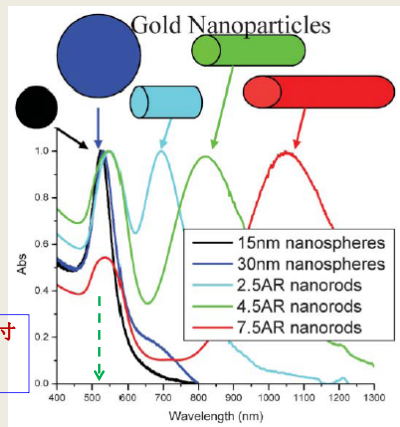
納米加工 光子學和等離激子學

取自 <http://www-ece.rice.edu/~halas/>

64

金納米粒子 Gold nanoparticles

色彩 決定於粒子的**形狀**
(球, 籠, 棒, 管) 和**尺寸**大小



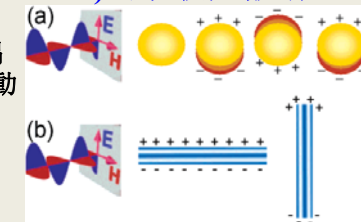
金 納米粒子的吸收峰 跟隨其**形狀**和**尺寸**
大小 移動

取自 *Chem. Soc. Rev.*, 2006, 35, 209-217

65

表面等離子激元(surface plasmon)的吸收與散射

- (a) 入射光(電磁波)與金屬納米球相互作用, 產生了感應電偶極子, 偶極子跟隨電場同步振動, 這種振動被稱為**表面等離子體激元**.
- (b) 金屬納米棒 表面電子的橫向和縱向振動.



我們可以在上一張幻燈片見到金 納米球的**表面等離子體激元**的吸收峰位於**綠光**波段(520 nm), 這樣我們就可以解釋為什麼 Faraday 金膠體溶液的**色彩是紅色的**.

取自 *Langmuir* 2006, 22, 32-41

上一張幻燈片還表明金 納米球的直徑增大, 吸收峰輕微**紅移**. 隨著金納米棒的長度直徑比增大, 縱向吸收峰大幅度**紅移**到紅外區.

66

光熱效應 Thermal-photon effect

納米粒子把吸收了的光能, 轉化成熱能, 溫度因而升高. 由於納米粒子熱容量非常小, 溫度大幅上升, 達到着火點而燃燒.

軟組織(皮膚, 肌肉)的紅外線吸收很低

紅外線熱療 (飛利浦 InfraCare 紅外線照護燈)(穿透皮膚的表皮層與真皮層而將溫熱效應作用在皮下組織內的微血管, 淺層肌肉以及關節部位的肌腱和韌帶, 從而舒緩疼痛)

治療應用 Therapeutic application

- 生物分子和抗體容易附在金納米粒子上
- 金納米粒子的**等離子體激元共振吸收**比光熱染料吸收大十萬倍

把金納米粒子附在癌細胞上, 通過光熱效應將激光能量轉化成熱能, 癌細胞升溫燃燒, 鄰接的正常細胞完好無損傷.

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使用閃光燈閃照蝴蝶鱗片, 黑色鱗片燃燒,
白色鱗片無損傷.
閃照鍍金(銀)的白色鱗片, 鱗片燃燒.

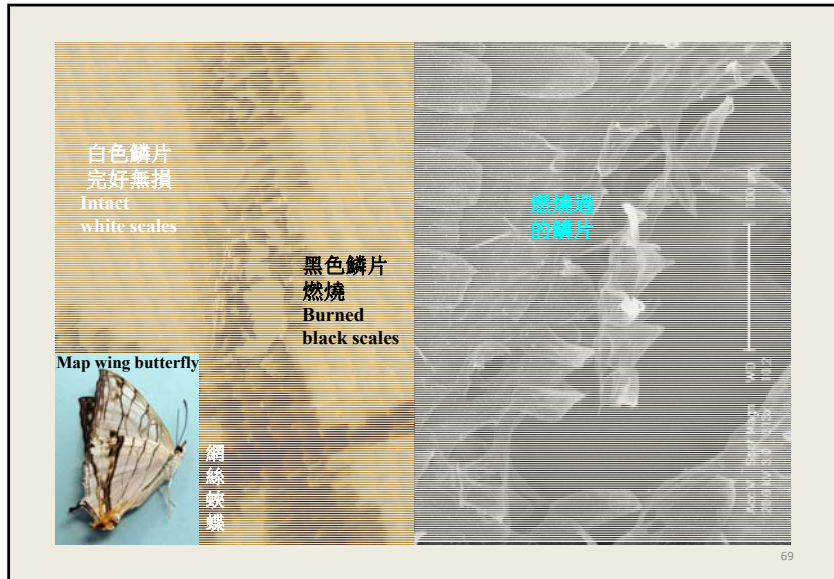
Flash ignition of a Paris peacock butterfly wing with a camera flash light

Canon 580EX flash unit

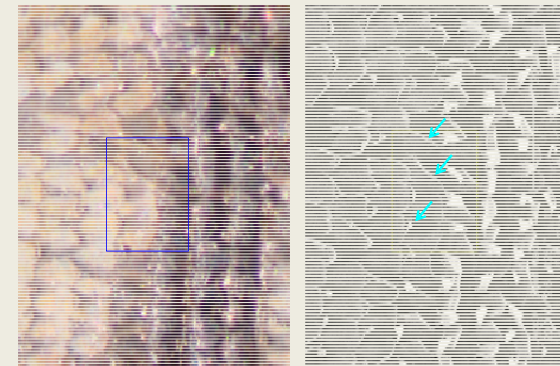
巴黎翠鳳蝶鱗片



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閃照鍍銀的白色鱗片, 鱗片燃燒 Flash ignition of silver coated white scales



表面等離子體激元
共振吸收
Surface plasmonic
resonant
absorption

取自 Zheng Zeng 2008, M. Phil Thesis, Department of Physics, HKUST

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展望未來納米世界 Future outlook of nanomaterials

納米探測器體積小, 可以很容易地到處存放, 在紙張和衣料裏面, 隨身衣物變成我們周圍環境的記錄儀.

- 各種各樣的極小探測器 extremely small detectors
- 超薄顯示器 superthin monitor
- 定時釋放少量藥物 timely release of medicine
- 防水, 防彈, 變色衣服
water-, bullet-proof, colour adjustable clothing
- 裝備了太陽能加熱器, 制冷器, 攝像機的衣服
clothes fitted with solar powered heater/cooler, camera
- 隱形斗篷 invisible cloaking
- 各種各樣意想不到的應用 other unexpected applications
 - 綠色光源

71

Gold Nanoparticles Could Transform Trees Into Street Lights

<http://inhabitat.com/gold-nanoparticles-could-transform-trees-into-street-lights/>

“意想不到”的綠色
光源

用金納米粒子激發樹
葉發光, 可以取代傳
統路燈???



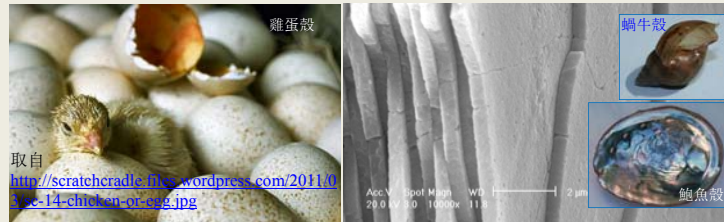
By implanting the gold nanoparticles into tree leaves, scientists in Taiwan were able to induce the chlorophyll in the leaves to produce a red emission. Stimulated by uv light, the gold nanoparticles produce a blue-violet fluorescence to trigger a red emission in the surrounding chlorophyll.

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動物和植物在數億年的進化過程中，發展了各種納米結構。大自然是傑出的納米結構工程師。

人類最近才開發納米技術，我們可以從身邊的動物和植物，學習到很多有用的納米結構設計理念。

Thank you for your attention



取自
<http://scratcheradlc.files.wordpress.com/2011/01/see-14-chicken-egg.jpg>

Nano platelets of calcite 碳酸鈣 納米薄片

73

Using nature to grow batteries, Angela Belcher

http://www.ted.com/talks/angela_belcher_using_nature_to_grow_batteries.html (10 minutes)


June 4, 2013 (<http://web.mit.edu/newsoffice/2013/belcher-wins-lemelson-mit-500k-award-0604.html>)

MIT professor Angela Belcher, one of the world's leading nanotechnology experts, has been named the recipient of this year's \$500,000 Lemelson-MIT Prize, which honors an outstanding inventor dedicated to improving the world through technological invention.

Belcher was scientifically motivated by the *shell of the abalone* (This particular snail would later become the focus of her PhD dissertation.) The abalone shell is comprised of 98% calcium carbonate (an inorganic compound) and 2% organic protein, a combination that makes the shell exceptionally strong. This principle – how marine life evolved to make such hard materials from its environment – led Belcher down her path of bio-inspired innovation. Today, her group focuses on coaxing biological materials to work with inorganic materials, such as electronics.

One of her recent inventions is a *lithium-ion battery powered by engineered viruses*. The batteries have the same energy capacity and power performance as state-of-the-art rechargeable batteries being considered to power plug-in hybrid cars, and they could also be used to power a range of personal electronic devices.

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納米及先進材料研發院有限公司
Nano and Advanced Materials Institute Limited

Application of Nanomaterials: Recent Product Developments and Future Perspectives

Dr. Connie Kwok
R & D Director, Bio & Healthcare Products
7 June 2013

EDB NSS Enriching Knowledge Series of the Physics Curriculum (2)
Atomic World - The Use of Nano Technology in our Daily Life and Nature

Confidential Materials

Company Mission

Nano and Advanced Materials Institute Ltd. (NAMI)



- Acting as the focal point for conducting **market-driven** R&D aimed at developing **innovative** products and processes from product **conceptualization to market** in the areas of **nanotechnology** and **advanced materials**



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About NAMI

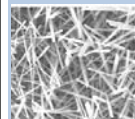
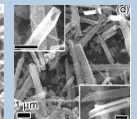
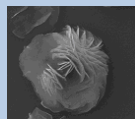
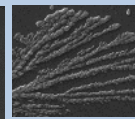
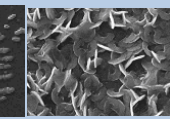
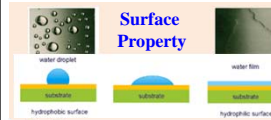
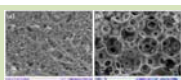

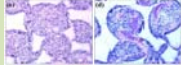
- Is an **independent R&D center** totally owned by HKUST; it is funded by the Hong Kong Government and industry
- Serve **Hong Kong and Mainland industries** in technology development and commercialization
- Connect fundamental research and commercial production by performing **applied research** and **pilot-scale testing**





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Nano Technology

- A rapid growing science of producing and utilizing nano-sized particles that measure in nanometers (1 nm = 10⁻⁹ meter).
- Nano particles can be observed only through Electron Microscope (e.g. TEM, SEM, ESEM).
- Emergence of novel and powerful **Morphology** and **Characteristics** when they reach down to the nano scale.

 Nanowire	 Nanotube	 Nanoflower	 Nanotree	 Nanoblade
 Surface Property		 Solid Nanospheres		 Porous Nanospheres
		 Cell response		



Confidential Materials

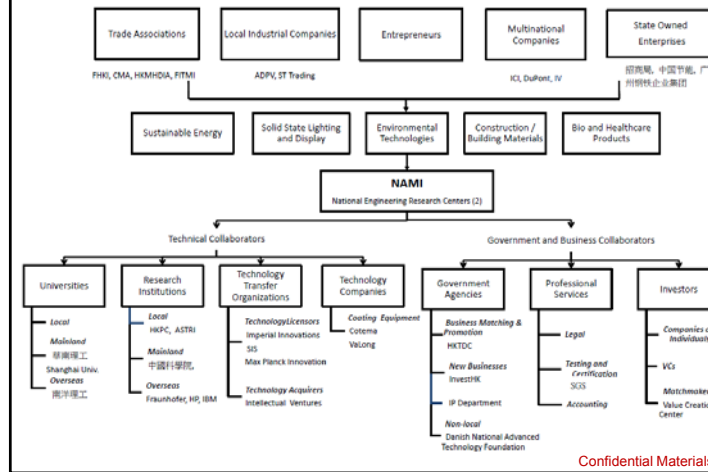
Different Types of Projects

- **Contract research projects** (solely funded by industry)
- **Sponsored projects** (funded by industry and NAMI)
- **Seed projects** (solely funded by NAMI)
- **During 2012-2013,**
 - A budget for R & D projects was over \$170 M
 - Industry funded around 40% of our R&D projects, a percentage that was the highest in the Hong Kong research centers.



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NAMI's Clients and Collaborators

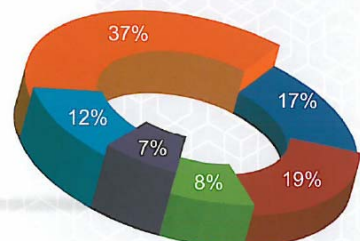


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NAMI's Projects (by number, March 2012)

Five Focused Market Sectors

- Sustainable Energy
- Display & Solid State Lighting
- Construction/ Building Materials
- Environmental Technologies
- Bio & Healthcare Products
- Others



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Lab and Office

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At HKSTP

- Existing Office (B16, 608-9) – 4,236 sq.ft.



- New Office (B15, 515-6) – 4,179 sq.ft.



At HKUST

- Existing Lab (B11, 301-7) – 10,608 sq.ft.



- New lab (B11, 308-9) – 3,547 sq.ft.



- Office space (Rm 3641-3649) – 3,746 sq.ft.



- Lab space: 1,888 sq.ft.



NAMI's Five Areas of Focus

Construction Materials Sustainable Energy
Environmental Technologies
Display & Solid State Lighting Bio & Healthcare Products

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Bio and Healthcare Products

- Healthcare Products and Diagnostic Devices
 - Nano-coating: antibacterial, bioactive, non-fouling, waterproof
 - Rapid high-throughput biochips
 - Diagnostic Reagent Kits
- Nanotechnology in Drug Delivery
 - Nano-particles for Pharmaceutical Formulations
 - Botanical Herbs in Transdermal Delivery
 - Cosmeceuticals in Skincare Products
- Biotechnology Products
 - Recombinant Technologies
 - Gene, Protein and Tissue Engineering

Examples in topics highlighted in green are to be discussed in this presentation

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NAMI's Areas of Focus

Construction Materials Sustainable Energy
Environmental Technologies
Display & Solid State Lighting Bio & Healthcare Products

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Healthcare Products and Diagnostic Devices

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(1) Antibacterial Coating with Nano Metal/Metal Oxide

nano coating on different surfaces

How does it work?

- 1) Penetration of metal ions through cell membrane.
- 2) Interaction of metal ions with cysteine [SH]-containing enzymes.
- 3) Enzyme inhibition leading to bacteria cell death.

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On site evaluation at a local hospital Proprietary coated and non-coated keyboards (from October 2012 – March 2013, 6 months)

According to keyboard #

Keyboard #	No. of bacteria colonies on No Coating > Coating	No. of bacteria colonies on Coating > or = No Coating
Keyboard 6	~28	~10
Keyboard 8	~20	~15
Keyboard 10	~10	~5

According to month

Month	No. of bacteria colonies on No Coating > Coating	No. of bacteria colonies on Coating > or = No Coating
October	~7	~1
November	~14	~8
December	~9	~5
January	~17	~8
February	~8	~5
March	~5	~3

*p value < 0.05**

- The trend continued to demonstrate that coated keys consistently had less bacteria compared with uncoated keys for 6 months with statistical significance.
- Data collection until 30 June 2013

Durable Antibacterial Coating for Keyboards used in Hospital Setting

FEATURES

- Kills 99% of bacteria within 1 hour (under experimental conditions).
- Being effective even after routine wiping with water, soap and 70% ethanol.
- Provides long-lasting, anti-bacterial effect.
- Gives transparent look.
- Being low cost.
- Uses simple coating process.
- Compliant to RoHS (Restriction of Hazardous Substances Directive).
- Compliant to SVHC (Substance of Very High Concern). Confidential Materials

Convenient Spraying & Low Temperature Curing Process

Obstetric and Gynecology Clinic- Consultation Room
Neonatal Intensive Care Unit (NICU)-Nursing Station
Intensive Care Unit (ICU)-Nursing Station
High Dependency Unit- Nursing Station
Pediatrics Ward- Nursing Station
Out-patient Clinic- Treatment Room

(2) Plasma Surface Treatment on Devices

- **Key advantages**
 - ✓ Ultrathin, pinhole-free, stable coating conforming to any shapes or forms
 - ✓ Surface can be fine tuned to give almost any chemical properties without affecting the bulk properties
 - ✓ Clean, green yet efficient coating process without toxic waste to worry about
- **Surface chemistries are critically important in medical and diagnostic Devices (other than physical dimensions)**
 - ✓ Well-known examples of hydrophobic vs. hydrophilic surfaces

Hydrophobic Surface: initial contact, anchoring, spreading, Protein unfolds and denatured

Hydrophilic Surface: initial contact, no anchoring, no binding, Protein stays intact

Dead fibroblasts Healthy fibroblasts

Ranella et al, Acta Biomaterialia, 2711 (2010).
Rabe et al, Advances in Colloid and Interface Science, 87 (2011). Confidential Materials

Plasma-Treated Microplates for Diagnostic Application

Bioactive Surface to Enhance Biologics Binding

- Achieved surface functionalization to favor HIV Ab binding in ELISA
 - Specific surface oxygen content %
 - Specific functional groups: Negative and positive ion fragments by ToF-SIMS

Untreated
NAMI Treated
Benchmark

m/z	Fragments
41	H-C≡C-O ⁻
42	H ₂ C=C=O ⁻
43	H ₂ C=CH-O ⁻
45	CH ₂ -CH ₂ -O ⁻

C₈H₇O⁻ m/z: 119

Negative ion fragments

Positive ion fragments

Chemical Structure	m/z
<chem>CHO+</chem>	29
<chem>C2H3O+</chem>	43
<chem>C2H5O+</chem>	55
<chem>C2H7O+</chem>	57
<chem>C2H9O+</chem>	107

Biomarker	XPS Elemental analysis		Biological binding for HIV	Biorecognition Sensitivity (IO, OI)
	Oxygen %	Silicon %		
Biomat-HB 17/3	2.00	0.00	Yes	1.192
Biomat-HB	2.00	0.00	Yes	1.056
Jet-Fil-AMB	0.31	0.17	NO	0.846
Jet-Fil-MB 17/3	0.31	0.17	NO	0.743
E14-7 A	2.40	0.00	YES	1.057
E14-15A	1.00	0.23	YES	1.124
E14-7 B	6.93	0.13	YES	1.043
E14-15 B	2.76	0.03	YES	1.110
E14-7C	1.74	0.23	YES	1.204
E14-15C	1.28	0.00	YES	1.083

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Multiplex Protein-Based LOC for Infectious Diseases

(Proof of Concept Study)

Multiplex NanoArrays

- To design coupling chemistries specific for biomarkers selected (sample, positive and negative controls included)
- To design and nanoprint spot panels for multiplex (n diseases) diagnostic kits. Each spots only required less than 20nL of antigen reagents, substantially saving costs and time of operations compared to traditional assays using μL of reagents

+

Potential Impact:
An LOC integrating automated microfluidic device for screening multiple diseases.

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(3) In vitro Diagnostic Tools

Multiplex, Rapid, Inexpensive LOCs

- Rapid, High-throughput, Low-cost *In Vitro* Diagnostic Devices
 - Protein-, DNA-, Cell Capture-based for:
 - Animal Health (Monitoring of farm animals' and pets' health)
 - Human Diseases (Detection of infectious diseases, early cancers)
 - Food Safety (Surveillance of toxic chemical additives)

DNA-based
(Hybridization)

Protein-based
(ELISA)

Cell Capture-based
(Anti-EpCAM for capturing CTCs)

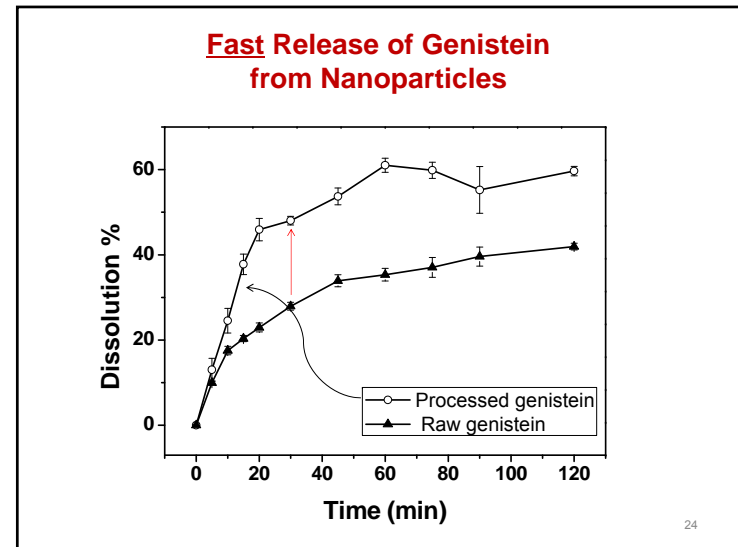
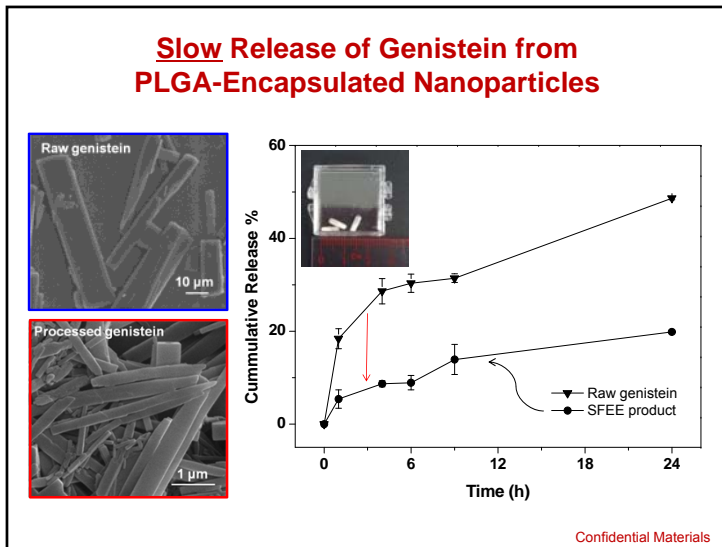
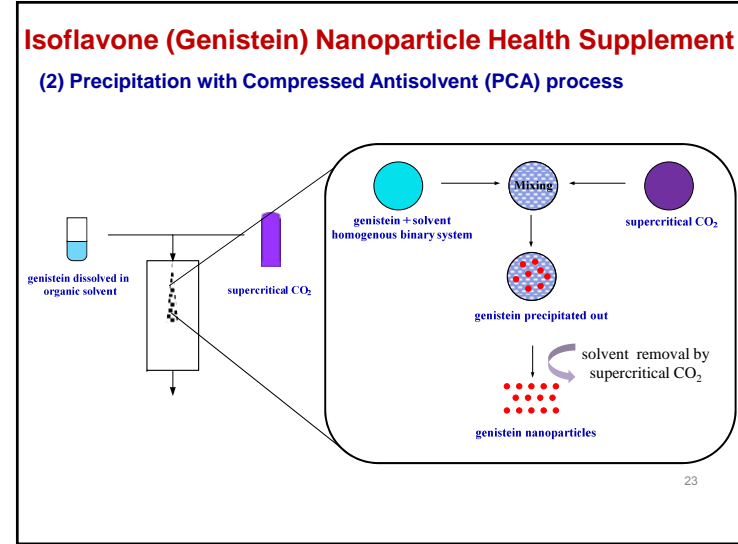
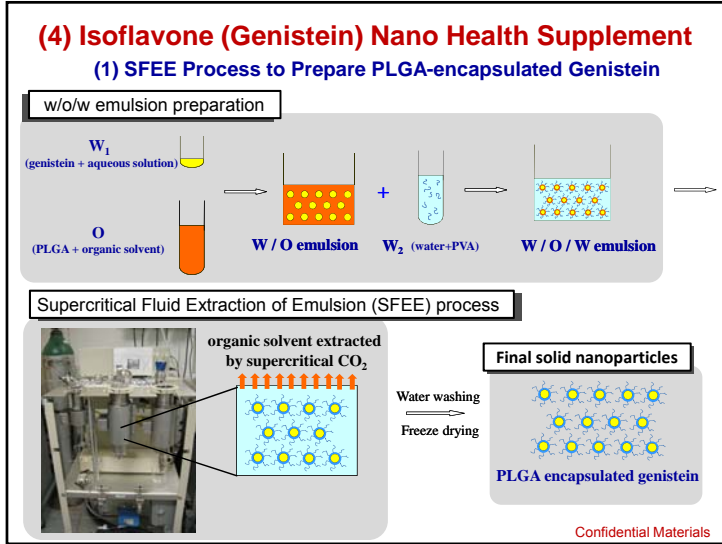
Wang et al. Angew. Chem. Int. Ed. 3084, (2011).

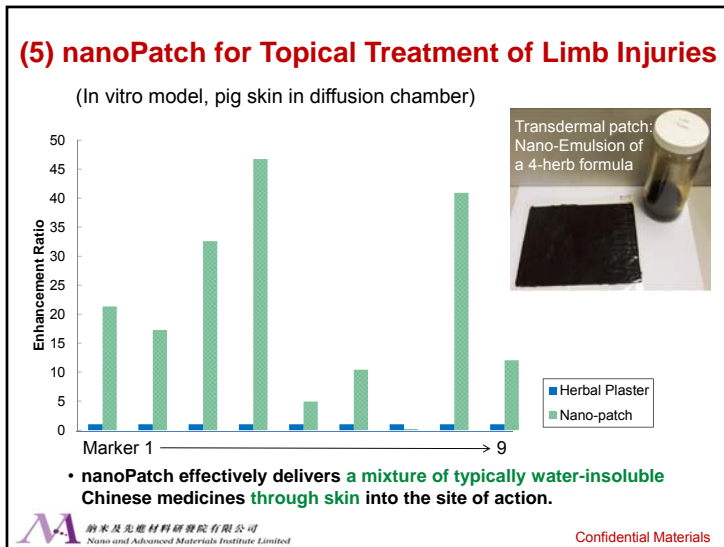
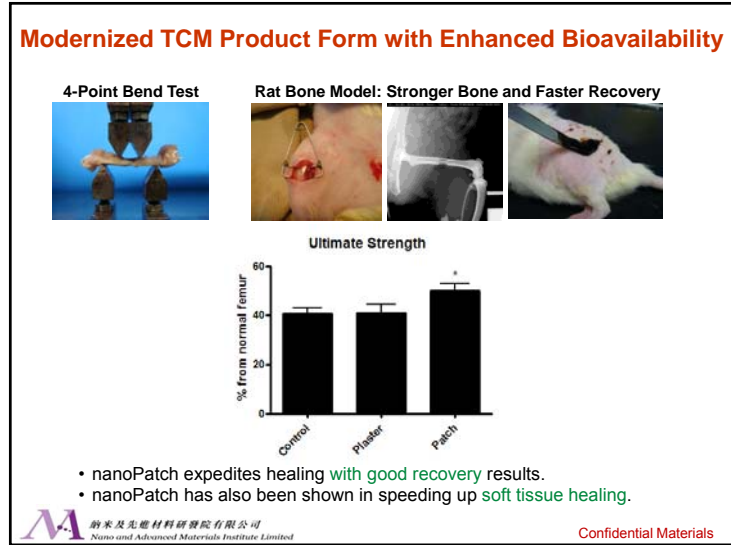
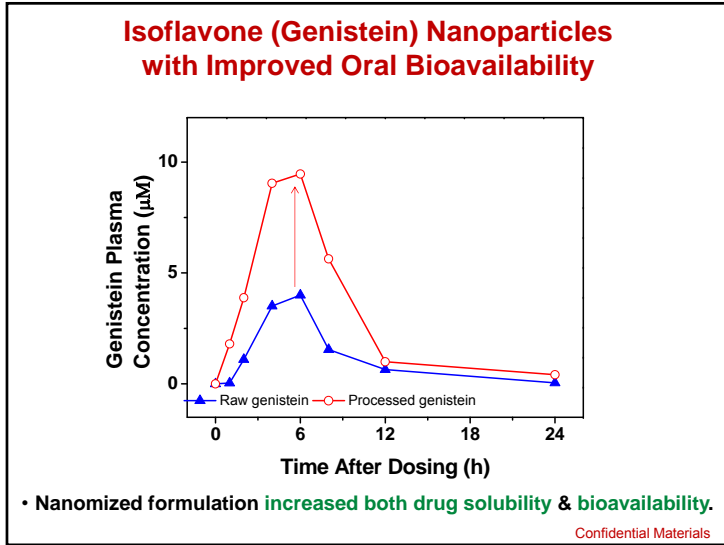
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Nanotechnology in Drug Delivery

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(6) Cosmeceuticals in Skincare Products

- Nano-encapsulation platform technologies to deliver various sizes & charges.
 - Small molecules (e.g. herbal medicines)
 - Midsize molecules (e.g. peptides)
 - Macromolecules (e.g. growth factor proteins, epidermal growth factor)

Preparation Method with EGF (6k Da)	Size (nm)	Distribution width (nm)	Zeta potential (mV)	Encapsulati on efficiency	pH value
Film-dispersion emulsion	29.1	27.1 - 36.1	-43.52 ± 0.61	16.8%	7
Reverse-phase evaporation emulsion	80.6	70.9 - 97.8	-37.23 ± 0.38	13.5%	7
Solid-in-oil emulsion	215.8	193.8 - 253.5	-30.76 ± 2.77	88.3%	6


The protein-loaded vesicular systems are hydrodynamically stable (about -30mV)

Solid-in-oil dispersion has the highest encapsulation efficiency among the three nanomization methods


Formulations are mild to skin

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NAMI's Five Areas of Focus



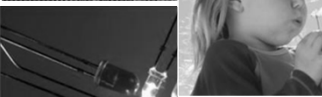
Construction Materials



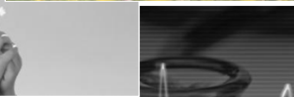
Sustainable Energy




Environment Technology



Display & Solid State Lighting

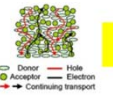



Bio & Healthcare Products


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OPV Technology at NAMI

OPV Materials, Structures, and Manufacturing Line Development




R2R Printing System



Flexible polymers PV bring novel applications

- Mobile phone
- Umbrella
- Tent
- Portable electronics
- Etc.

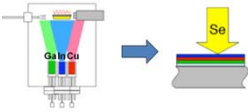
• R2R pilot line to bridge technology to volume production

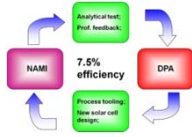
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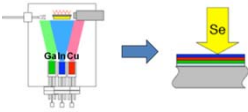
PhotoVoltaic (PV) Technology Development

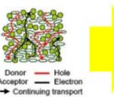
Thin Film amorphous-Si Development with Dupont Apollo (2nd generation)



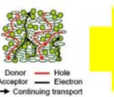



Thin Film CIGS Manufacturing Process Development (2nd generation)






OPV Materials, Structures, and Manufacturing Line Development (3rd generation)





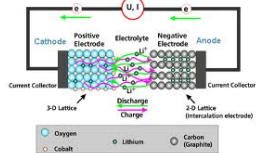
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• 2nd and 3rd Gen PV Technologies at NAMI

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Nano Materials/Technology for Battery Storage


Typical Li Ion Battery (LIB)



Nano Features	Improvement in Battery
Increased Electrode Surface Area	High Power Density, Short Charging Time, Reduced Weight
Nano Shape/Structure	Reduced Electrode Degradation, Improved Safety
Nano Encapsulation	Improved Stability and Safety
Separation of Electrode/Electrolyte	Increased Shelf Life

NAMI Direction in Battery Development:

- Low Cost Advanced Materials & Manufacturing Technology
- High Capability, High Voltage, Safe Anode Materials

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NAMI's Five Areas of Focus

Construction Materials

Sustainable Energy

Environmental Technologies

Display & Solid State Lighting

Bio & Healthcare Products

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Materials Development for Printed Electronics

Metal NW & CNT Synthesis to Printable Transparent Conductor

Nanomaterial Inks + **Scalable Printing / Coating Techniques** = **Transparent Conductive Film**

- Transparent conductive films can be obtained from nanomaterial inks with scalable coating techniques

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Why Printed Electronics?

- 6+ Patterning Steps vs. 2 Steps Printing/Cure

Conventional Process Flow (Lithography)

Source: Tech-On

Printing Process Flow (Additive Deposition)

Printed Electronics

- Simplified Process Flow
- Significant Cost Saving
- Lower Barrier to Entry to Market

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Printed Temperature Sensors

Opportunity for Low Cost Temperature Sensor integrated with RFID for Controlled Temperature Storage and Transportation in Cold Chain: Food, Pharmaceuticals, & Consumer Electronics.

TurboTag wireless temperature monitoring and data logging **THINFLIM** RF sensor and tag for food storage

Biggest Opportunity in Temperature Sensors is Cost Reduction:

- Current sensors in market typically cost **US\$15-25 per unit**
- Printed devices will cost **< 10% of current sensors!**
- Printing Manufacturing Techniques can easily scale sensor and array sizes for different applications

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LED Thermal Management

Heat Dissipation Path

- Unlike incandescent and fluorescent lamps, LED lifetime is significantly impacted by high operating temperature
- LED lifetime estimated to decrease by half every 10°C increase in operating temperature
- Nano materials can enhance thermal conductivity in two interfaces – Die to Substrate and Substrate to Heat Sink

* K.Zhang et al., Nanotechnology, 19, No. 215706

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NAMI's Five Areas of Focus

- Construction Materials
- Sustainable Energy
- Environmental Technologies
- Display & Solid State Lighting
- Bio & Healthcare Products

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Key Nano Technologies in LED Applications

Metallic Nano Filler to Improve Conductivity

- Metallic Nano Fillers to improve thermal and electrical conductivity
- Thermal Conductivity expected to increase from <10 to >40 W/mK
- Applicable to other Electronics Products

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Self Cleaning & Antibacterial Properties of Photocatalytic Coatings

(A) Mineralization of organic pollutant on a photocatalytic coating

(B) Self-cleaning property of photocatalytic coating

(C) Bacteria killed over photocatalytic coating

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TiO₂ Photocatalytic Applications



Air purification and disinfection system



High-end water purification and disinfection system



Clothing with TiO₂



Self-cleaning tiles



Anti-fogging mirrors



TiO₂/dye-sensitized solar cells



Hydrogen generation

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Nano Materials for Functional Coatings



Nano Coating for Wooden Surfaces
Nano materials functional coating that is low cost and environmentally friendly:

- Replace VOC solvent based processes that are not environmentally friendly
- Green process that provides anti-scratch, water proof, and acid & base resistance properties



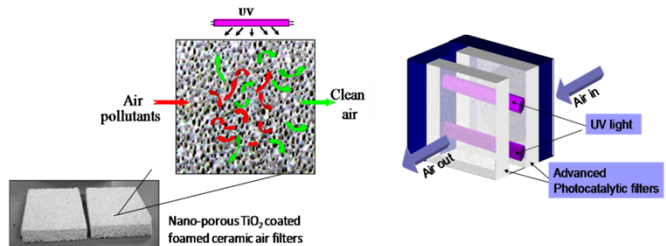
Mirror like Coating
Nano materials functional coating that is low cost and environmentally friendly:

- Replace expensive ECP process on metal surfaces that uses toxic and non green chemicals
- Provide mirror like reflectivity, good adhesion, anti-scratch & anti-corrosion properties on metal or plastic surfaces

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Advanced Nano-Porous TiO₂ Photocatalytic Air Filter



- Nano-porous structured TiO₂ coating increase the photocatalytic efficiency in air purification
- Foamed ceramic filters with **tortuous pore structures enhance turbulence and mixing**
- The open-porous and reticulate structure offers the catalytic system **excellent gas-dynamic properties & sufficient contact** between the gaseous reactants with the surface of the catalysts

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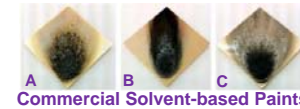
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Multifunctional Environmental Friendly Paint

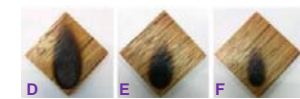
Nanosol-based Paint with Functional Additives

Benefits:

- Anti-Scratch
- Low VOC
- Non-Combustible
- Water Resistance
- Household Chemical Resistance
- Anti-Microbial



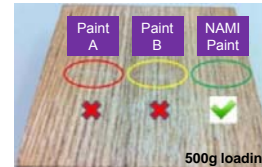
Commercial Solvent-based Paints



Commercial Water-based Paints



NAMI Paint Non-Combustible



Anti-Scratch

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VOC Regulation Body	Max. VOC content (g/L)
EU Directive 2004/42/CE	130 (Water-based) 300 (Solvent-based)
Hong Kong	550
China	250

NAMI Paint: 2.4 g/L – 23 g/L
Extremely Low VOC Content

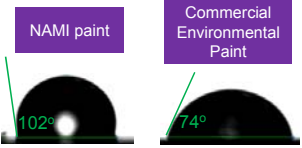
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Multifunctional Environmental Friendly Paint

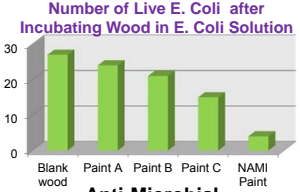
Nanosol based Paint with Functional Additives

Benefits:

- Anti-Scratch
- Low VOC
- Non-Combustible
- High Water Resistance
- Household Chemical Resistance
- Anti-Microbial

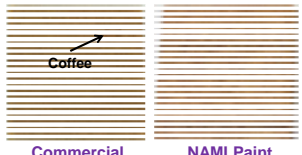


High Water Resistance



Sample	Number of Live E. Coli
Blank wood	~28
Paint A	~25
Paint B	~22
Paint C	~18
NAMI Paint	~5

Anti-Microbial



Household Chemical Resistance

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MLC Samples with Full Stack Composite Coating



- Environmentally Friendly Materials and Coating Technology
- Comparable Appearance and Properties to EP samples

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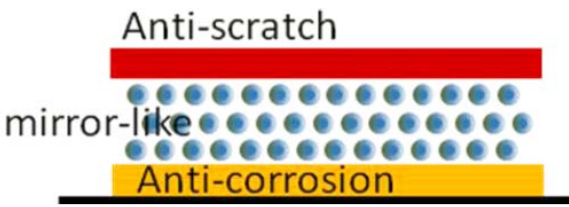
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Composite Mirror Like Coating

Environmentally Friendly Materials & Coating Processes

Mechanism: 3 functional coating layers to replace the electroplating treatment

- 1) Bottom coating: anti-corrosive function;
- 2) Middle coating: decorative function;
- 3) Surface coating: anti-scratch function.




- Coatings fabricated from common widely available materials
- IP in formulation and fabrication method/procedure

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NAMI's Areas of Focus



- Construction Materials
- Sustainable Energy
- Environmental Technologies
- Display & Solid State Lighting
- Bio & Healthcare Products

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NAMI R&D in Building Materials

Opportunities in Smart & Sustainable Buildings

- Hot & Humid Climate in highly populated Hong Kong provides challenging opportunities in Building Materials Development

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Maintenance of Building Materials

Preventive Self Healing Concrete

Self Healing Concrete Mechanism

- Silicate microcapsules incorporated in concrete
- Cracks release silicate healing agent
- C-S-H (Calcium Silicate Hydrate) formed to "glue" the concrete

Cracks of 100µm was "repaired" after 10 days

- Self Healing Concrete extends maintenance schedule and increases service life for concrete

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Energy Conservation Building Materials

Thermal Insulating Cementitious Building Materials

Under constant heat flux, Indoor Temp could be reduced if:

- Increase the wall thickness
→ Not practical
- Decrease the thermal conductivity of the wall panel construction materials
→ Research target

- Develop a structural lightweight concrete (>30MPa) with satisfactory thermal insulation property
- Develop a lightweight ductile Fiber Reinforced Cementitious Composites (FRCC) with high water/chemical penetration resistance to provide sufficient durability against steel corrosion

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NAMI's Five Areas of Focus

Construction Materials

Sustainable Energy

Environmental Technologies

Display & Solid State Lighting

Bio & Healthcare Products

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The screenshot shows the NAMI website interface. At the top, there is a navigation menu with links for 'Call for Proposals', 'Contact Us', 'Login / Sign Up', and '繁體 | 简体'. Below the menu, there are tabs for 'R&D Focus Areas', 'Ready-To-Market Technologies', 'R&D Funding', and 'News & Events'. The main content area features a large banner for 'Commercialization' with the text: 'NAMI facilitates successful collaboration to transform scientific advancements into marketable and high value-added products.' To the right of the banner is a section for 'Bio & Healthcare Products'. Below the banner is a calendar for June 2013, with the current day being June 5th. To the right of the calendar is a news article titled 'Nanotechnology & Advanced ...' dated 28th June 2013, with the text: 'Innovative technologies not only turn ideas into marketable products, but also lead to improved performance and reliability of existing products and processes. This can be exemplified by the enhanced functional capabilities of coating materials in ...Read More'. At the bottom of the page, there is a footer with the same navigation menu as the top.

For more information, please visit <http://www.nami.org.hk/>

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