



七大光电子产业介绍

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刘文是国内外知名的光电子器件专家，他1992-1998年就曾任原邮电部固体器件研究所总工程师；1992年开始获得国务院特殊津贴；2003~2011年任光迅科技公司总工程师，在2008年8月获得中国证监会正式批准在深圳中小企业版上市（深市代码002281）。是国内第一家通信光电子器件上市企业。2005年获国务院颁发的华人华侨专业人士“杰出创业奖”，2006年3月他受武汉邮科院委派，兼职参加华中科技大学武汉光电国家实验室建设，后受聘为教育部“长江学者奖励计划”特聘教授、博士生导师；刘文已获美国发明专利授权10项、中国专利授权80余项。

刘文1998~2000曾经在加拿大北方电讯（NORTEL）公司工作，期间曾经获得北方电讯总裁奖。2013年调入中国科技大学工作。现任光学与光学工程系光电子科学与技术省重点实验室主任，还兼任先进技术研究院副总工程师。

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光电子研究与产业概况

An overview of optoelectronics R&D and Industries

光电子技术涉及七大领域：包括太阳能光伏、显示、图像探测、LED、激光与激光应用、光纤通信、红外与光传感等产业。总的产业规模不亚于微电子。



- 光伏产业 (Photovoltaic Industry)
- LED产业 (LED Industry)
- 光电显示 (Optoelectronics Display)
- 激光与激光应用 (Laser and the applications)
- 图像探测 (Imaging Detection), CCD 和 CMOS 成像芯片
- 红外探测、传感 (Infrared detector and Sensors)
- 光纤通信产业 (Fiber optical Communication)



全球光电生态系统规模

2018年全球GDP实现了6.9%的健康增长，从2017年的80.2万亿美元增长至85.8万亿美元，其中有一半的贡献来自世界上的两大经济体——美国（20.5万亿美元，比2017年增长5.4%）和中国（13.6万亿美元，比2017年增长10%）。

那么在大约86万亿美元的全球GDP中，光电行业贡献了多少比例呢？2018年全球光电产品与服务的总收入约为7~12万亿美元，大约占全球GDP的13%。由此可见，光电行业在全球经济中占据着不容小窥的地位。

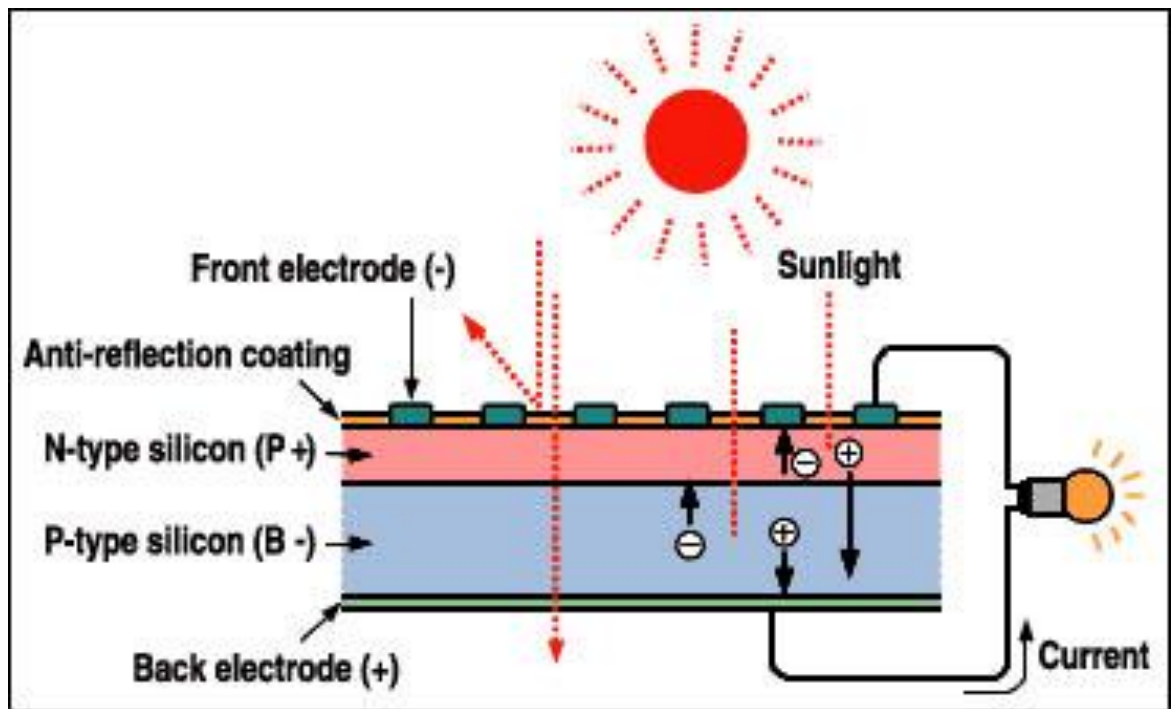


太阳能光伏产业发展概况

Solar Photovoltaic Industry



Power generation principle



光伏效应的基础

The basis of photovoltaic effect

The sun shines on the semiconductor p-n junction, forming a new hole by - electron pairs. Under the action of the p-n junction electric field, the holes flow from the n region to the p region, and the electrons flow from the p region to the n region, and the current is formed after turning on the circuit. 太阳光照在半导体p-n结上，形成新的空穴由-电子对。在p-n结电场的作用下，空穴由n区流向p区，电子由p区流向n区，接通电路后就形成电流。



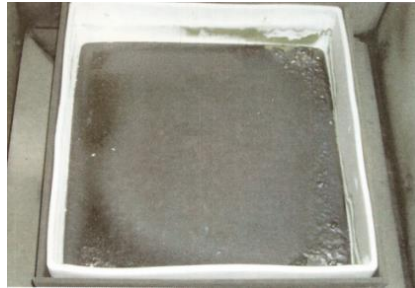
Solar cell material types

太阳能电池种类材料

- 单晶硅
Silicon Crystal

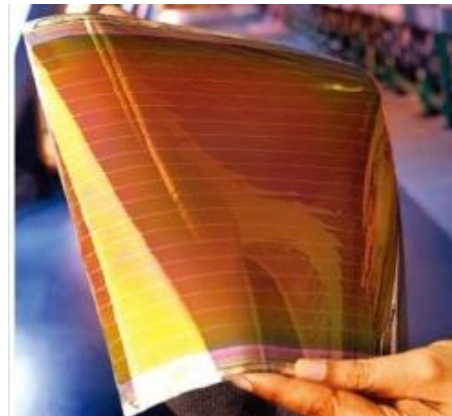


- 多晶硅
PolySilicon

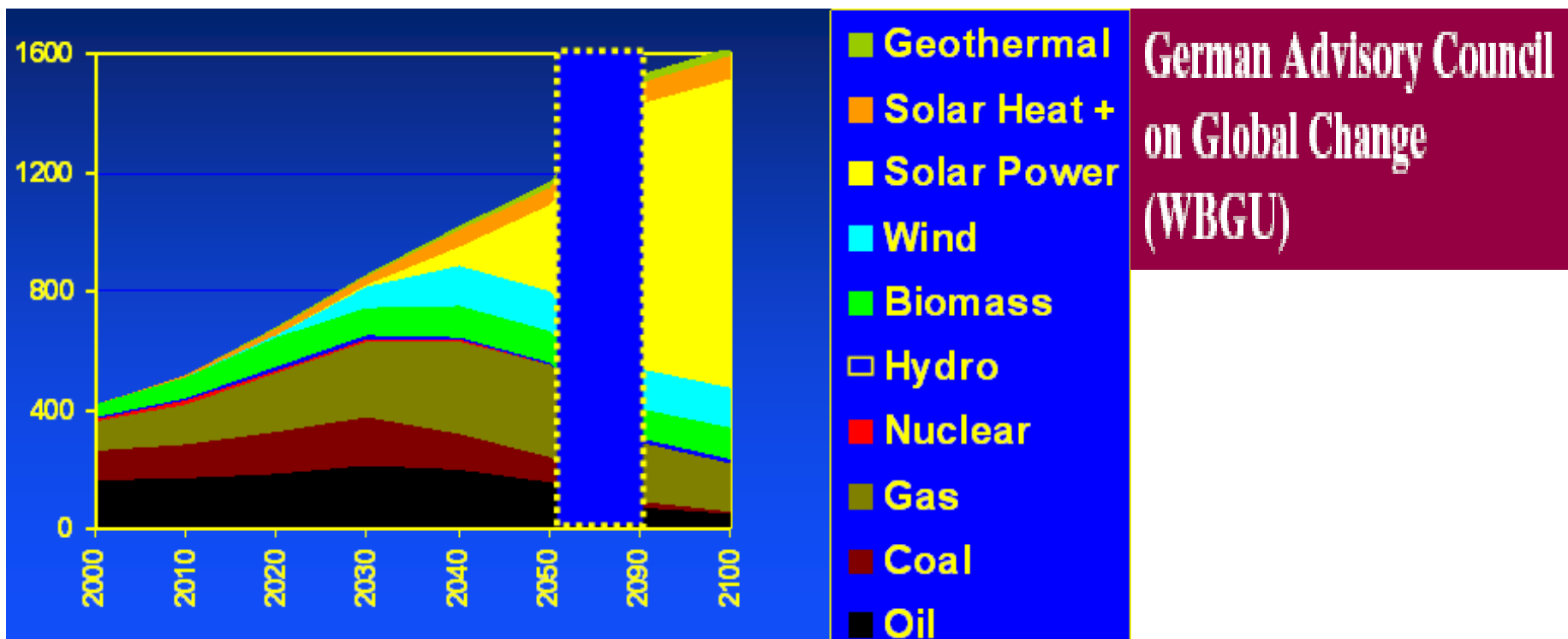


- 薄膜太阳能电池

- a) 碲化镉薄膜太阳电池
- b) 硫化镉太阳能电池
- c) 砷化镓太阳能电池
- d) 铜铟硒太阳能电池
- e) 硫化铜太阳能电池



Solar energy eventually will be the main source of energy to meet human needs 太阳能最终将是满足人类需求的主要能源

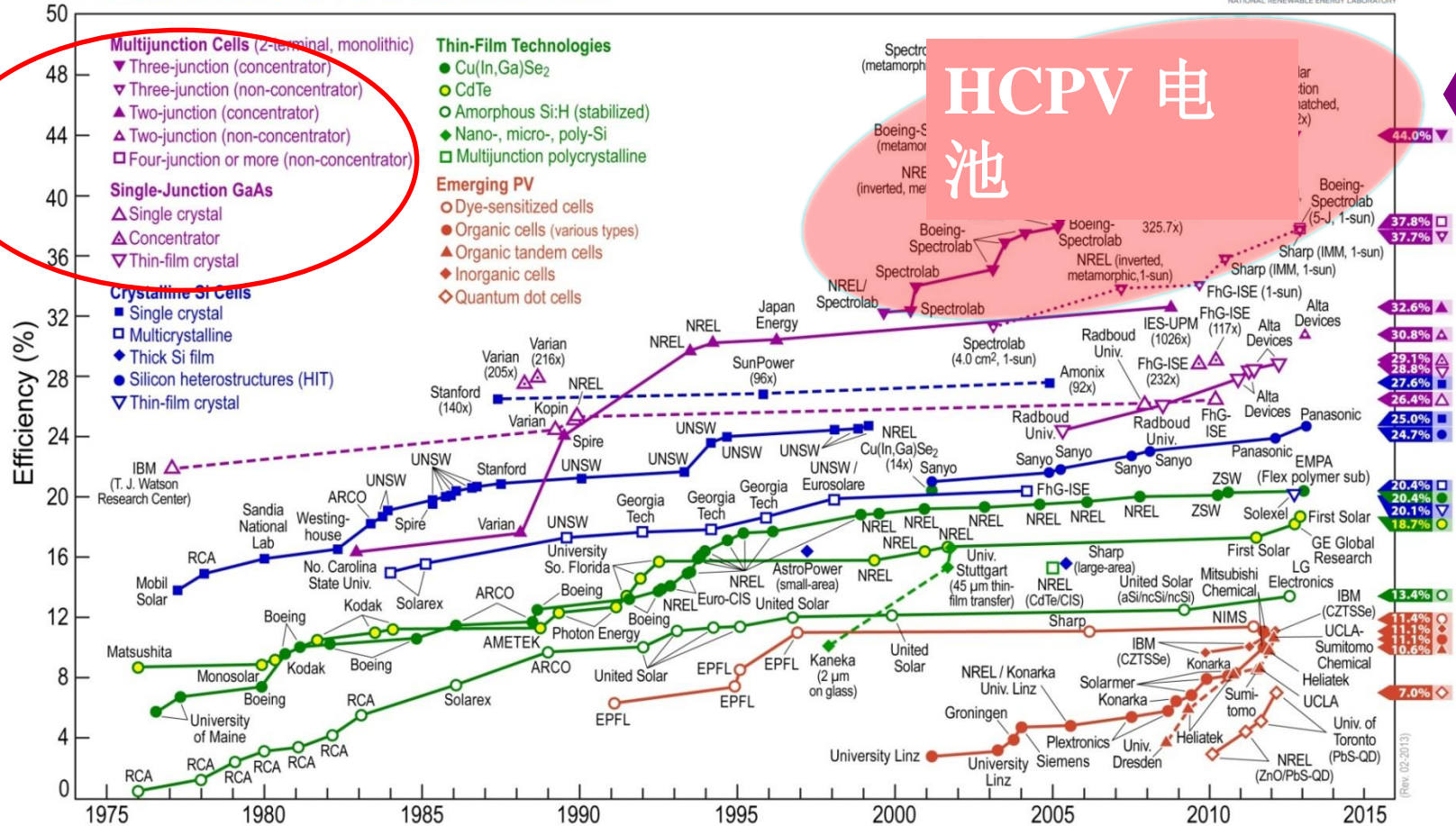


太阳能是人类目前已知的、绿色的、能满足人类能源需求的最佳选择。从可用总量上看，水能、风能、潮汐能都不能满足人类长远需求，而地球每天接收的太阳能相当于全球一年所消耗总能量的200倍，如此巨大的能量足以满足人类需求。

各种太阳能电池研究进展情况

2013-1

Best Research-Cell Efficiencies

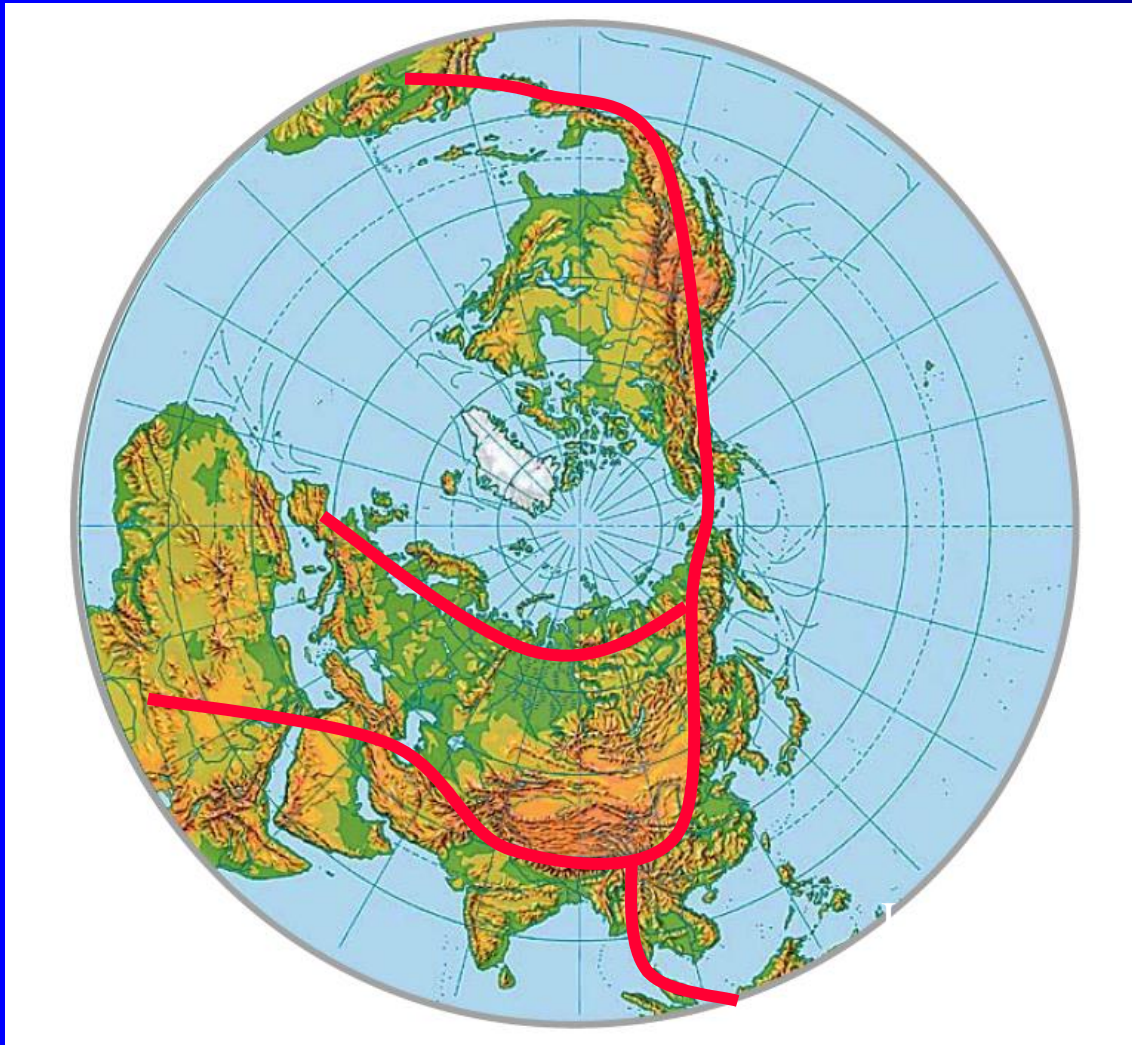


44.0%

HCPV 电
池

(Rev. 02-2013)

马丁·格林教授的设想：跨洋高压电缆



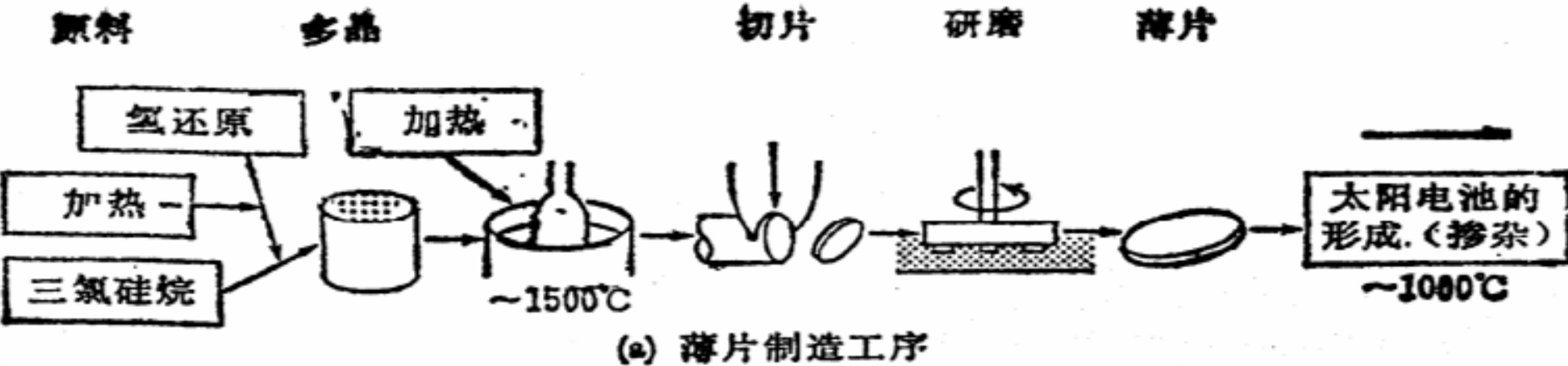
白天欧亚大陆发电，往美洲送电；
夜晚美洲大陆往中国、日本送电。



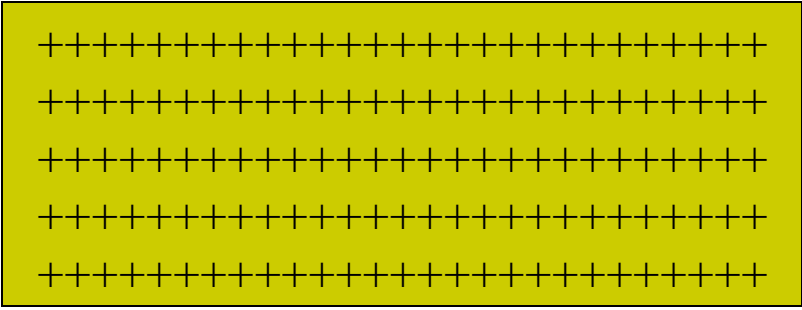


太阳能电池工艺流程Solar photovoltaic cell processing

单晶硅的制作 (To obtain Single Crystal Silicon)



单晶硅的工艺流程最终得到一种富含电子的P型硅片:



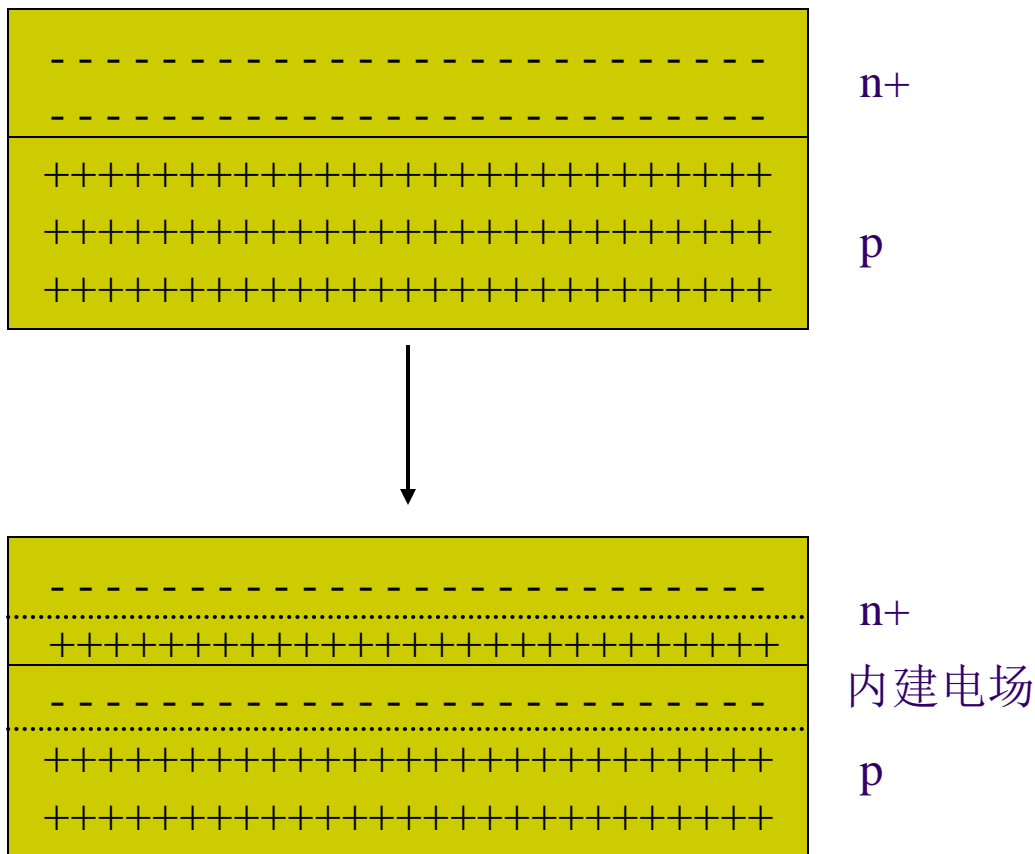
p type



太阳能电池工艺流程 Solar photovoltaics cell processing

PN结的形成 (To form the PN junction)

在P型硅片上表面利用气相扩散，涂敷扩散和离子移植技术形成一种n+反型层，进而构成PN结：

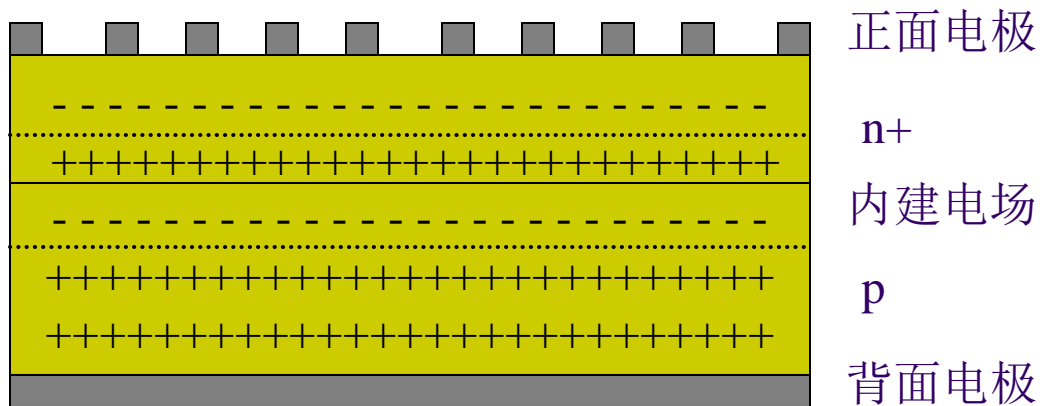




太阳能电池工艺流程Solar photovoltaic cell processing

电极的制作 (to manufacture the electrodes)

在完成PN结器件之后进而做正、背面电极：

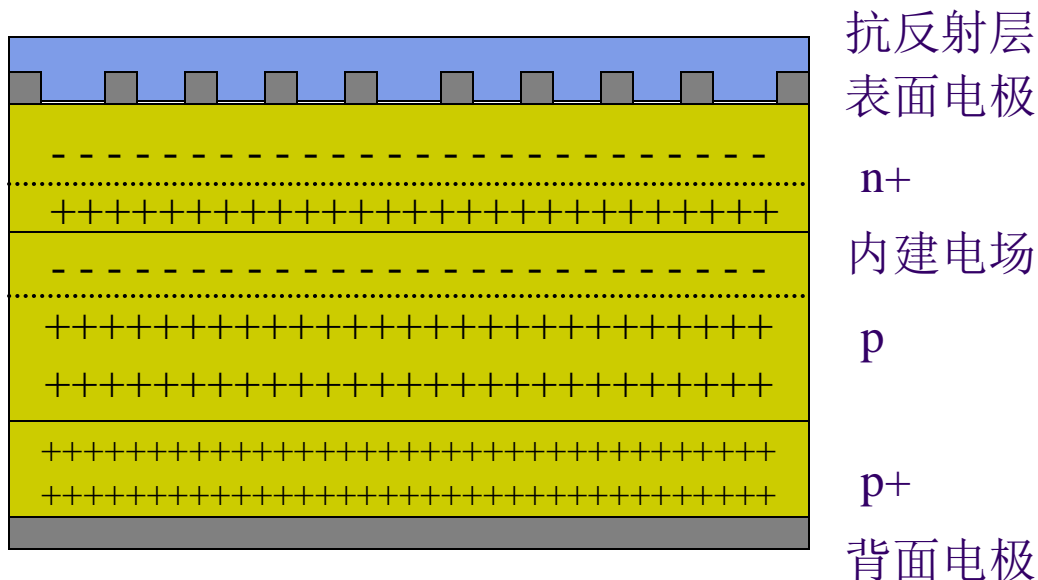




太阳能电池工艺流程Solar photovoltaic cell processing

高效率硅太阳能电池的工艺之势垒增强

在背电极与p基地之间加做一层p+高参杂层以形成一高低势垒，其与上面的n+p结势垒方向一致，从而提高了电路的开路电压，同时，减少背表面的复合作用：

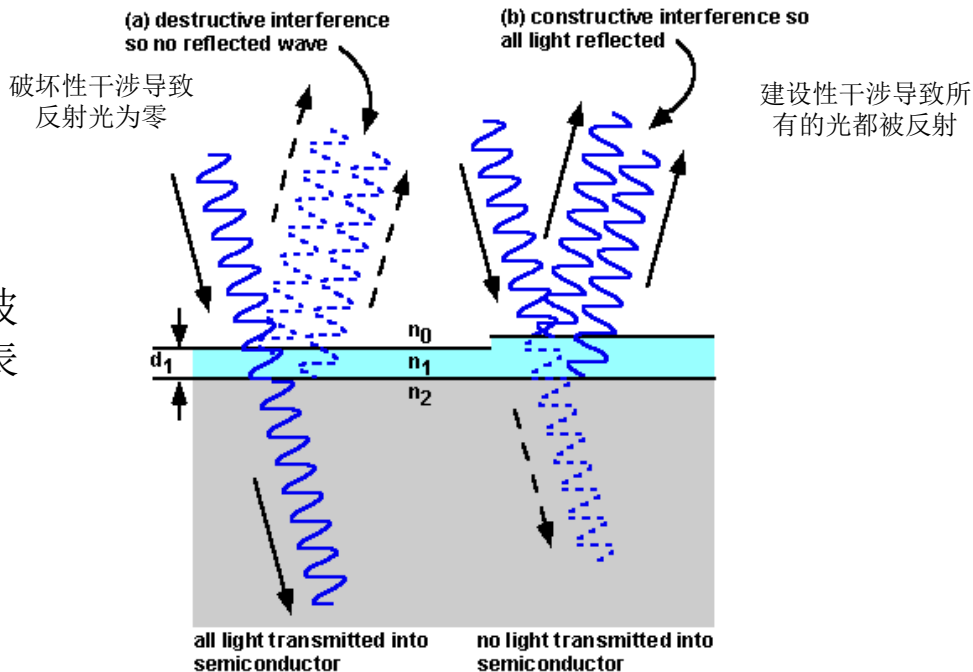




减反射膜 Antireflective film

The antireflective film on the solar cell is similar to the film on other optics (such as a camera lens). They contain a thin layer of dielectric material, the thickness of the film specially designed, light interference between the film effect, to avoid the surface as in the semiconductor as reflected. These avoidance of reflected light and other light destructive interference, resulting in reflection of the battery light intensity is zero. In addition to the anti-reflective film 铺在太阳能电池上的减反射膜与在其他光学器件（如相机镜头）上的膜相似。它们包含了一层很薄的介电材料层，膜的厚度经过特殊设计，光在膜间发生干涉效应，避免了像在半导体表面那样被反射出去。这些避免被反射出去的光与其它光发生破坏性干扰，导致被反射出电池的光强为零。

使用厚度为四分之一波长的减反射膜来减少表面反射



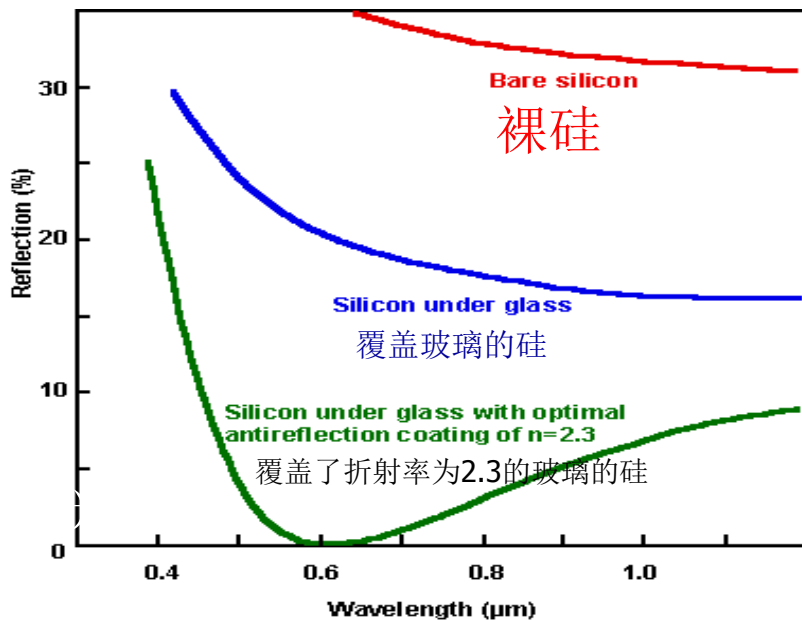


减反射膜 Antireflective film

减反射膜的厚度经过特殊设计，刚好为入射光的波长的四分之一。计算过程如下，对于折射率为 n_1 薄膜材料，入射光波长为 λ_0 ，则使反射最小化的薄膜厚度为 d_1 ：
$$d_1 = \lambda_0 / 4 n_1$$

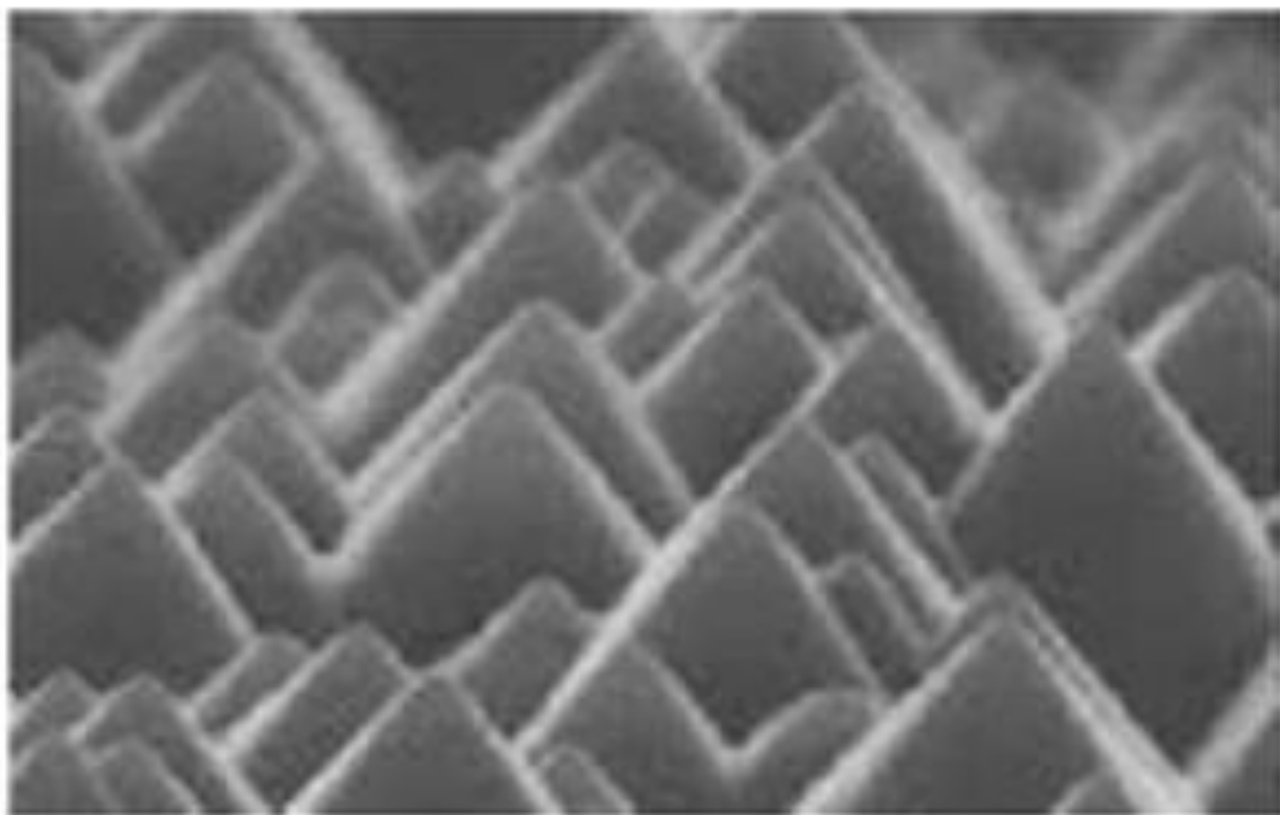
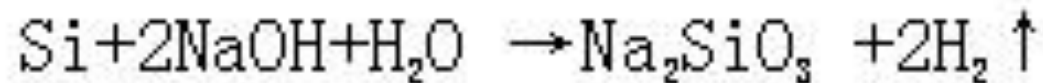
如果减反射膜的折射率为膜两边的材料的折射率的几何平均数，反射将被进一步降低。即 $n_1 = \sqrt{n_0 n_2}$

尽管，通过上面的公式，选用相应厚度、折射率膜和相应波长的光，能使反射的光减少到零，但是每一种厚度和折射率只能对应一种波长的光。在光伏应用中，人们设计薄膜的厚度和反射率，以使波长为 $0.6\mu\text{m}$ 的光的反射率达到最小。因为这个波长的能量最接近太阳光谱能量的峰值



如果镀上多层减反射膜，能减少反射率的光谱范围将非常宽。但是，对于多数商业太阳能电池来说，这样的成本通常太高。

制绒工艺的化学反应式与碱制绒硅片表面外貌





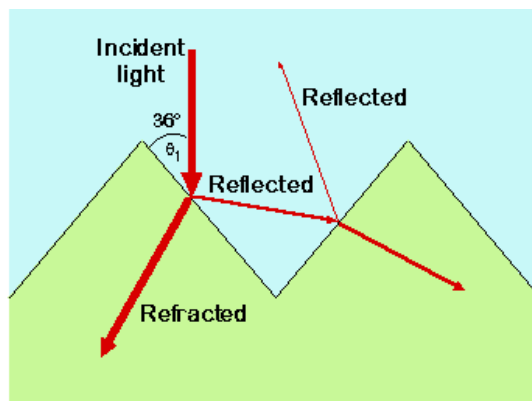
光陷阱 Optical trap

对上面的折射定律公式进行调整，则可计算光在电池入射的角度（即折射角）：

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin \theta_1\right)$$

对于经过表面制绒的单晶硅太阳能电池，由于晶体表面的存在而使得角度 θ_1 等于 36° ，如下图所示

光在经制绒的太阳能电池上的反射和入射。



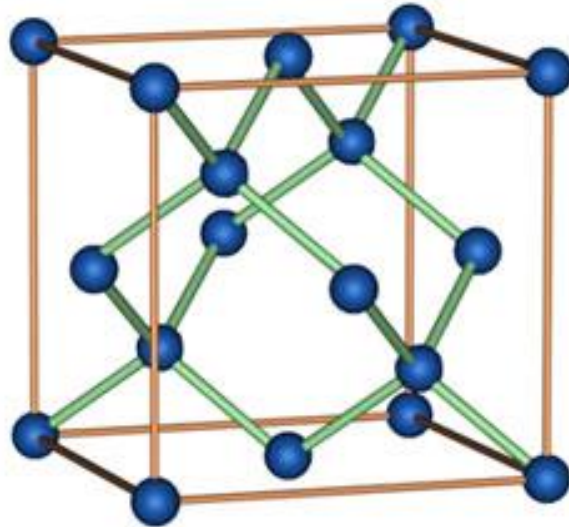
如果光线从折射率大的介质入射到折射率小的介质，将有可能发生全反射。此时的入射角为临界角，在上面的方程中，设 θ_2 为 0 ，得：

$$\theta_1 = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

利用全内反射，可以把光困在电池内面，是穿入电池的光成倍增加，因此厚度很薄的电池也能拥有很长的光路径长度。

各向异性碱腐蚀 Anisotropy alkali etch

- 对于单晶硅而言，选择择优化学腐蚀剂，就可以在硅片表面形成金字塔结构，称为绒面结构，又称表面织构化。对于（100）的p型直拉硅片，最常用的是各向异性碱腐蚀，因为在硅晶体中，（111）面是原子最密排面，腐蚀速率最慢，所以腐蚀后4个与晶体硅（100）面相交的（111）面构成了金字塔结构。如下图所示，为单晶硅制绒后的SEM图，高 $10\ \mu\text{m}$ 的峰时方形底面金字塔的顶。





尚德制备流程

P型单晶硅99.999%

要求并不高，
但是原材料国内比较稀缺

长绒面 (表面结构-V形槽, 增加光吸收率)

化学腐蚀

利用单晶硅的各项异性

扩散制结

气相扩散POCl₃

在P型Si上扩散生长N型半导体厚0.3~0.5um

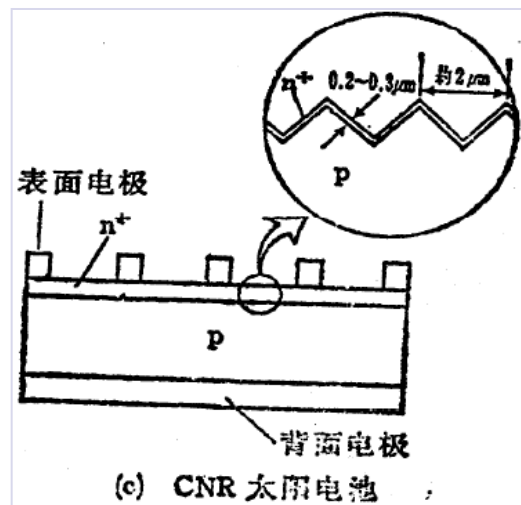
由于重掺杂效应和晶格缺陷

化学腐蚀

剩下0.1~0.2um厚度



2006 Richest man in China





2017 Commercial crystal silicon panel power generation capacity 2017商用晶硅电池板发电能力





R&D of n - type back - gate electrode photovoltaic cells n型背栅电极光伏电池的开发

IBC (Interdigitated back contact) battery initially mainly used in the condenser system, Battery selection n-type substrate material, before and after the surface are covered with a layer of thermal oxide film to reduce the surface composite. Using the photolithography technique, phosphorus and boron are locally diffused on the back of the battery to form P-zone, N-zone, and P + region, n + region located above. The P + and N + regions formed by the re-expansion can effectively eliminate the voltage saturation effect under high converging conditions.

IBC电池选用n型衬底材料，前后表面均覆盖一层热氧化膜，以降低表面复合。利用光刻技术，在电池背面分别进行磷、硼局部扩散，形成有指状交叉排列的P区、N区，以及位于其上方的P+区、n+区。重扩形成的P+和N+区可有效消除高聚光条件下的电压饱和效应



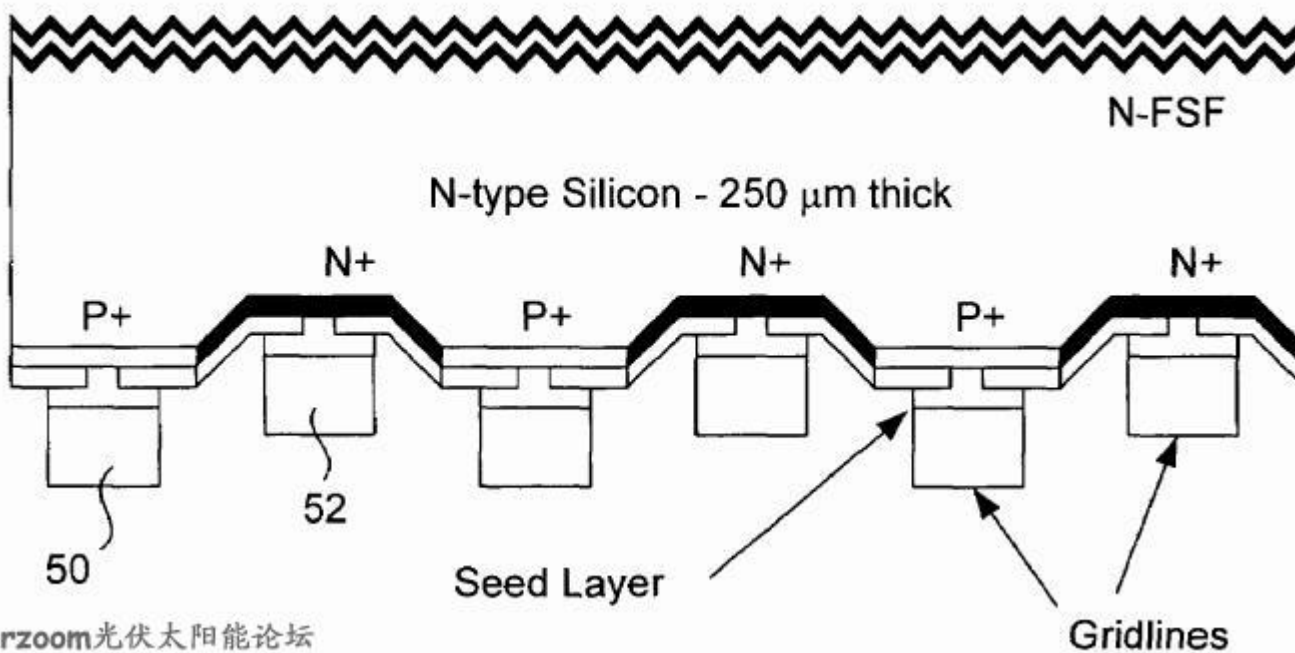
R&D of n - type back - gate electrode photovoltaic cells n型背栅电极光伏电池的开发

In addition, the coverage area of the P + and N + region contact electrodes almost reaches 1/2 of the back surface, greatly reducing the series resistance. The core issue of the IBC battery is how to prepare the P and N regions with better quality and interdigitated intervals on the back of the battery. In order to avoid the complex operation caused by the lithography process, a layer of boron-containing interdigitated diffusion masking layer can be printed on the back of the battery. The boron on the masking layer is diffused and enters the N-type substrate to form the P + region, The area of the film, after the formation of phosphorus diffusion N + area. Through the screen printing technology to determine the back diffusion area has become the focus of the current research.此外，P+和N+区接触电极的覆盖面积几乎达到了背表面的1/2，大大降低了串联电阻。IBC电池的核心问题是如何在电池背面制备出质量较好、呈叉指状间隔排列的P区和N区。为避免光刻工艺所带来的复杂操作，可在电池背面印刷一层含硼的叉指状扩散掩蔽层，掩蔽层上的硼经扩散后进入N型衬底形成P+区，而未印刷掩膜层的区域，经磷扩散后形成N+区。通过丝网印刷技术来确定背面扩散区域成为目前研究的热点。



R&D of n - type back - gate electrode photovoltaic cells

n型背栅电极光伏电池的开发

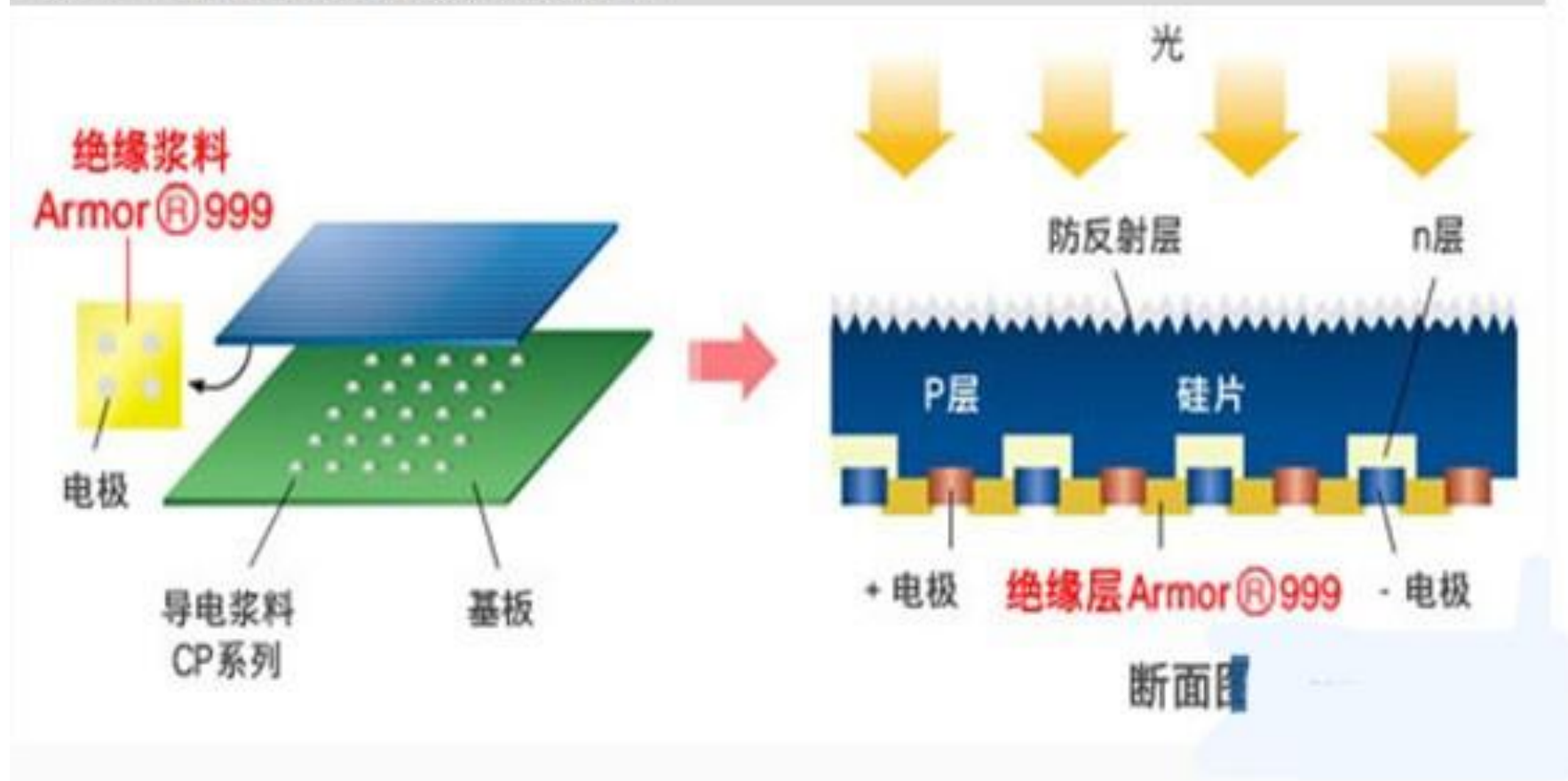




R&D of n - type back - gate electrode photovoltaic cells

n型背栅电极光伏电池的开发

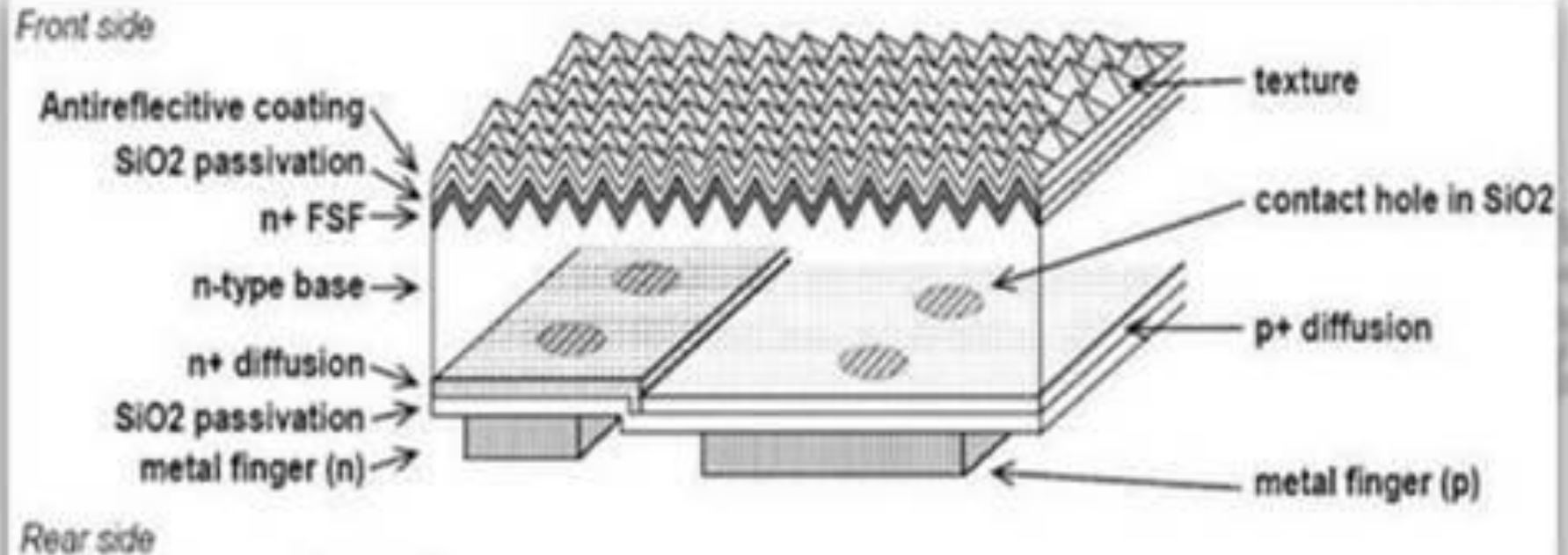
IBC/MWT 背接触电池电极的应用参考





R&D of n - type back - gate electrode photovoltaic cells

n型背栅电极光伏电池的开发



資料來源：Sunpower (2004/06)



IBC電池技術产业化进展Progress in Industrialization of IBC Cell Technology

美商SunPower公布2016年第四季營收結果與最新的技術發展成果。該公司在菲律賓賓所設置的Fab 4成功以IBC電池技術，使太陽能電池的轉換效率提升到25%，創下業界新高。

SunPower人員在線上記者會中表示，位於菲律賓的Fab 4採用N型單晶IBC電池技術，2017年預計將產能提高到350MW。而Fab 4廠的研發成果也十分斐然，電池轉換效率已來到25%之多；SunPower將IBC視為該公司次世代技術的發展主軸，持續帶領著全球技術發展。

位於馬來西亞、產能達800MW的Fab 3廠，SunPower今年規劃斥資美金1億元，將其電池產線也升級到N型單晶IBC電池技術，亦即X-Series。加上其他的升級與擴產需求，SunPower預估2017年的資本支出將來到1.2億美金。

在Fab 3與Fab 4廠持續進行升級的過程中，SunPower將繼續以X-Series模組作為主力產品，並加強P-Series模組的供貨能力，同時強化在中國的市場經營。X-Series的產能預計將在今年底達到350MW。

P-Series模組所需之電池主要是向外採購而來，並在墨西哥的組裝廠組裝。P-Series系列模組中，已有200MW的多切片電池（multi-cut cells）模組和直接背接觸電池（direct cell-to-cell contact）模組在去年第四季量產；今年第一季預計還會有200MW投產。



Introduction of Thin Film Photovoltaic Industry

薄膜光伏产业发展介绍

In 2007, the bright performance of First Solar in the United States brought a new era of film industry, a low cost of \$ 1.3 / watt, a conversion rate of around 11%, a huge order in Europe and North America, and a large-scale production that was not restricted by raw materials. Of high profits, high income, high reliability and earnings expectations, but also prompted the industry to find a film era is coming. In 2007 and 2008, the global PV industry is the most hot part of the field of thin film, Taiwan almost instantly put more than 10 thin film project, the domestic amorphous silicon leader Rio Tinto new energy successfully IPO, followed by the domestic IPO companies include, involving amorphous Silicon thin film : Tianwei change (600550), variety shares (600770), Gan shares (000899). 2009 industry experts predict that by 2030, thin-film solar cells will account for more than 30% of the overall share of solar cells, which is equal to crystalline silicon solar cells.

2007年美国 First Solar 的亮丽表现则带来了薄膜产业的新纪元，1.3 美元/瓦的低成本，11%左右的转换率，欧洲北美的巨额订单，不受原料限制的大规模生产成就了First Solar 的高利润，高收入，高可靠的盈利预期，也促使产业界发现属于薄膜时代的来临。在2007年和2008年间，全球光伏产业最为火热的环节就是薄膜领域，台湾几乎瞬间投入了超过 10 个薄膜项目，国内的非晶硅龙头拓日新能源顺利上市，随后国内市场当中，涉及非晶硅薄膜电池的上市公司主要包括：天威保变（600550）、综艺股份（600770）、赣能股份（000899）。2009年行业专家预测，到2030年，薄膜太阳能电池将占整体太阳能电池份额的30%以上，从而与晶体硅太阳能电池平分秋色。



薄膜太阳能电池的种类

Different type of thin film solar cells

- 非晶硅 (Amorphous Silicon, a-Si)
- 微晶硅 (Nanocrystalline Silicon, nc-Si, or Microcrystalline Silicon, uc-Si)
- CIS/CIGS (铜铟硒化物)
- CdTe (碲化镉)
- 色素敏化染料 (Dye-Sensitized Solar Cell)
- 有机导电高分子 (Organic/polymer solar cells)



非晶硅(Amorphous Silicon, a-Si)

非晶硅的优点在于对于可见光谱的吸光能力很强，而且利用溅镀或是化学气相沉积方式生成薄膜的生产方式成熟且成本低廉，材料成本相对于其他化合物半导体材料也便宜许多；不过缺点则有转换效率低(约12~13%)，以及会产生严重的光劣化现象的问题，因此无法打入太阳能发电市场，而多应用于小功率的消费性电子产品市场。未来在具有成本低廉的优势之下，仍将是未来薄膜太阳能电池的主流之一。

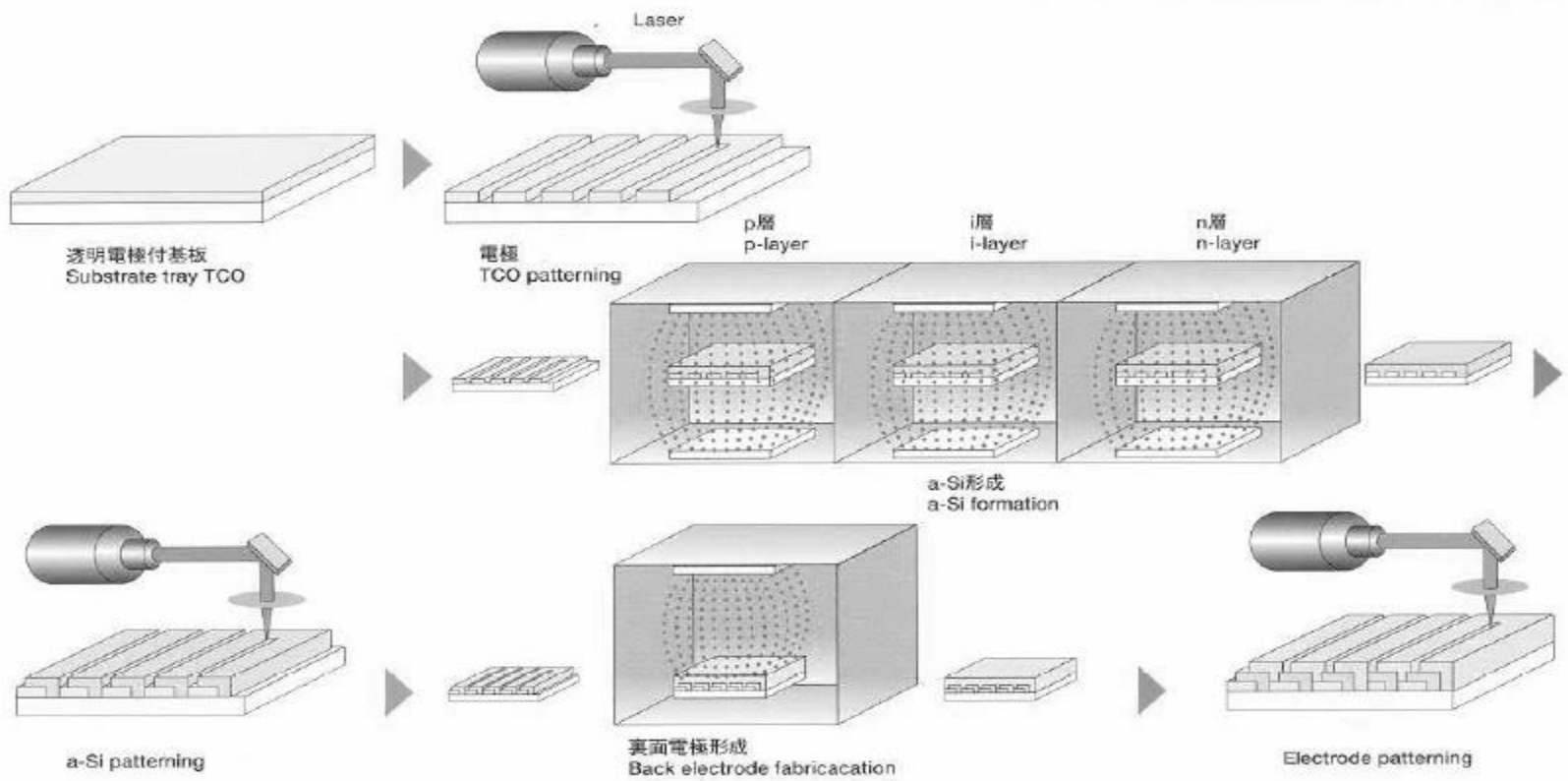
The advantage of amorphous silicon is that the absorptive capacity of the visible spectrum is strong and the production of the film by sputtering or chemical vapor deposition is mature and inexpensive and the cost of the material is much cheaper than that of other compound semiconductor materials. But the shortcomings are low conversion efficiency (about 10 ~ 12%), and will produce serious problems of light degradation, and will cause serious light deterioration of the problem, it can not enter the solar power market, and more used in low-power consumer electronics market. The low cost advantage, will remain the future of thin film solar cell as one of the mainstream.



非晶硅薄膜太阳能电池制造流程(玻璃基材)

非晶硅薄膜太阳能电池制造流程(玻璃基材)

Process of Manufacturing Amorphous Solar Cell (Glass Substrate)





非晶硅薄膜太阳能电池制造流程 (玻璃基材)

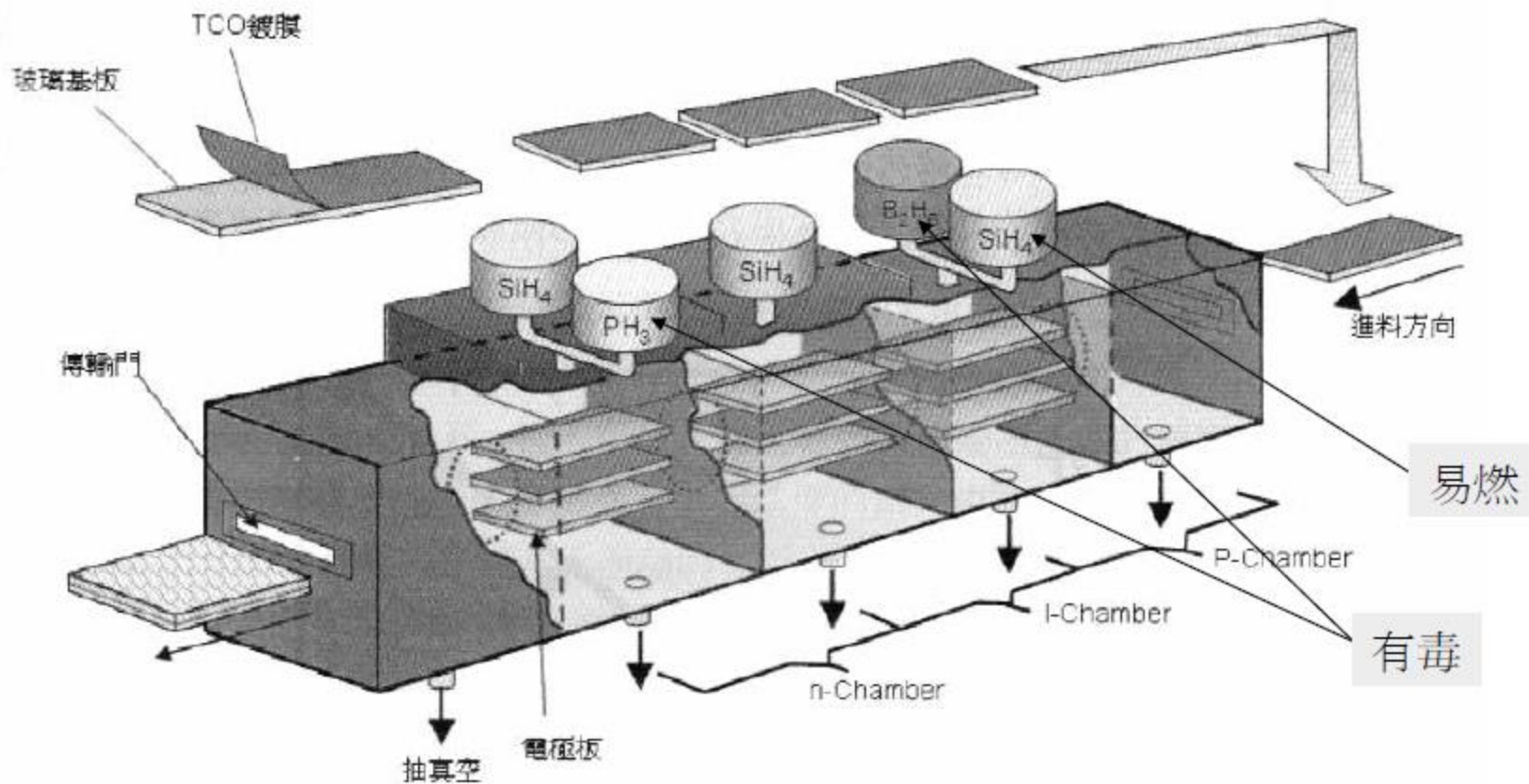


图 8.4 一貫作業在玻璃基板上利用 PECVD 法生產 p-i-n 結構的非晶矽薄膜之示意圖



非晶硅薄膜太阳能电池

“Amorphous Si:H Thin-film Solar Cell”





CIGS(铜铟镓硒化物)

CIGS(Copper Indium Gallium Diselenide)属于化合物半导体。这种材料的吸光(光谱)范围很广，而且稳定性也相当好。转换效率方面，若是利用聚光装置的辅助，目前转换效率已经可达30%，标准环境测试下最高也已经可达到19.5%，足以媲美单晶硅太阳能电池的最佳转换效率。在大面积制程上，采用软性塑料基板的最佳转换效率也已经达到14.1%。由于稳定性和转换效率都已经相当优异，因此被视为是未来最有发展潜力的薄膜太阳能电池种类之一。

CIGS belongs to compound semiconductors. The absorbance (spectrum) of this material is very wide and the stability is better. Conversion efficiency, if the use of condenser device assistance, the current conversion efficiency has reached 30%, the standard environmental test has reached a maximum of 19.5%, enough to match the best conversion efficiency of monocrystalline silicon solar cells. In the large-scale process, the use of flexible plastic substrate, the best conversion efficiency has reached 14.1%. Because better stability and conversion efficiency have been quite excellent, it is considered to be one of the most promising thin film solar cells in the future.



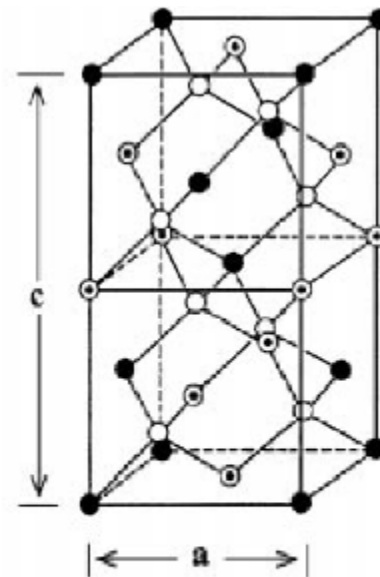
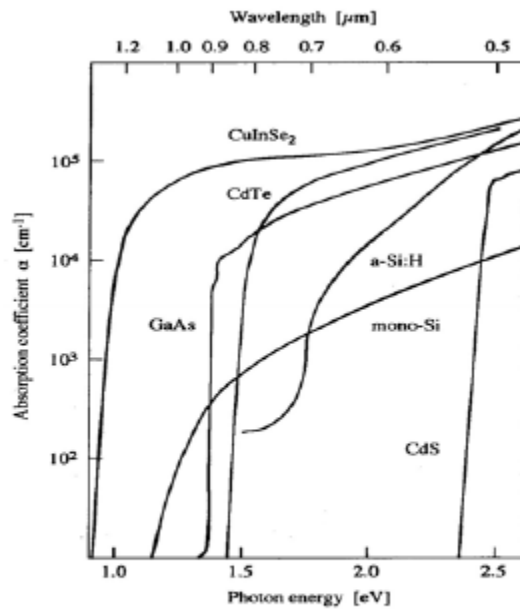
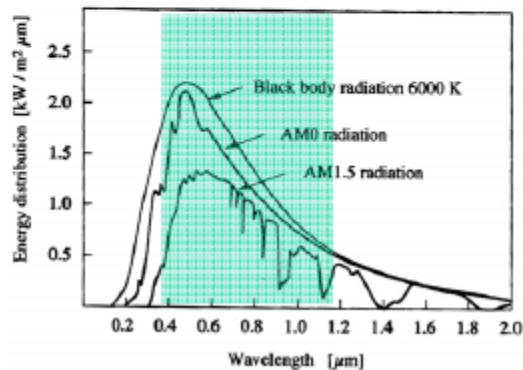
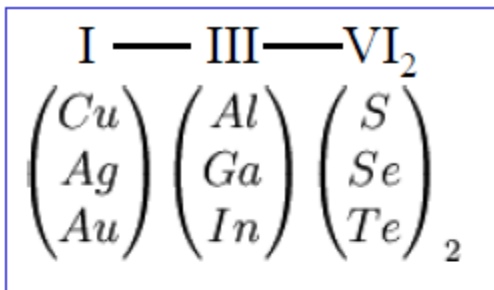
薄膜太阳能电池—CIGS薄膜电池

CIGS由于其高光电效率及低材料成本，被许多人看好。在实验室完成的CIGS光电池，光电效率最高可达约19.88，CIGS随着铟镓含量的不同，其光吸收范围可从1.02eV至1.68eV，此项特征可加以利用于多层堆栈模块，已近进一步提升电池组织效能。此外由于高吸光效率 ($\alpha > 10^4 \sim 10^5 \text{cm}^{-1}$)，所需光电材料厚度不需超过1 μm ，99%以上的光子均可被吸收，因此一般粗估量产制造时，所需半导体原材料可能仅只US\$0.03/W。

CIGS is favored by many people due to its high photoelectric efficiency and low material cost. In the laboratory, the CIGS photocell is capable of photoelectric efficiency up to about 19.88. With the indium gallium content, the light absorption range can range from 1.02eV to 1.68eV. This feature can be used in the multi-layer stack module. Step by step to improve battery tissue performance. In addition, due to the high light absorption efficiency ($\alpha > 10^4 \sim 10^5 \text{cm}^{-1}$), the required thickness of the optoelectronic material does not exceed 1 μm , more than 99% of the photons can be absorbed, so the general crude production, the required semiconductor raw materials may Only US \$ 0.03 / W.



薄膜太阳能电池- CIGS薄膜电池



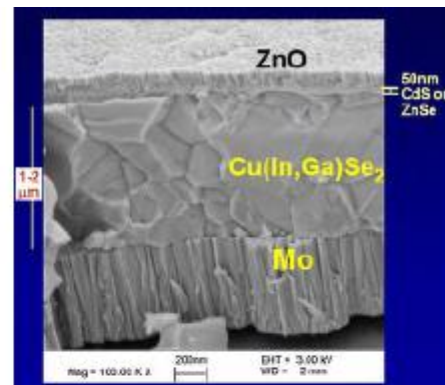
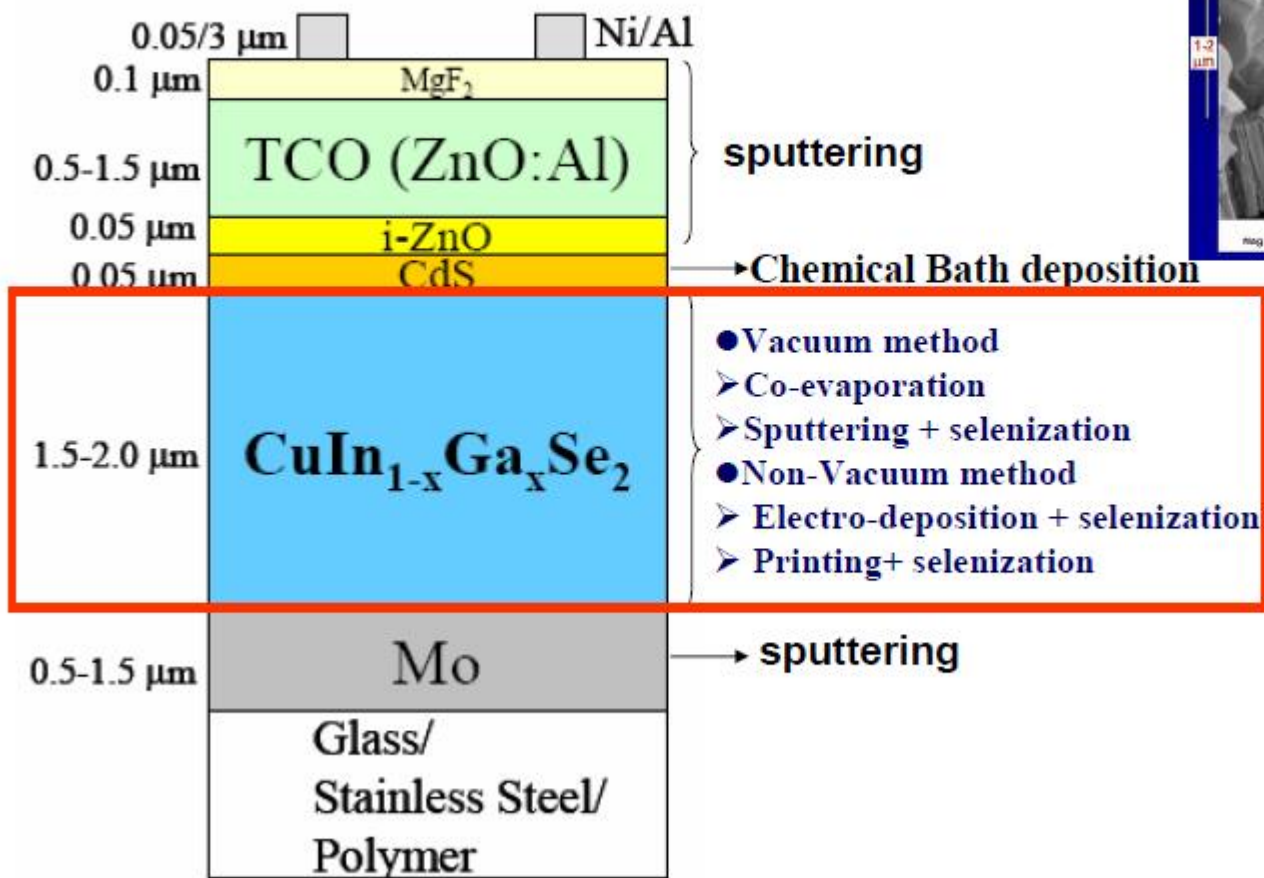
Chalcopyrite

● Cu ⊙ In ○ Se



CIGS 太阳能电池组件制作流程

Solar cell module production process





CdTe(碲化镉)

CdTe是二元化合物半导体，电池转换效率也不差：若使用耐高温(~600度C)的硼玻璃作为基板转换效率可达16%，而使用不耐高温但是成本较低的钠玻璃做基板也可达到12%的转换效率，转换效率远优于非晶硅材料。此外，CdTe在薄膜制程上远较CIS或CIGS容易控制，再加上可应用多种快速成膜技术(如蒸镀法)，模块化生产容易，因此容易应用于大面积建材，目前已经有商业化产品在市场营销，转换效率约11%。不过，虽然CdTe技术有以上优点，但是因为镉已经是各国管制的高污染性重金属，因此此种材料技术未来发展前景仍有阴影存在。CdTe is a binary compound, the efficiency is not bad: If the use of high temperature (~ 600 degrees C) boron glass as the substrate conversion efficiency of up to 16%, while the use of low temperature but low cost of sodium glass substrate Can achieve 12% ,CdTe in the film process far easier than CIS or CIGS control, coupled with the application of a variety of rapid film-forming technology (such as vapor deposition), modular production is easy, to large area of building materials , There are already commercial products in marketing, conversion efficiency of about 11%. However, because cadmium is already controlled by the country's highly polluting heavy metals, so the future development of this material technology is still the shadow of the existence.



CdTe Film Deposition

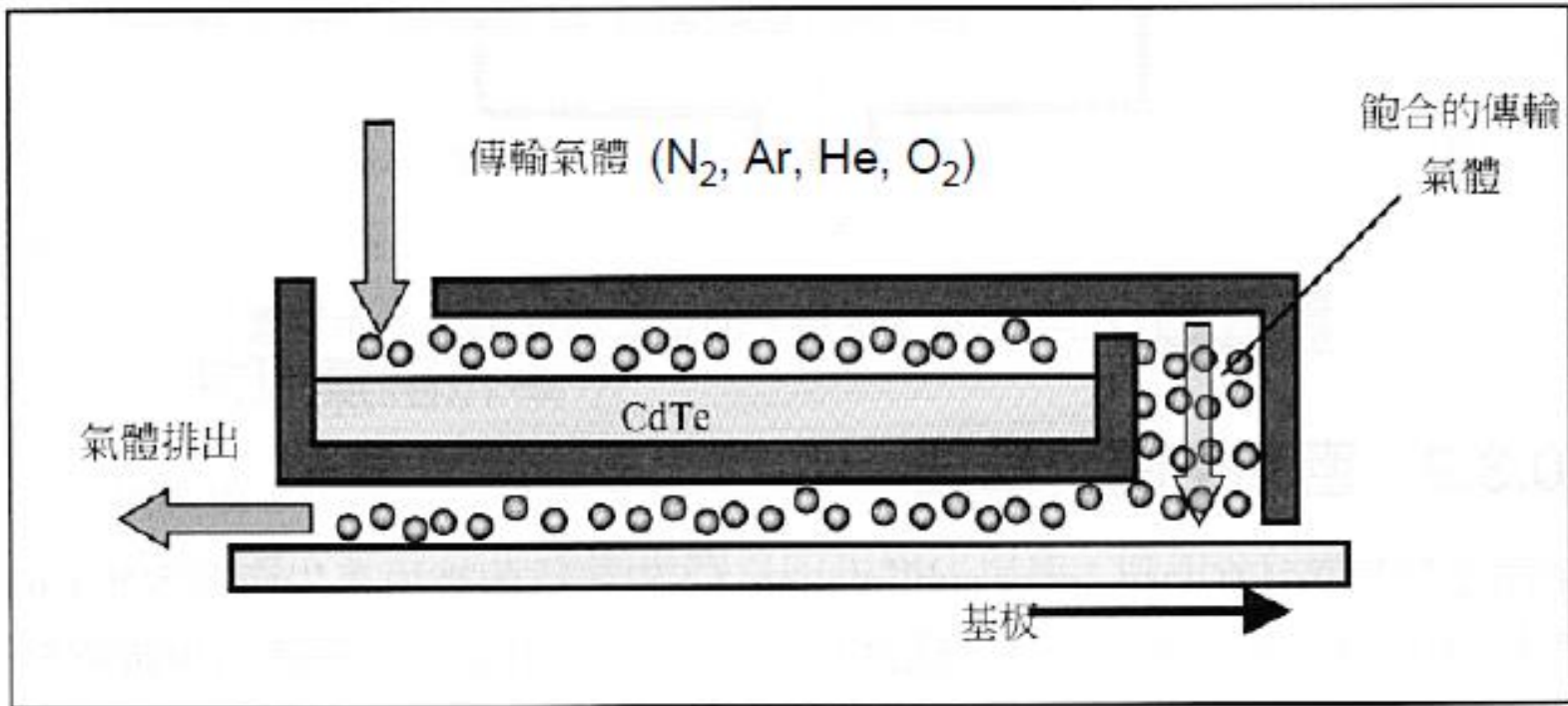


圖 10.5 利用氣相傳輸沉積法來製造 CdTe 薄膜之示意圖



CdTe Film Deposition

- Spray deposition
 - CdTe + CdCl₂ + propylene glycol 丙二醇
- Organic Chemical Vapor Deposition (MOCVD)
 - Dimethylcadimium 二甲基鎘 + diisoprppyltellurium 二異丙基碲
- Screen-print deposition
 - Cd + Te + CdCl₂ + 有機結合劑
 - 700 ° C sintering



Cadmium Telluride Thin-film Solar Cell for Rooftop ”

SAG First Solar ----CdTe Rooftop



Katzenbach Juwi



Memmingen SAG



染料敏化染料(Dye-Sensitized Solar Cell)

染料敏化感染料电池是太阳能电池中相当新颖的技术，产品是由透明导电基板、二氧化钛(TiO_2)奈米微粒薄膜、染料(光敏化剂)、电解质和ITO电极所组成。此种太阳能电池的优点在于二氧化钛和染料的材料成本都相对便宜，又可以利用印刷的方法大量制造，基板材料也可更多元化。不过目前主要缺点一是在于转换效率仍然相当低(平均约在7~8%，实验室产品可达10%)，且在UV照射和高热下会出现严重的光劣化现象，二是在于封装过程较为困难(主要是因为其中的电解质的影响)，因此目前仍然是以实验室产品为主。然而，基于其低廉成本以及广泛应用层面的吸引力，多家实验机构仍然在积极进行技术的突破。Dye-sensitized dye cells are quite innovative technologies in solar cells. They are made of transparent conductive substrates, titanium dioxide (TiO_2) nanoparticles films, dyes (photosensitizers), electrolytes and ITO electrodes. The advantage of such a solar cell is that the material cost of the titanium dioxide and the dye is relatively inexpensive and can be mass-produced by the printing method, and the substrate material can be more diversified. But the main drawback is that the conversion efficiency is still very low (average about 7 ~ 8%, laboratory products up to 10%), and in the UV irradiation and high heat will appear serious light degradation phenomenon, and the other is the packaging process More difficult (mainly because of the impact of which electrolyte), so it is still the main laboratory products. However, based on its low cost and wide application level of attraction, a number of experimental institutions are still active in technological breakthroughs.



First generation cells



More Si than microelectronics

Issues

- . thinner cells*
- . simpler Si purification*
- . higher conversion efficiency*



Second Generation: thin-film



李河君:
2015 Richest
man in China

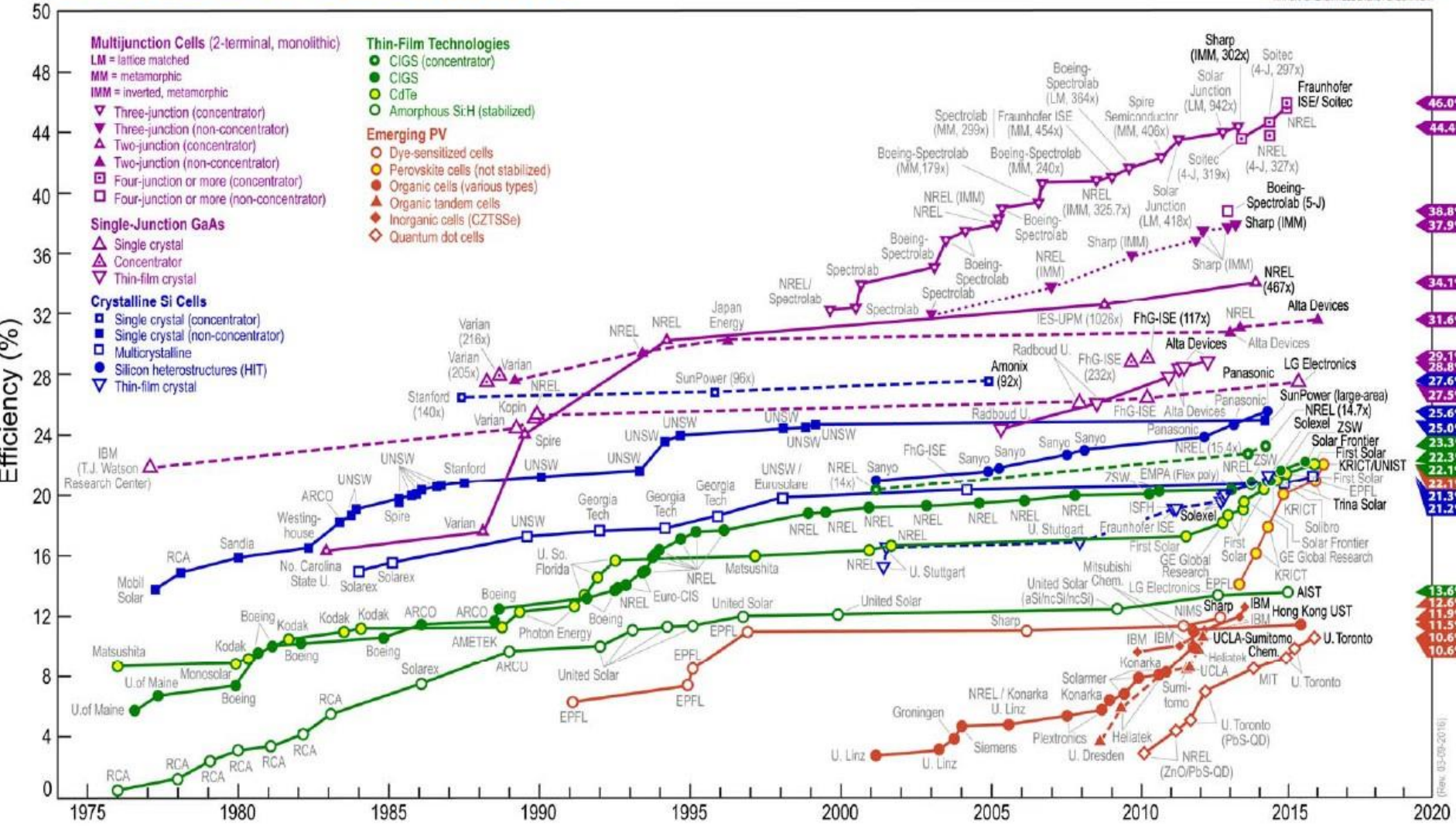
Thin-film Technologies

- **Silicon**
 - amorphous
 - microcrystalline
 - polycrystalline
- **Chalcogenide** (polycrystalline)
 - CIS, CIGS [Cu(In,Ga)(Se,S)₂]
 - CdTe
- **Dye sensitised, Organics**

Advantages

- low materials cost
- large manufacturing unit
- fully integrated modules
- aesthetics, ruggedness?

Best Research-Cell Efficiencies

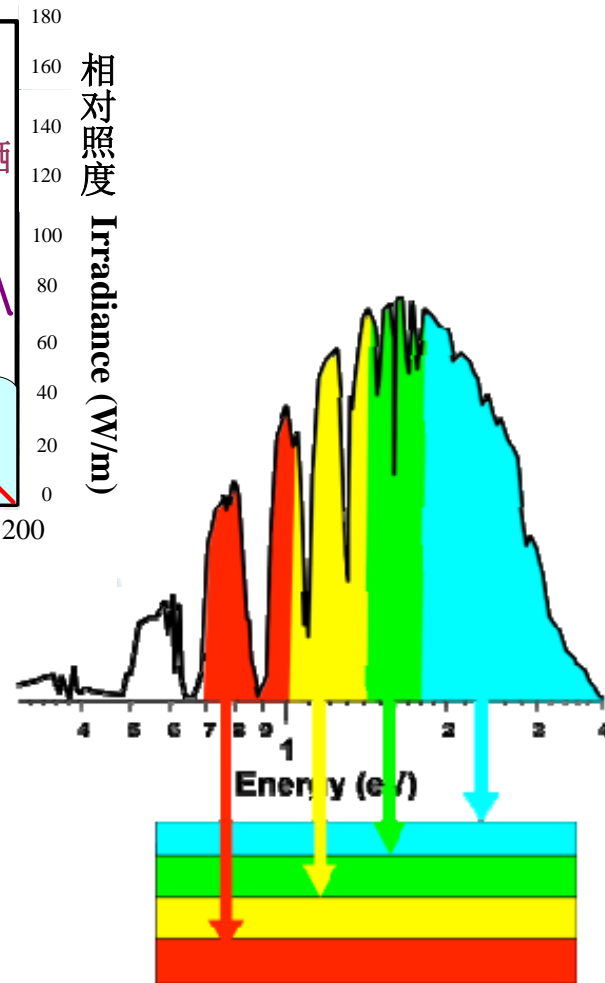
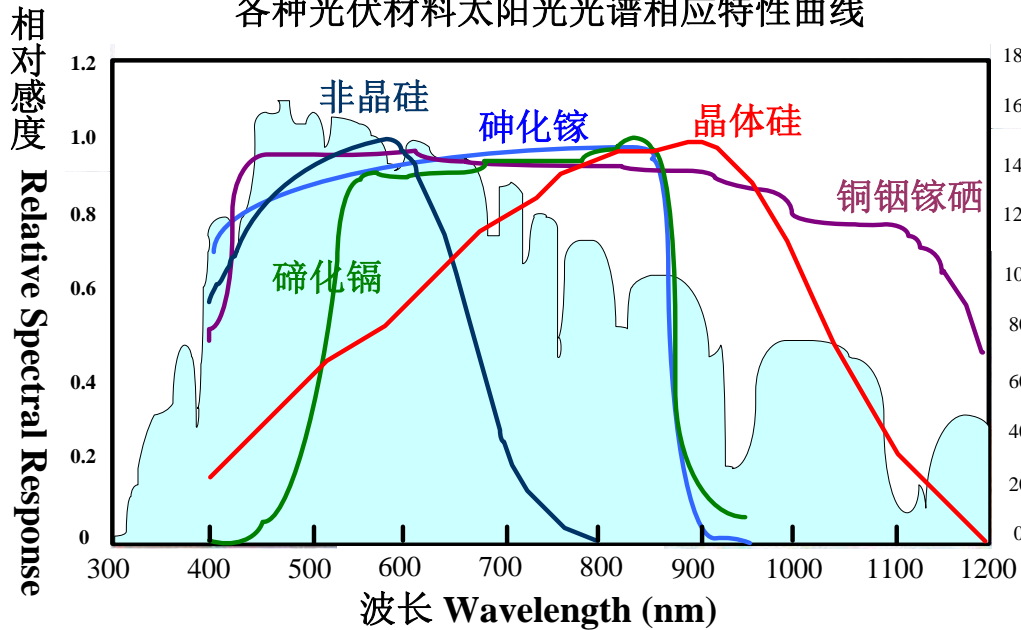


(Rev. 03-09-2016)

太阳光谱分布及对应材料图

Solar spectrum distribution and corresponding material map

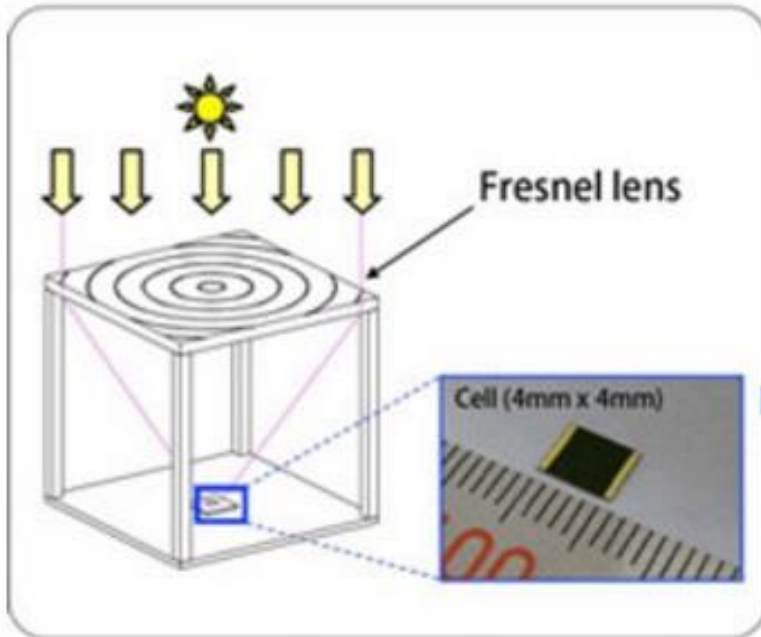
各种光伏材料太阳光谱相应特性曲线



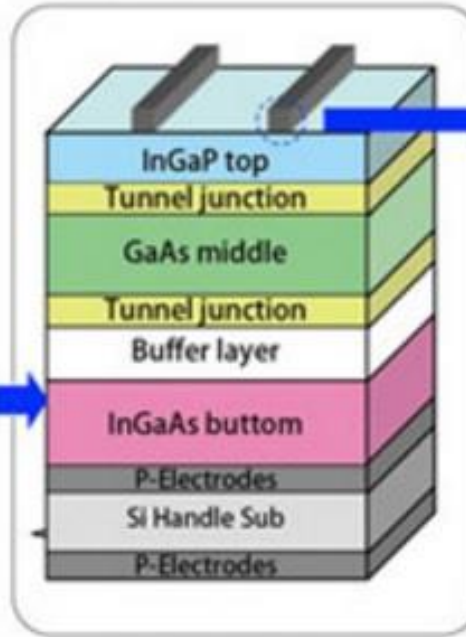


Multi-junction Solar Cell and CPV(Concentrating Solar Power)

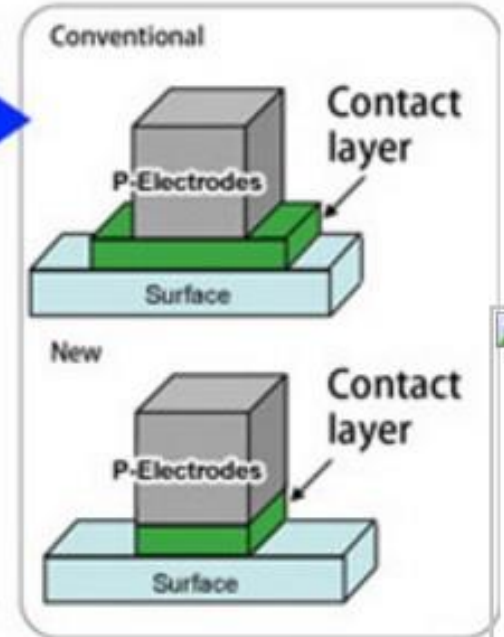
■ Concentrator solar cell system



■ Structure of a triple-junction compound solar cell



■ Comparison with a conventional structure



Picture: Concentrator triple-junction compound semiconductor solar cell with record conversion efficiency of 44.4%.



生产效率可望大大提升 Very High Productivity Can be Achieved



晶硅制作是一个高能耗、高污染工业。多结电池的制作采用MOCVD外延工艺，一台MOCVD一周可以生产1MW电池，相当于10吨晶硅。





Sharp sets CPV cell solar conversion efficiency record of 44.4% **19 June 2013**



Sharp's concentrator triple-junction compound solar cells use a proprietary technology that enables the efficient conversion of sunlight into electricity by means of a stack of three photo-absorption layers, the bottom-most of which is made from indium gallium arsenide (InGaAs).

Sharp says that, to achieve a concentrating conversion efficiency of 44.4%, it worked to widen the effective concentrator cell surface and ensure uniform width of the interface between the cell and the electrodes.

Because of their high conversion efficiency, compound solar cells have so far been used primarily on space satellites. However, Sharp's aim for the future is to apply this latest development in CPV power systems and make the use of compound solar cells more feasible in terrestrial applications.



NREL demonstrates 45.7% efficiency for CPV solar cell **16 December 2014**

The US Department of Energy (DOE)'s National Renewable Energy Laboratory (NREL) has demonstrated a conversion efficiency of 45.7% for a four-junction solar cell at 234 suns concentration.

NREL invented and developed the four-junction inverted metamorphic (4J IMM) cell with these challenges in mind. The new design consists of a gallium indium phosphide (GaInP) junction, a gallium arsenide (GaAs) junction, and two gallium indium arsenide (GaInAs) junctions that are lattice-mismatched to the substrate. The cell's peak efficiency of $45.7 \pm 2.3\%$ was measured under the AM1.5 direct spectrum at 234 suns concentration, but the device performs nearly as well at even higher concentrations, having 45.2% efficiency at 700 suns concentration.

The device has numerous other improvements over previous designs, including a broadband four-layer anti-reflection coating, a novel metamorphic tunnel junction interconnect, and what is claimed to be unprecedented performance from the GaInP top cell. Compared to standard GaInP subcells, this subcell has both higher voltage and reduced series resistance, which is essential for high efficiency at high solar concentrations. Through SunShot, the DOE supports private companies, universities and national laboratories working to drive down the cost of solar electricity to \$0.06 per kilowatt-hour.



Fraunhofer ISE, Soitec and Leti raise solar cell efficiency record from 44.7% to 46% 1 December 2014

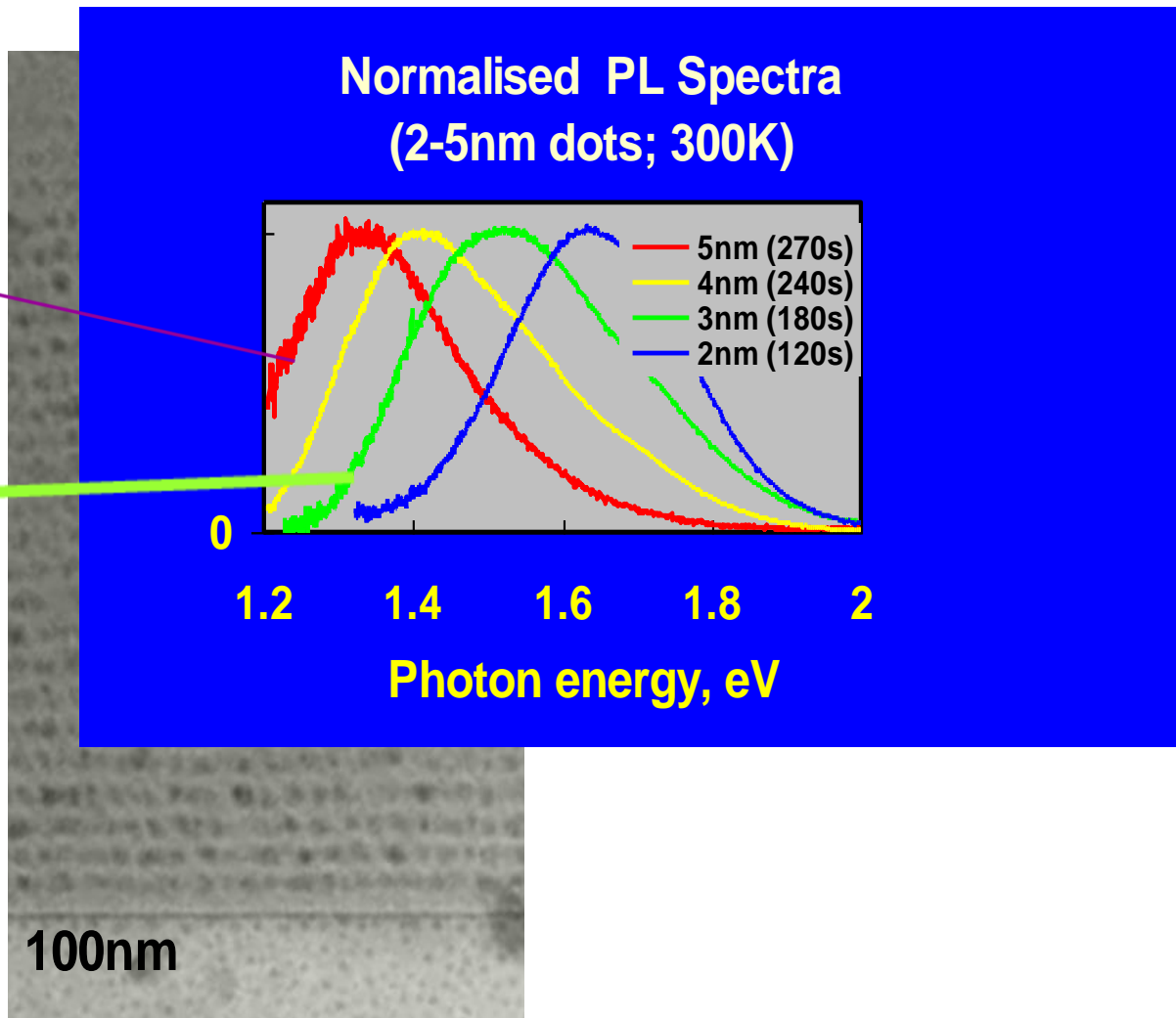
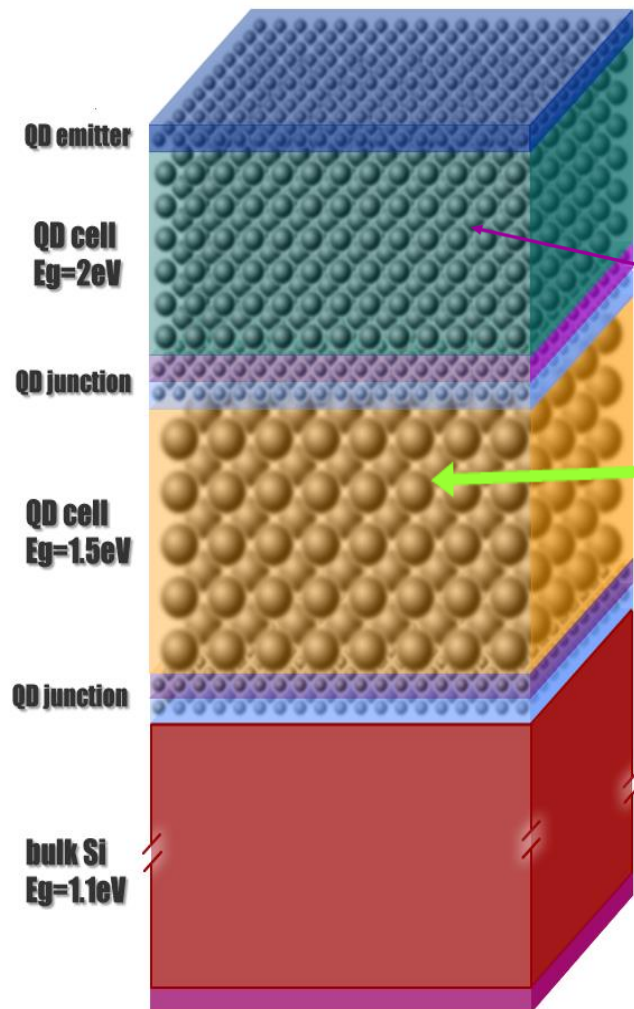
Bernin-based Soitec (which makes engineered substrates and CPV systems) and Grenoble-based micro/nanotechnology R&D center CEA-Leti of France, together with the Fraunhofer Institute for Solar Energy Systems ISE of Freiburg, Germany, have developed a multi-junction solar cell that has raised the record for the direct conversion of sunlight into electricity from 44.7% (set by Fraunhofer ISE, Soitec, CEA-Leti and Helmholtz Zentrum Berlin in September 2013) to 46%.

A special challenge that had to be met by the cell is the exact distribution of the photons between the four sub-cells. This was achieved by the precise tuning of the composition and thicknesses of each layer inside the cell structure. “This is a major milestone for our French-German collaboration,” says Dr Frank Dimroth, project manager for the cell development at Fraunhofer ISE. “CPV is the most efficient solar technology today and suitable for all countries with high direct normal irradiance,” he adds.

“It confirms we made the right technology choice when we decided to develop this four-junction solar cell and clearly indicates that we can demonstrate 50% efficiency in the near future,” believes Jocelyne Wasselin, VP Solar Cell Product Development for Soitec. “To produce this new generation of solar cells, we have already installed a line in France,” she adds. “It uses our bonding and layer-transfer technologies and already employs more than 25 engineers and technicians. This successful cooperation with our French and German partners will drive further increase of CPV technology efficiency and competitiveness.”



Si quantum dot tandem cell





Fresnel Lens is another the Key elements

Specification:

Size: 1000*1000mm

Thickness: 3mm

Material: optical acrylic

Groove pitch: 0.5mm

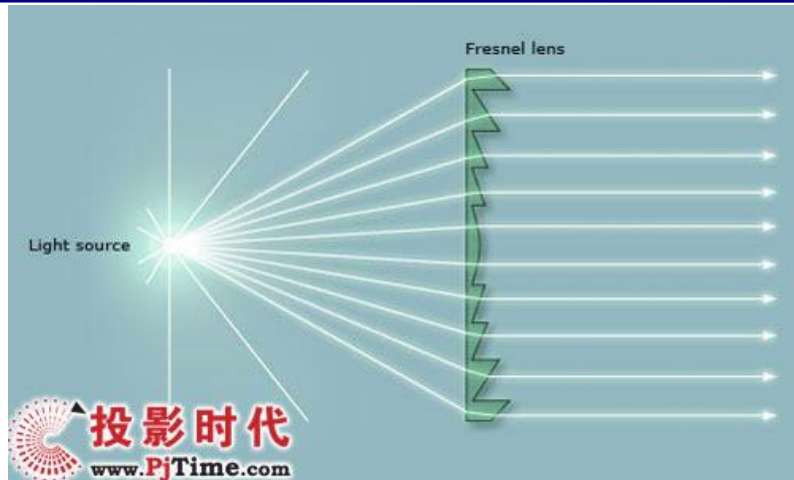
Focal length/Magnification: 880mm

The range of application:

- 1) focusing action
- 2) Widely used in solar energy system, CPV
- 3) Also be suitable for Solar energy collector system, start a fire under sunlight, hot water heater, solar furnace, LCD projector

Feature and advantages:

- 1) High light transmittance
- 2) High efficiency in focusing
- 2) We can provide customer fresnel lens, because we can make mould by ourselves
- 3) 10 years' professional induction and design
- 4) High quality and competitive price
- 5) CE, Factory Audit, ISO9001, AGC
- 6) Good after-sales service



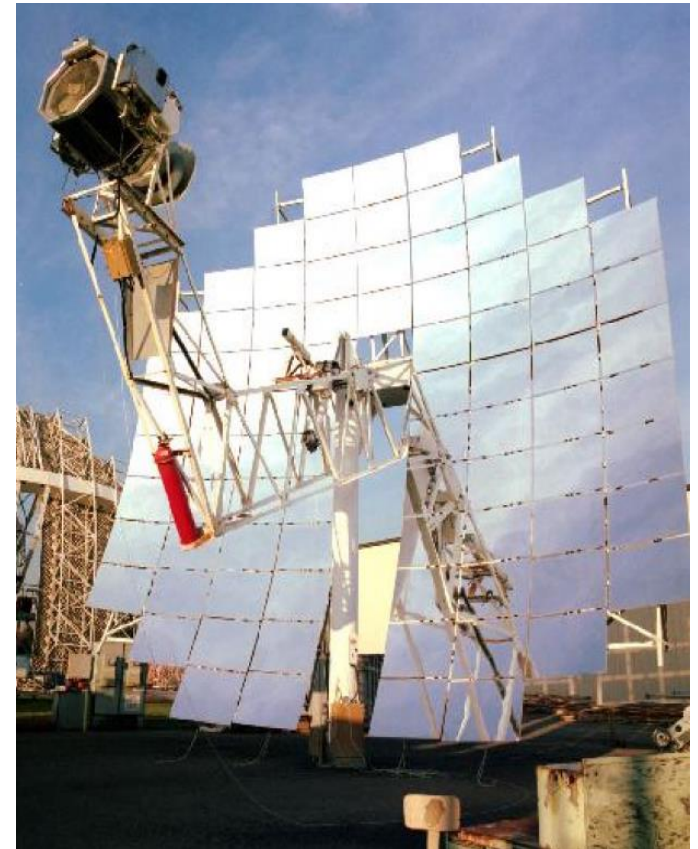


CPV Concentrating Solar Power Is it The third generation?

Photovoltaic
receiver



Stirling engine



钙钛矿晶体及电池结构

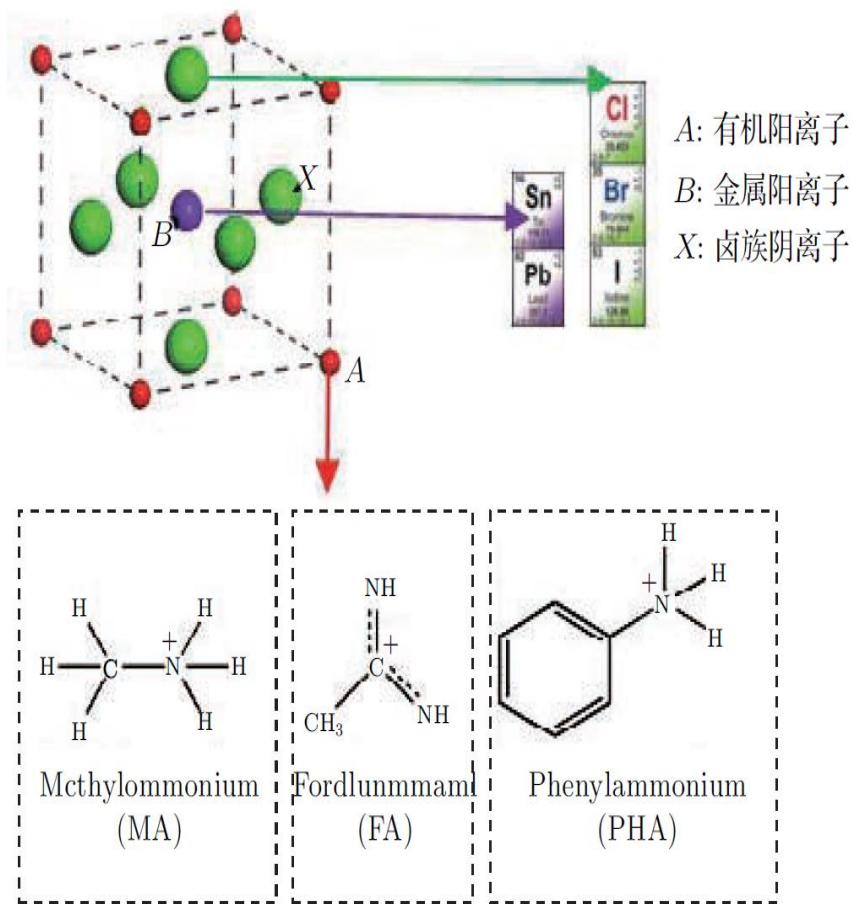


图1 钙钛矿晶体结构示意图

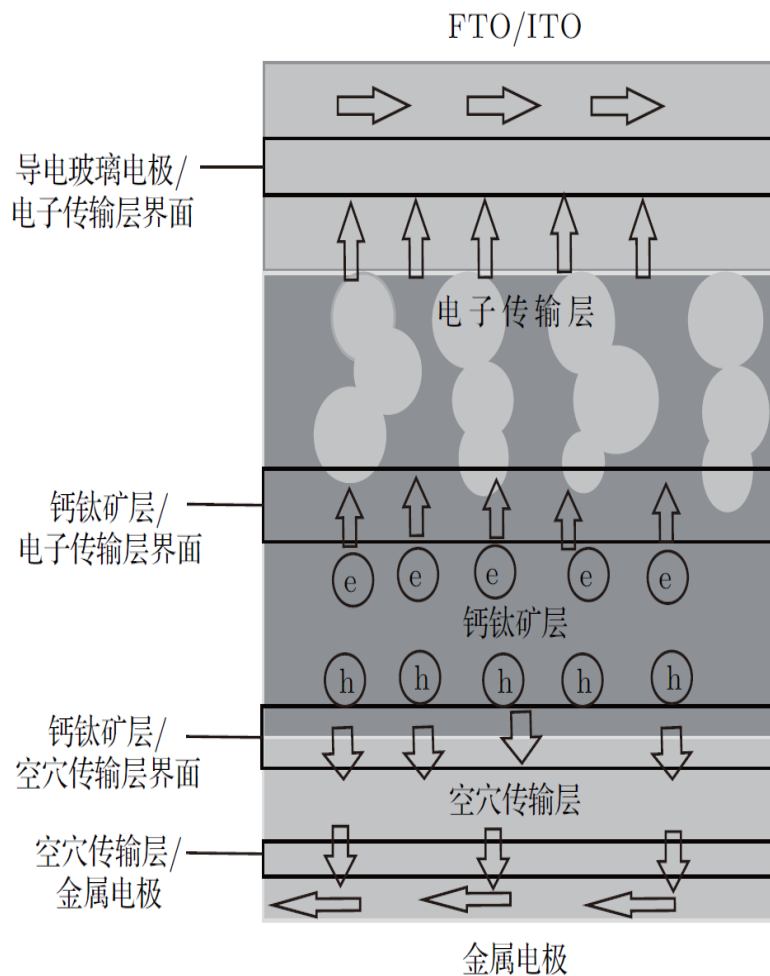


图2 钙钛矿太阳能电池结构示意图

钙钛矿电池常用结构

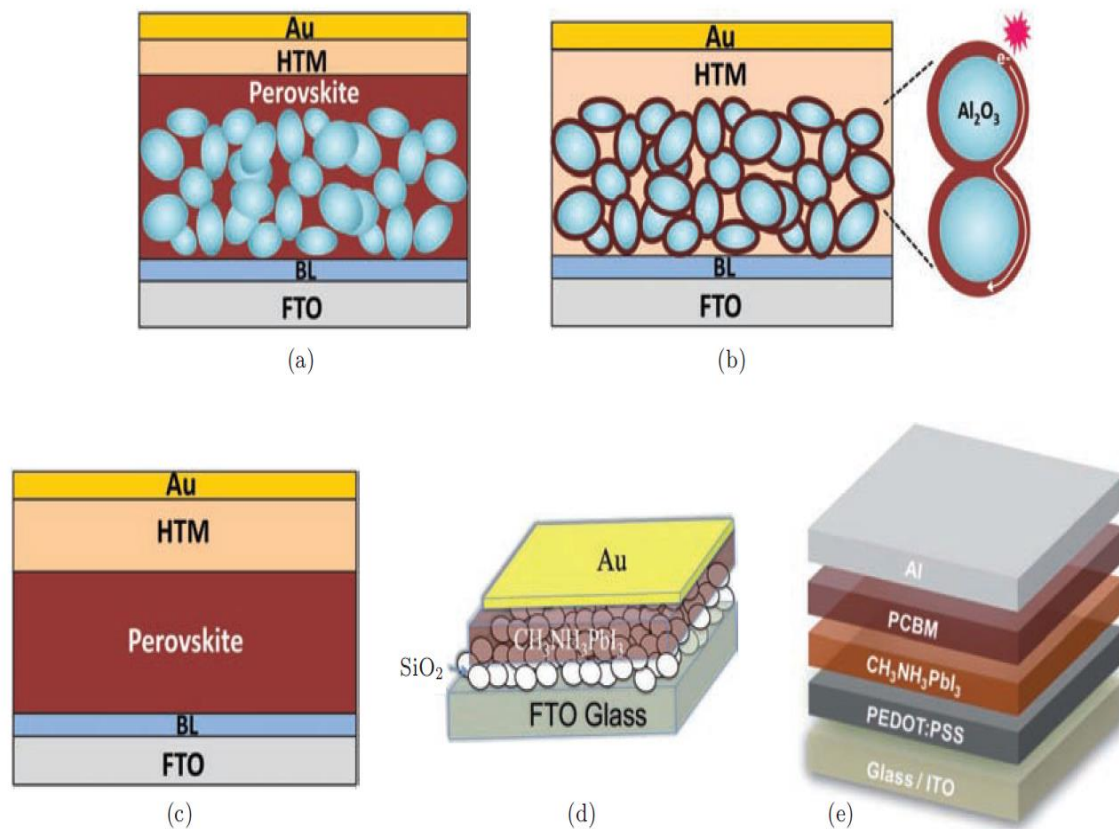


图3 钙钛矿太阳电池结构 (a) 介孔结构; (b) 介观超结构; (c) 平面结构; (d) 无HTM结构; (e) 有机结构
(FTO: 导电玻璃; BL: 致密 TiO_2 ; Perovskite: 钙钛矿; HTM: 空穴传输层)

钙钛矿电池常用材料

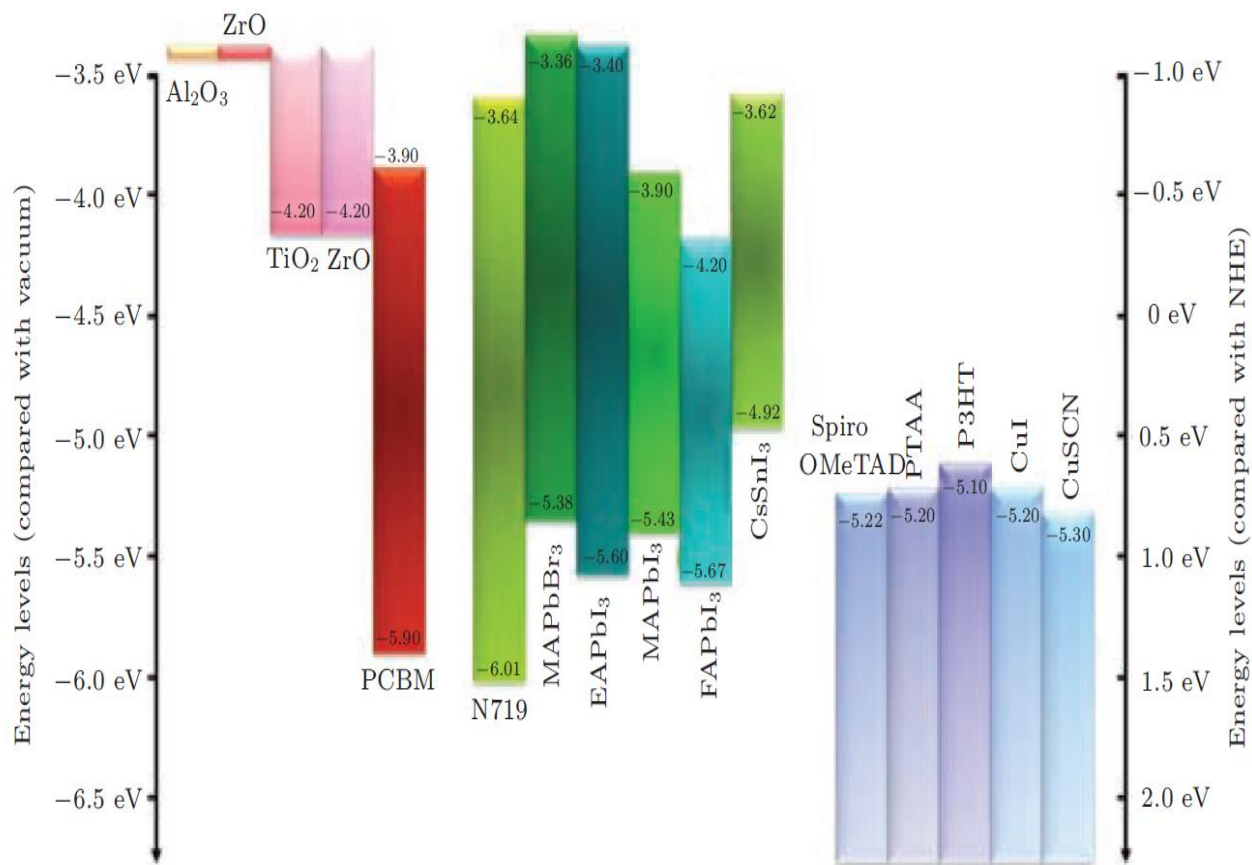


图4 钙钛矿电池常用材料能带结构图

钙钛矿电池制备工艺

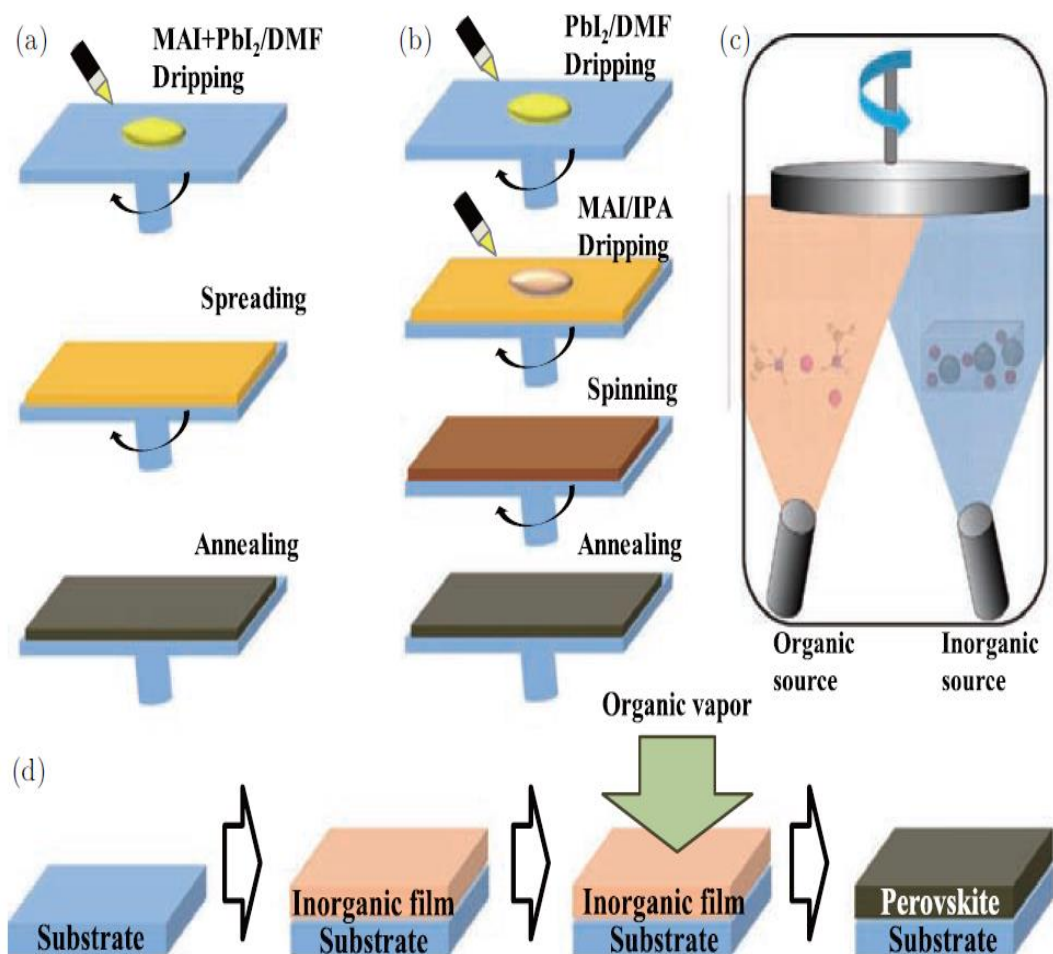
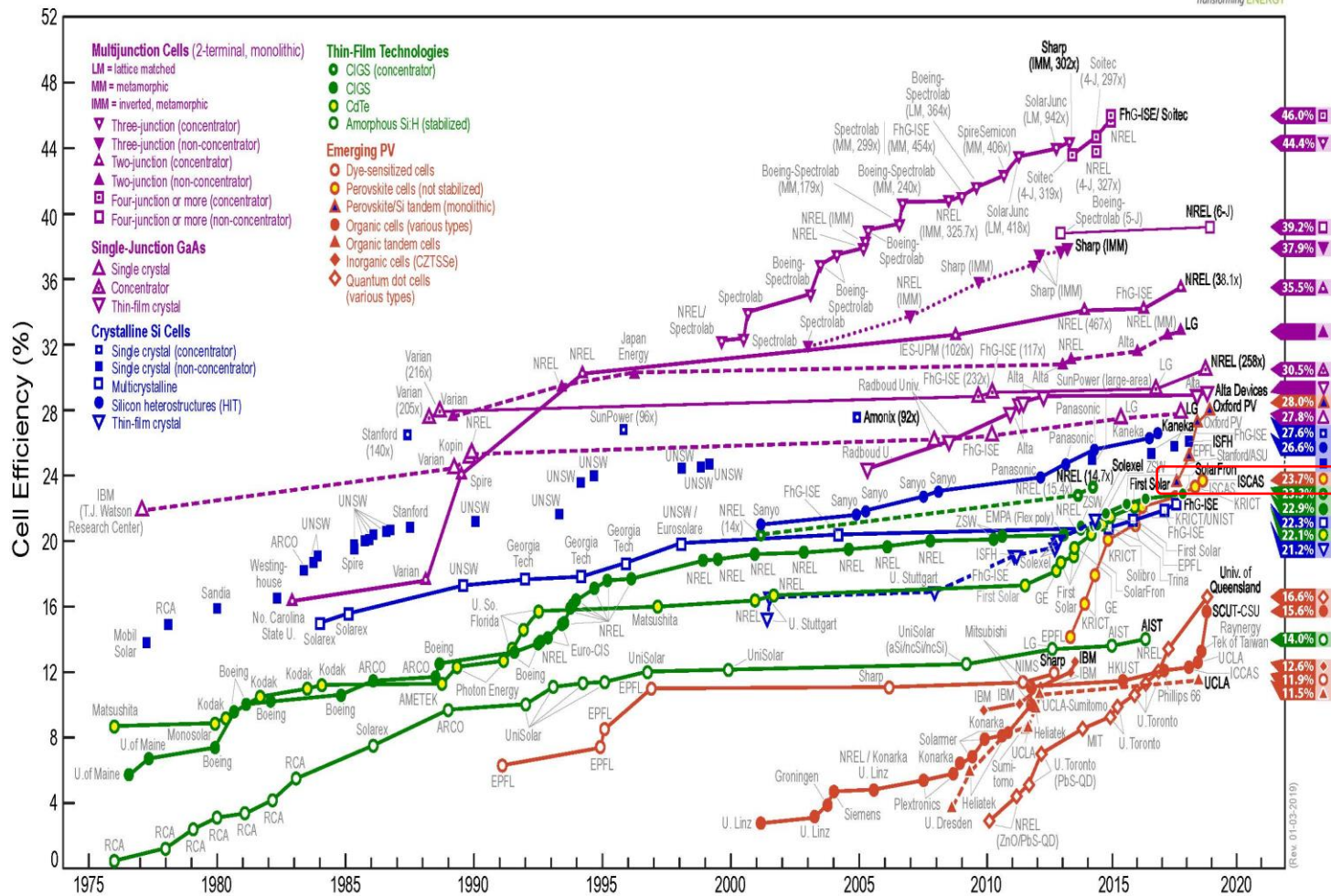


图5 钙钛矿电池制备方法 (a) 一步旋涂法; (b) 连续沉积法; (c) 双源气相蒸发法; (d) 溶液-蒸汽沉积法

太阳能电池效率比较

Best Research-Cell Efficiencies



ISCAS (中科院半导体所) 游经碧研究员团队取得钙钛矿电池23.7%的最高效率记录, 高于多晶硅太阳能电池的最高记录。

图6 太阳能电池实验室最高效率发展示意图

钙钛矿单节电池效率和寿命发展趋势

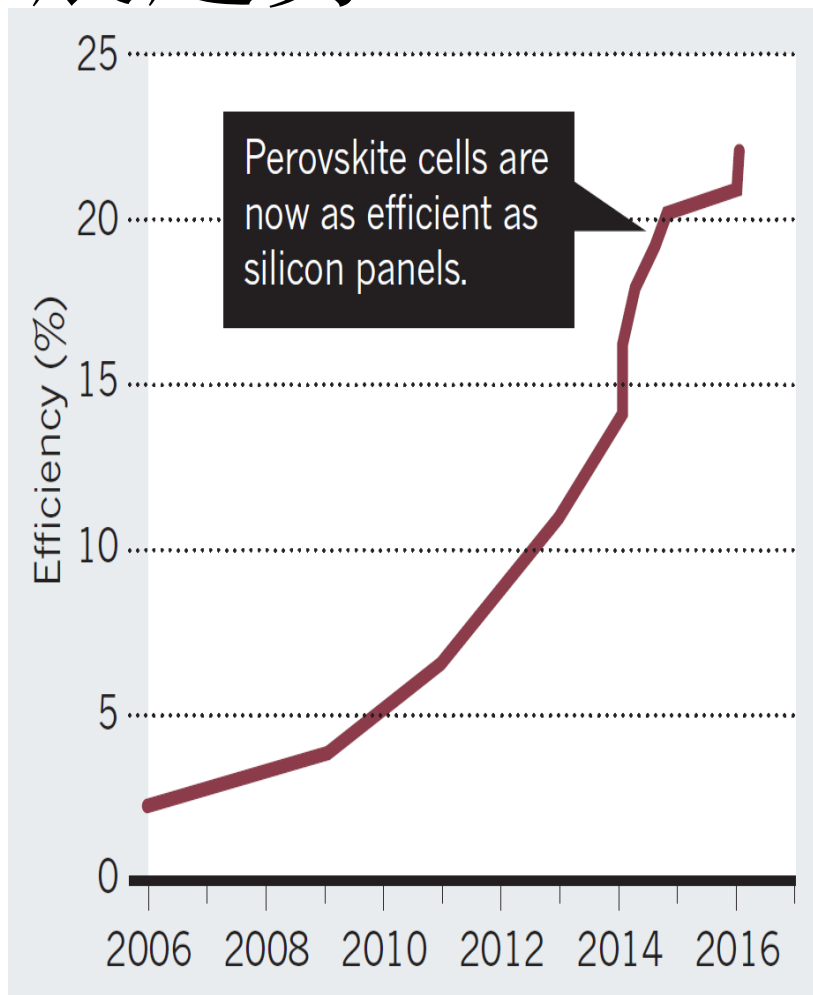


图7 钙钛矿电池效率发展

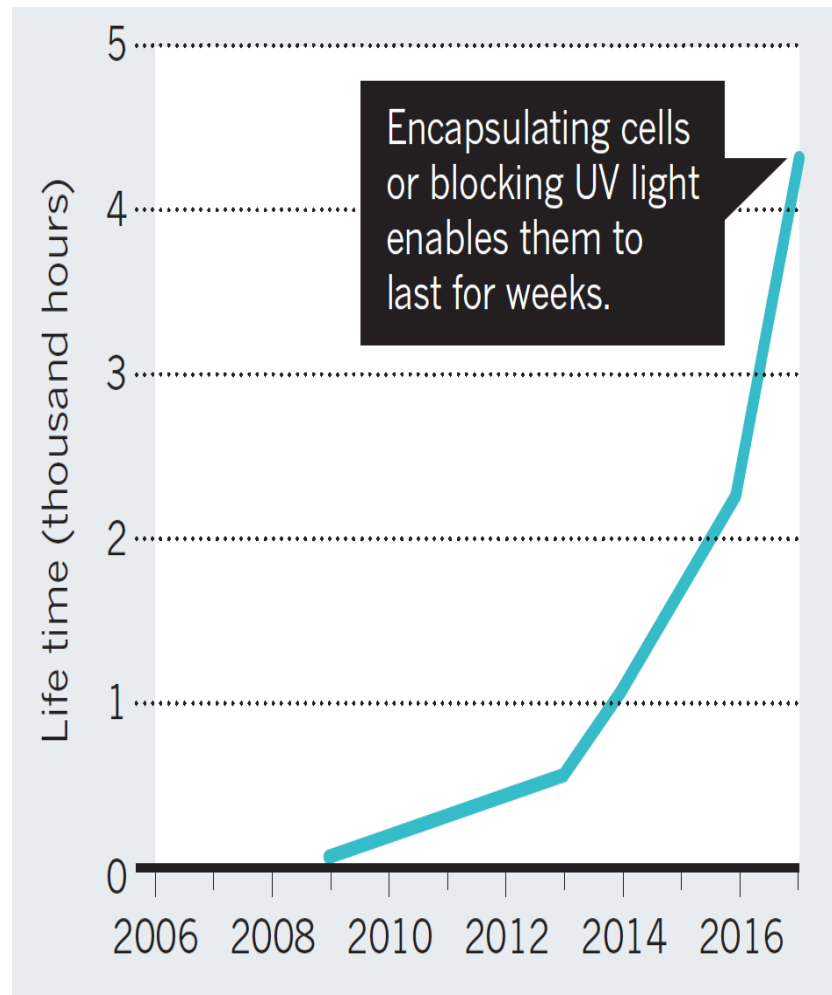


图8 钙钛矿电池寿命发展

钙钛矿电池商业化应用的难题

- 稳定性较差，易与水发生反应，受温湿度、极端光照条件影响较大，使用寿命较短（5~6个月）；
- 制备高效、大面积电池工艺尚不成熟；

改善电池稳定性的方法

- 调控钙钛矿材料的晶体结构，通过少量掺杂提高钙钛矿材料的相稳定性；
- 降低钙钛矿晶体缺陷，减少外界环境的渗透通道；
- 设计新的稳定的钙钛矿材料；
- 采用稳定的无机电荷传输层；
- 改善封装工艺等。

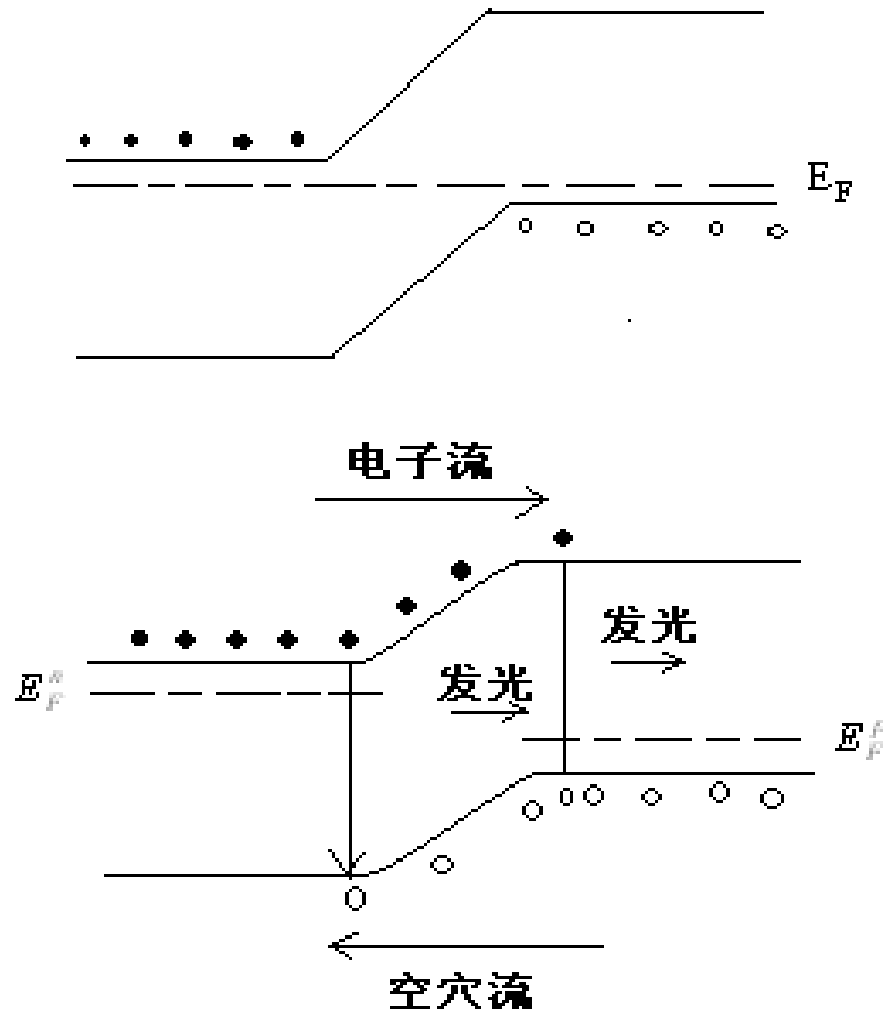


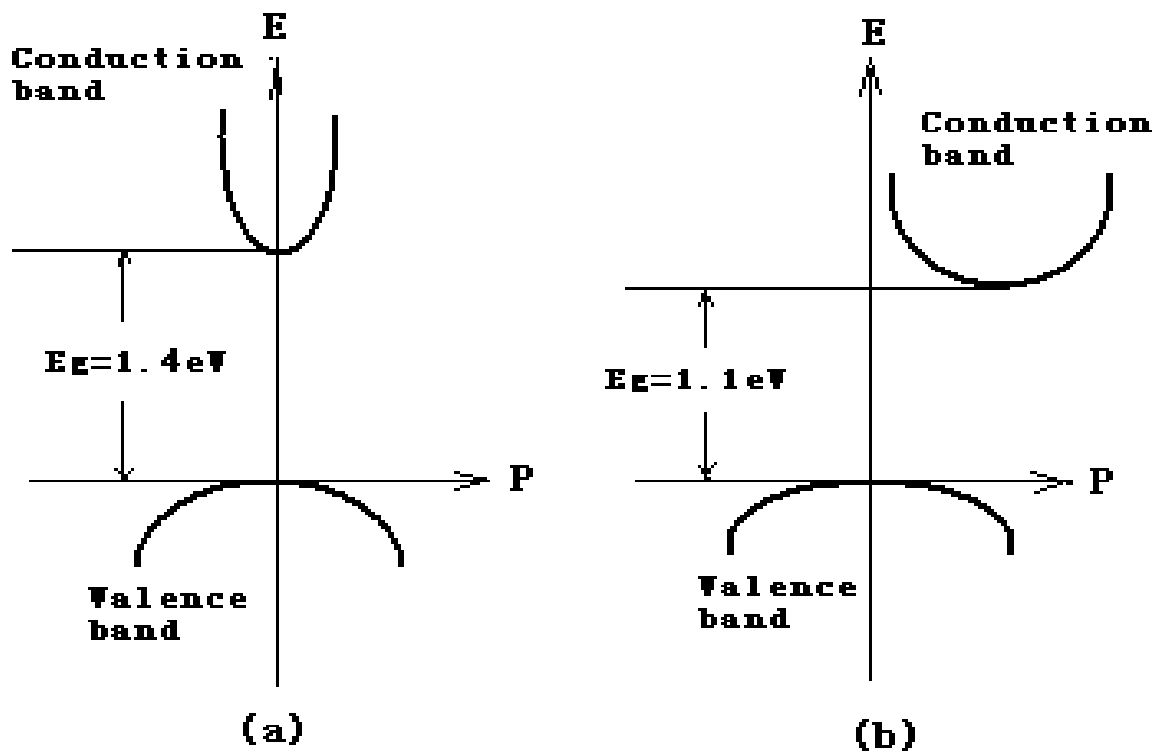
LED 产业介绍

LED industry



LED注入发光机制

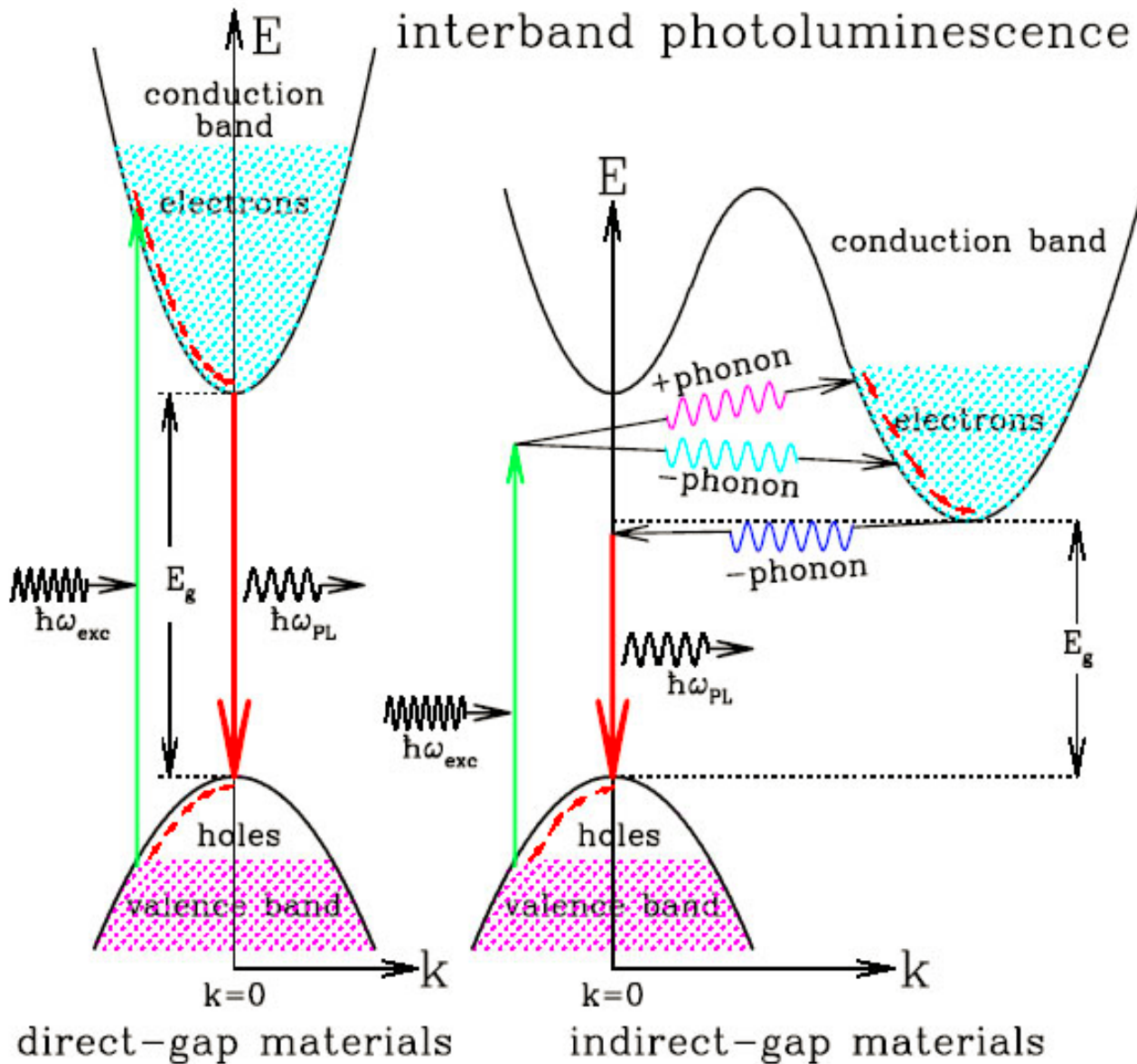




(a) GaAs(direct) (b) Si(indirect)

直接带隙半导体，都是常用的发光材料

interband photoluminescence





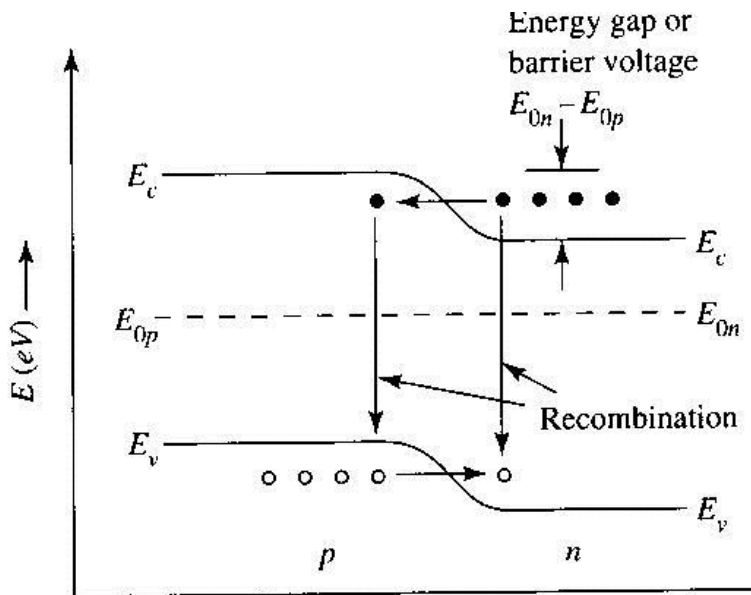
复合 Radiation recombination

Radiation recombination: banded composite, shallow donor - valence band or conduction band - shallow by the main compound (applied, the donor ionization energy is very small, transition and belt - band transition is difficult to distinguish, but due to the introduction of impurity level K is (000), the law of conservation of momentum is easy to meet and improve the probability of direct transition.), The combination of donor and acceptor, through the combination of deep level, such as electronic traps

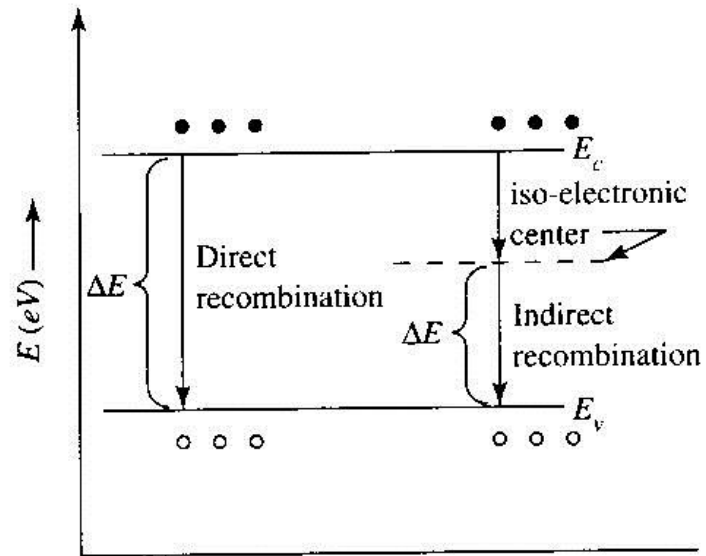
- Nonradiative compound: polyphonic compound, Auger complex, surface composite
- 辐射复合：带带复合、浅施主-价带或导带-浅受主间复合（施、受主的电离能都很小，跃迁与带-带跃迁很难区别，但由于引入杂质能级位于 K 为（000）外，则使动量守恒定律较易满足，提高了直接跃迁几率）、施、受主之间的复合、通过深能级的复合、等电子陷阱等
- 非辐射复合：多声子复合、俄歇复合、表面复合



Radiation from a Semiconductor Junction



(a) p-n junction



(b) Recombination in p-n junction

$$\text{wavelength of radiation: } \lambda = \frac{1240}{\Delta E(\text{eV})} \text{ (nm)}$$

where ΔE : energy gap (eV)

λ : wavelength of radiation (nm)

e.g. GaAs $\Delta E = 1.43$ eV, find the radiation wavelength

$$\lambda = \frac{1240}{1.43} \cong 876 \text{ (nm)} \Rightarrow \text{Near Infrared (NIR)}$$

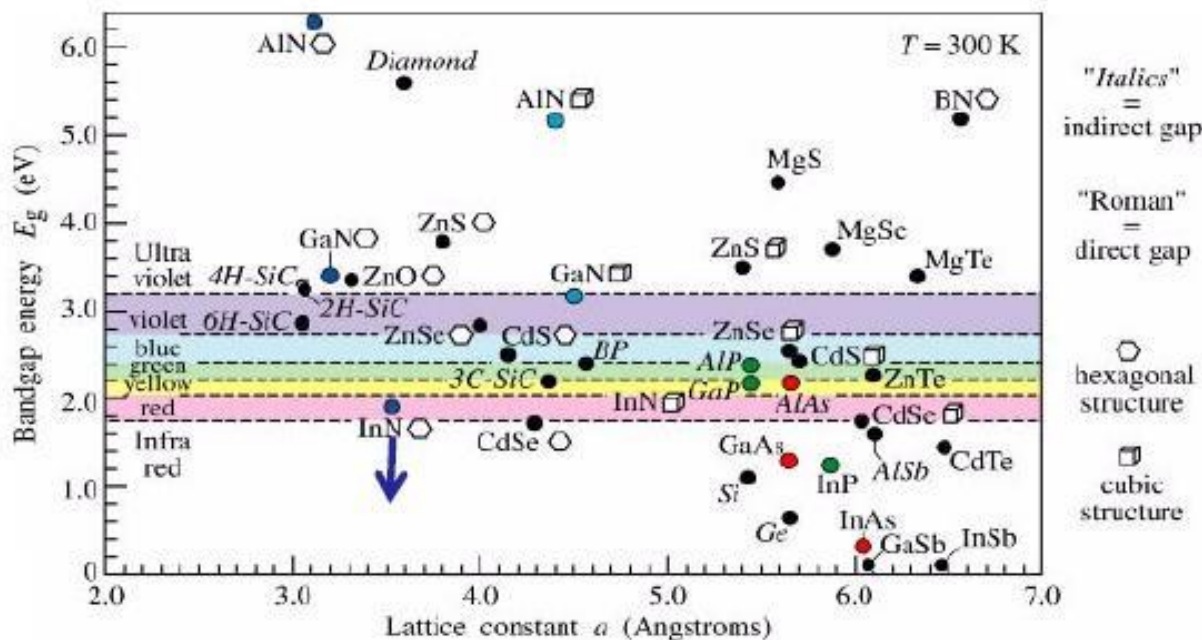


Choice of LED Materials

Choice of light emitting material usually based on the following initial considerations :

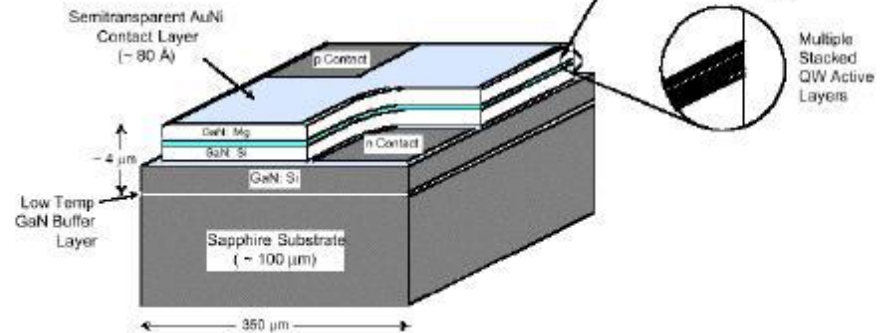
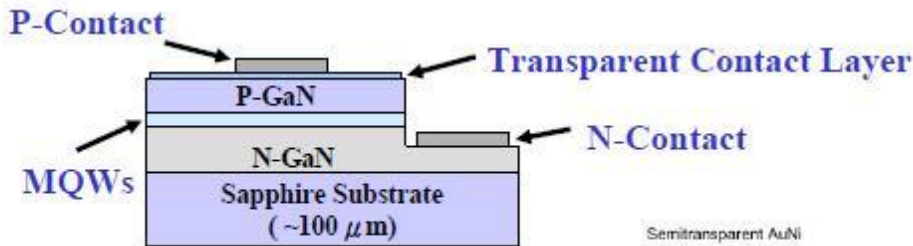
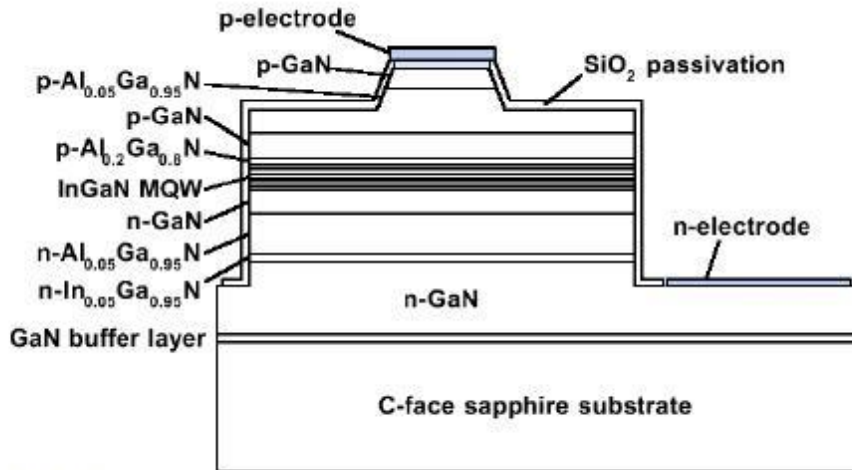
- (1) E_g of the material
- (2) appropriate substrate
- (3) availability of heterostructures

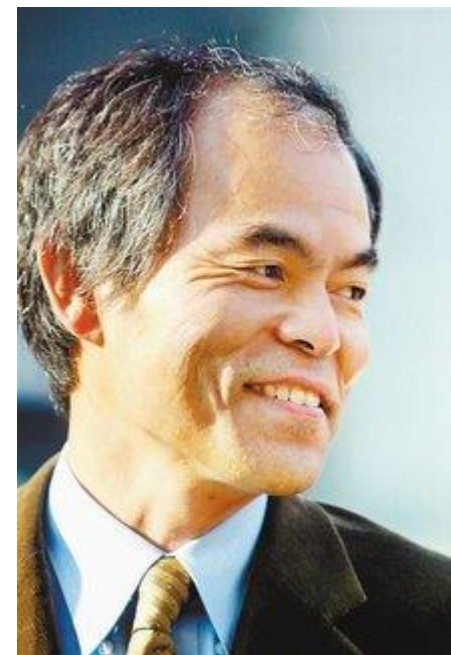
- Choice of Light Emitting Material
- Choice of Substrate
- Epitaxy Structure
- Chip Structure





High Brightness Blue LEDs





2014年诺贝尔物理
奖得主，中村修二
教授



1989: Starting Point of Research

Seeking to get Ph.D. by writing papers

- Very few papers written for GaN
- **Great topic to publish lots of papers!**

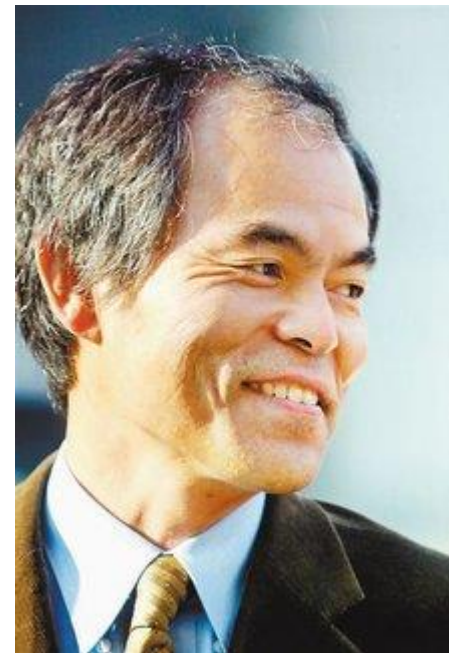
Working at a small company:

- Small Budget
- One Researcher

Commonly accepted in 1970s—1980s:

- **LEDs need dislocation density $< 1 \times 10^3 \text{ cm}^{-2}$**

Never thought I could invent blue LED using GaN...



2014年诺贝尔物理学奖得主，中村修二教授

LED各层结构

I

LED标准结构概述

I.1

如何在Sapphire上成长GaN

I.2

各种GaN材料
nGaN / InGaN / pGaN / AlGaN

GaN材料LED早期发展的瓶颈，除了材料本身制作不易外、整个LED也有其他难以克服的挑战。

首先，GaN没有适当的基板，晶格差异太大难以成长出质量良好的GaN材料。

GaN = _____ Al₂O₃ = _____ Si = _____ SiC = _____.

其次，即使制作出堪用的GaN，却不易制作P型GaN。导致LED整体结构难以实现。

这2个困难点先后被日本几位科学家解决

GaN成长问题:

1983日本田贞史等人以高温AlN作为缓冲层，再成长GaN。

1985日本名古屋教授Isamu Akasaki 以低温AlN作为缓冲层，成长GaN。

1991日亚研究员Nakamura 以低温GaN作为缓冲层，成长GaN。

至此已经大致解决GaN在sapphire上因为晶格差异过大而无法成长的问题。

P型GaN的制作问题:

1989日本名古屋教授Isamu Akasaki利用分子束照射Ga_{0.99}Mg_{0.01}N参杂Mg的材料得到明显的p型Ga_{0.99}Mg_{0.01}N。

1991日亚研究员Nakamura用热退火的方式得到p型Ga_{0.99}Mg_{0.01}N。

至此GaN LED制作的2大难题先后被 Akasaki与Nakamura教授解决。

1993第一颗Ga_{0.99}Mg_{0.01}N LED(蓝光LED)问世，发明人Nakamura。

I.1 如何在Sapphire上成长GaN LED

目前行业采用的方法基本上是基于Nakamura的外延方式。

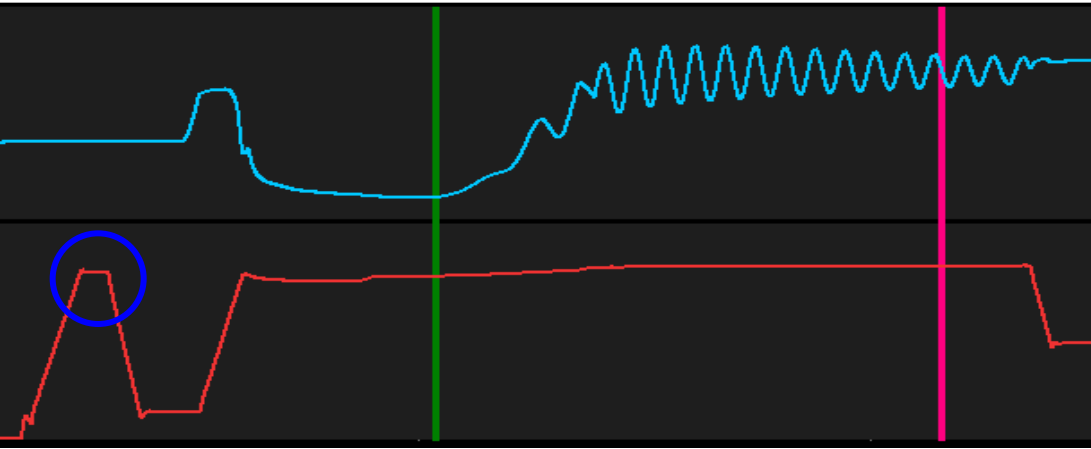
先以低温(约530c)GaN作为缓冲层，再高温(1060c)成长晶格质量较佳的GaN。

P型GaN的制作也是采用Nakamura用热活化(退火)的方式，在约530c(700c)将外延片放入退火炉活化p型GaN。

外延生长时有2个十分重要的量测参数，基板温度与基板的反射率。尤其是透过基板的反射率，可以让我们理解，薄膜成长过程的变化。

下面我们透过反射率曲线，来解释GaN的成长方式。

I.1 如何在Sapphire上成長GaN LED

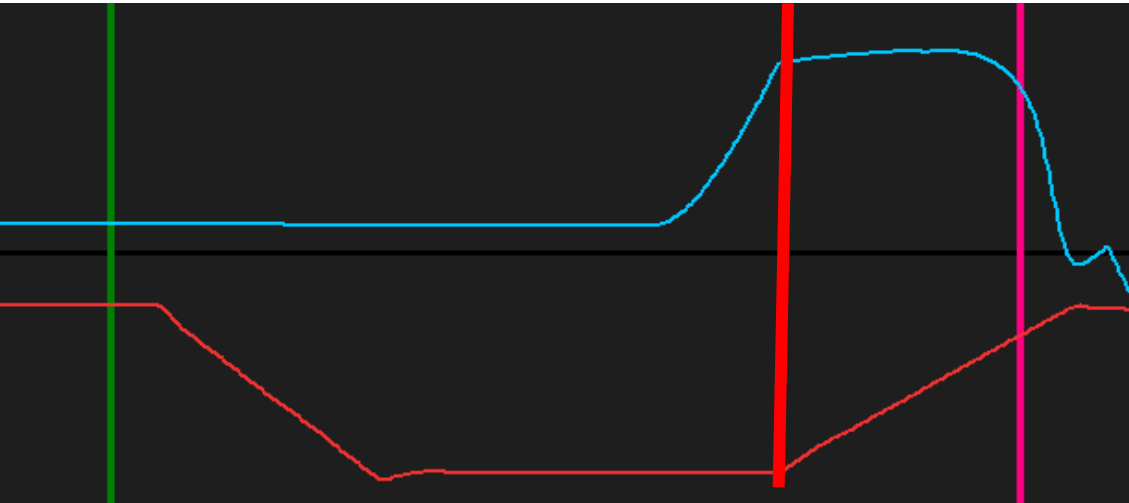


H化

- **H化温度：**1080°C左右 6分钟
- **H化作用：**在开始生长之前，将蓝宝石衬底在高温的氢气气氛中清洁衬底表面，去除杂质、水分等，如去除表面的氧化物薄膜。

Sapphire

I.1 如何在Sapphire上成長GaN LED



BUFFER

- **Buffer**温度：550°C 左右
- **Buffer**作用：在蓝宝石衬底上生长**GaN**为异质结生长，两种材料之间晶格失配大，所以先在较低的温度下，生长很薄的一层**GaN**缓冲过渡层。减小异质结生长所产生的缺陷。
- **Buffer**层的厚度薄厚对后面**GaN**生长温度、片子表面的粗糙度均有一定影响，快测功率有差异，但包灯后功率相近。

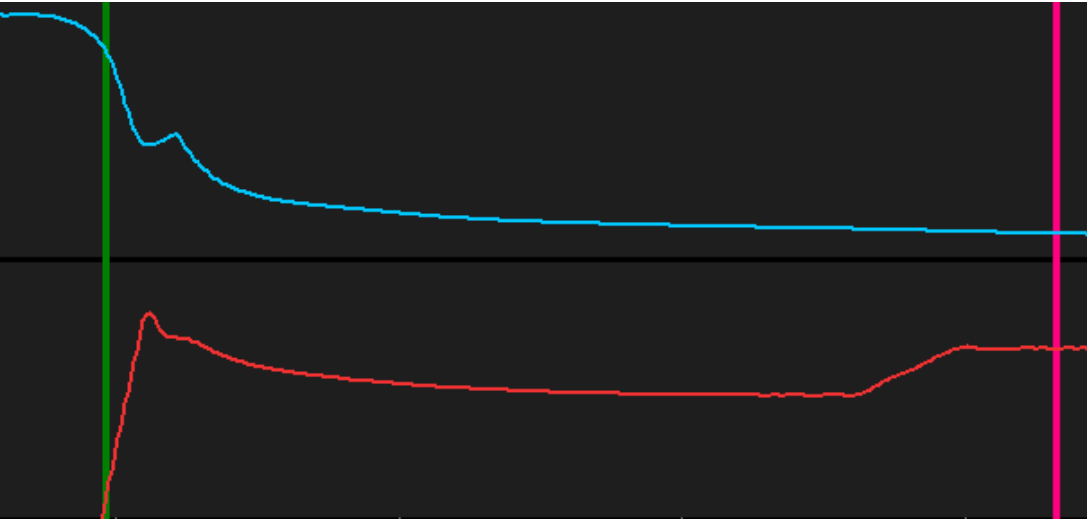
Buffer

Sapphire

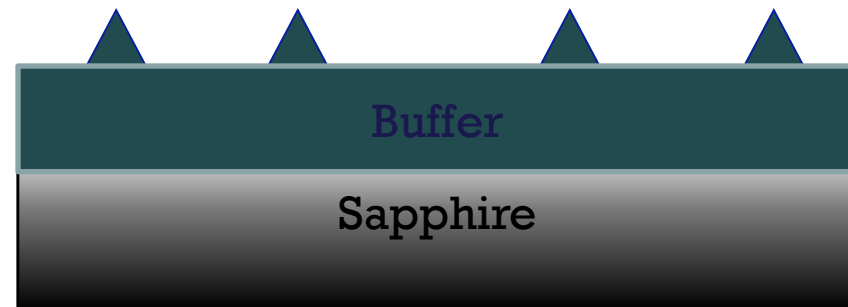
I.1

如何在Sapphire上成長GaN LED

3D

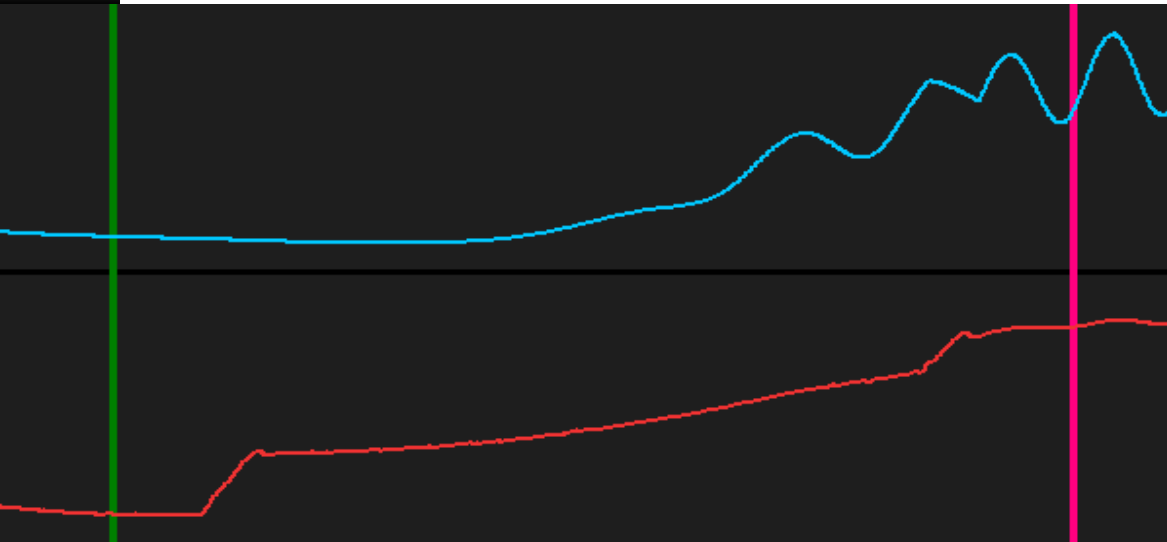


- 3D的温度：1060°C左右
- 3D：在buffer之后，升温后经高温后留下一层薄薄的Ga_N晶种，该层即是以这些Ga_N晶种为基础以三维模式进行生长。
- 3D层生长的质量好对后面的Ga_N生长表面有很大影响（如黑点升温，亮点降温），该层温度相对低能提升VZ。降低IR，但可能会导致VF上升。

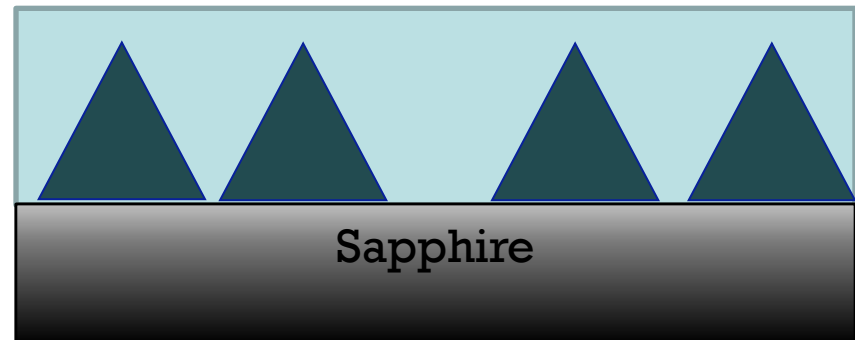


I.1 如何在Sapphire上成長GaN LED

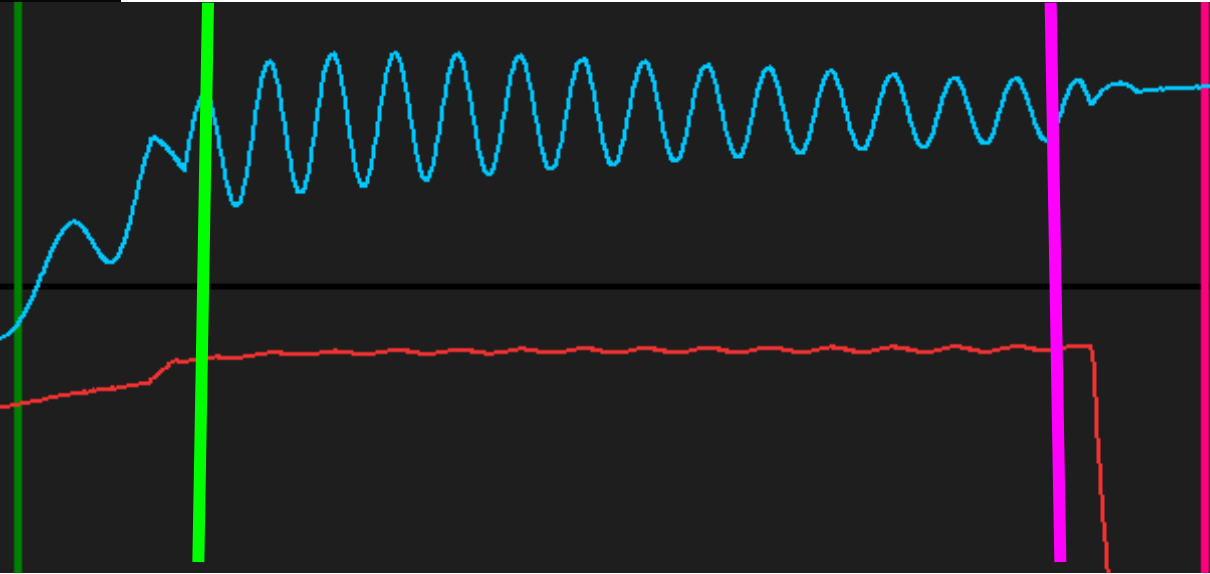
UGaN (2D、GR)



- UGaN的温度：1085°C左右
- UGaN的作用：该层是在三维生长结束后快速的进行二维生长，填平3D未长平区域，得到较平GaN表面。该层能对3D层的生长缺陷进行覆盖。
- 当该层温度过低时，表面可能出现黑点，过高时可能导致表面出现亮点（气泡），该层对VZ、IR、VF、ESD均有影响。

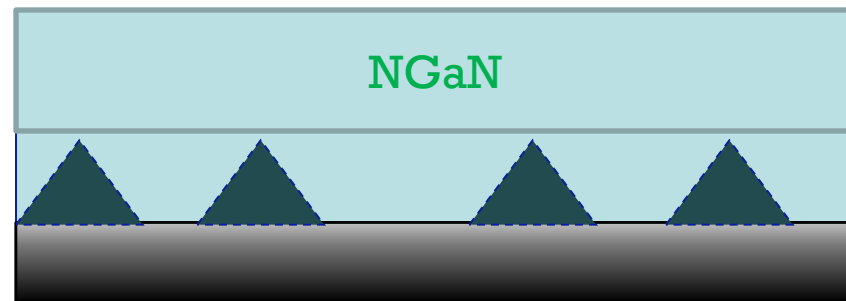


I.1 如何在Sapphire上成長GaN LED

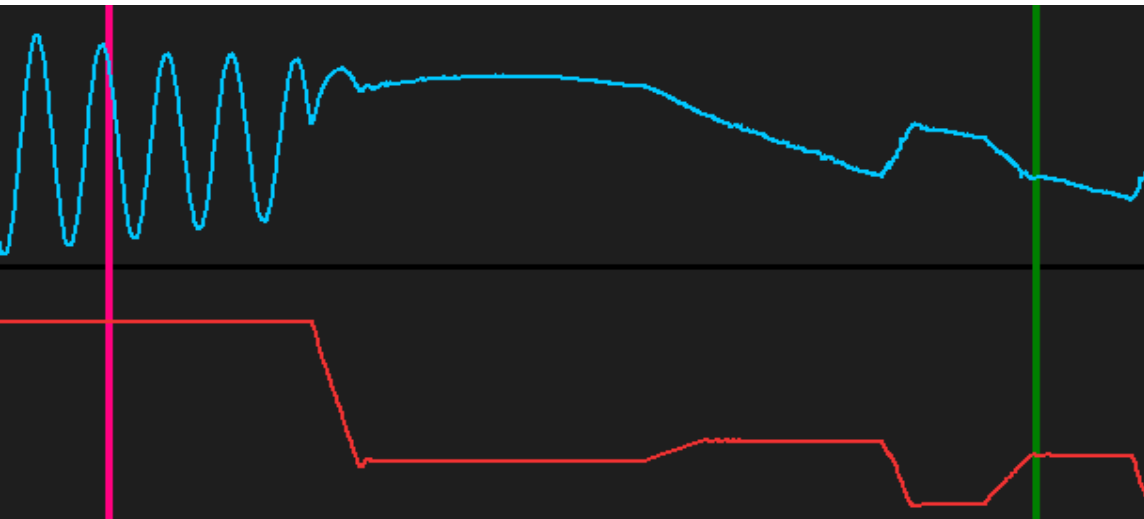


NGaN

- **NGaN**的温度：1095℃左右
- **NGaN**的作用：在高温下生长**GaN**,并在生长中掺入施主杂质（如**Si**），为二极管发光提供辐射复合载流子即电子。该层为**LED**欧姆接触提供**N**型。
- 该层温度过低会导致出现黑点，过高会导致表面出现**Si**裂，两种表面缺陷都会导致**ESD**变差。

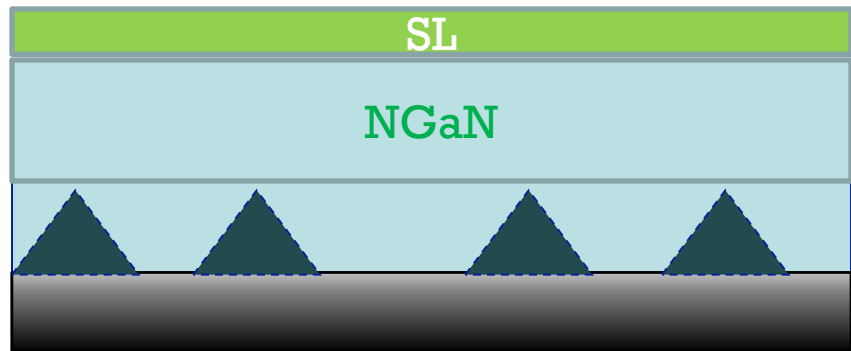


I.1 如何在Sapphire上成長GaN LED



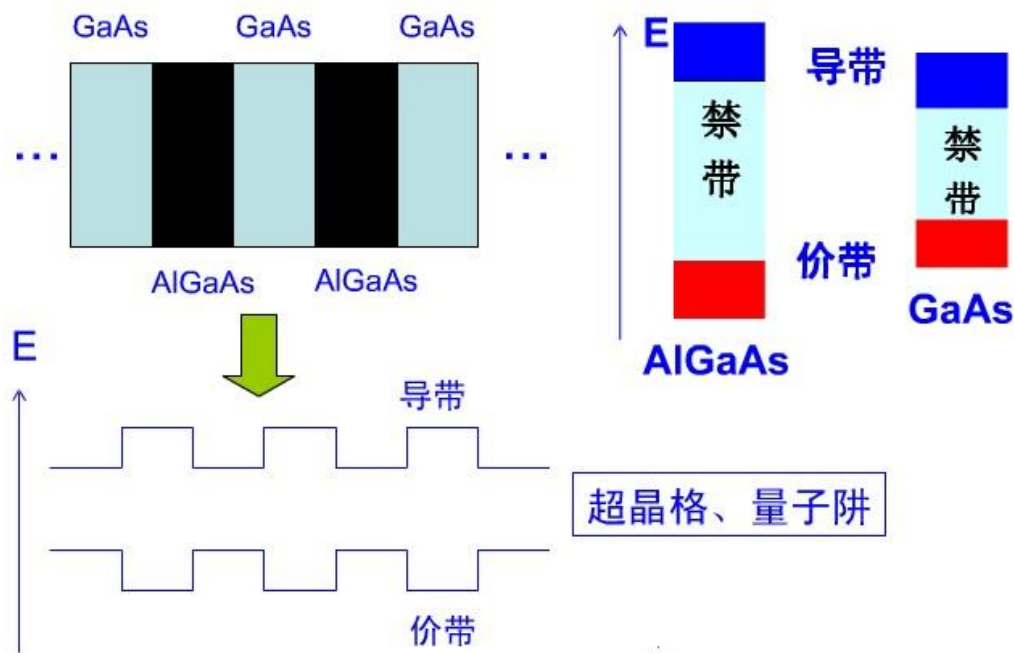
SL

- **SL**的温度：805°C左右
- **SL**的作用：这层也是发光层，部分光由这层产生。同时，这层也为**MQW**的生长起到过渡作用。
- 该层的周期个数对**ESD**有一定影响。





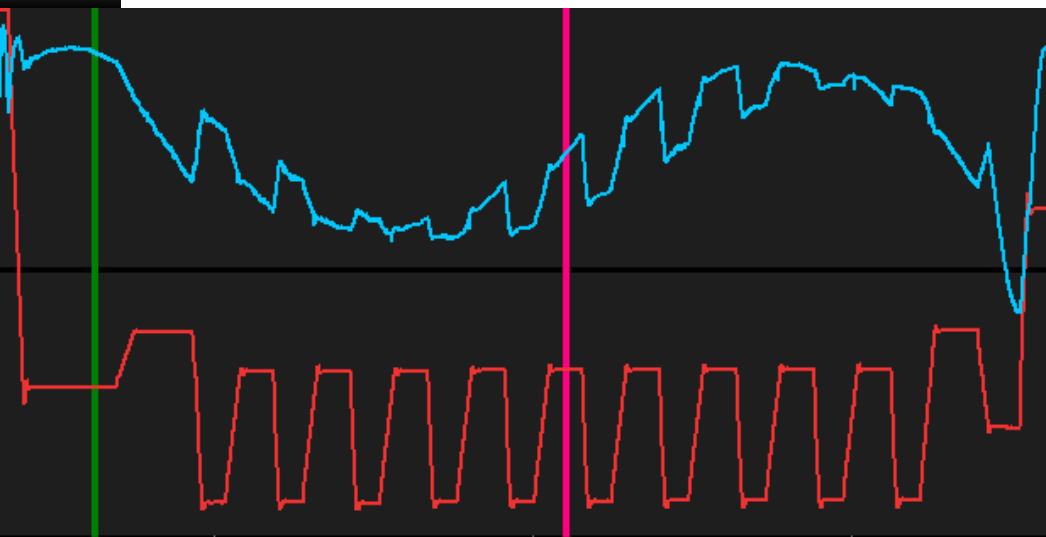
- 1970年: Esaki(江琦) 提出超晶格半导体的概念
- 1971年: 生长出GaAs/AlGaAs 超晶格材料



量子阱中的电子态、声子态和其他元激发过程以及它们之间的相互作用，与三维体状材料中的情况有很大差别。在具有二维自由度的量子阱中，电子和空穴的态密度与能量的关系为台阶形状。而不是象三维体材料那样的抛物线形状。

量子阱的基本特征是由于量子阱宽度(与电子的德布罗意波长可比的尺度)的限制，导致载量子阱流子波函数在一维方向上的局域化，量子阱中因为有源层的厚度仅在电子平均自由程内，阱壁具有很强的限制作用，使得载流子只在与阱壁平行的平面内具有二维自由度，在垂直方向，使得导带和价带分裂成子带。

I.1 如何在Sapphire上成長GaN LED



MQW

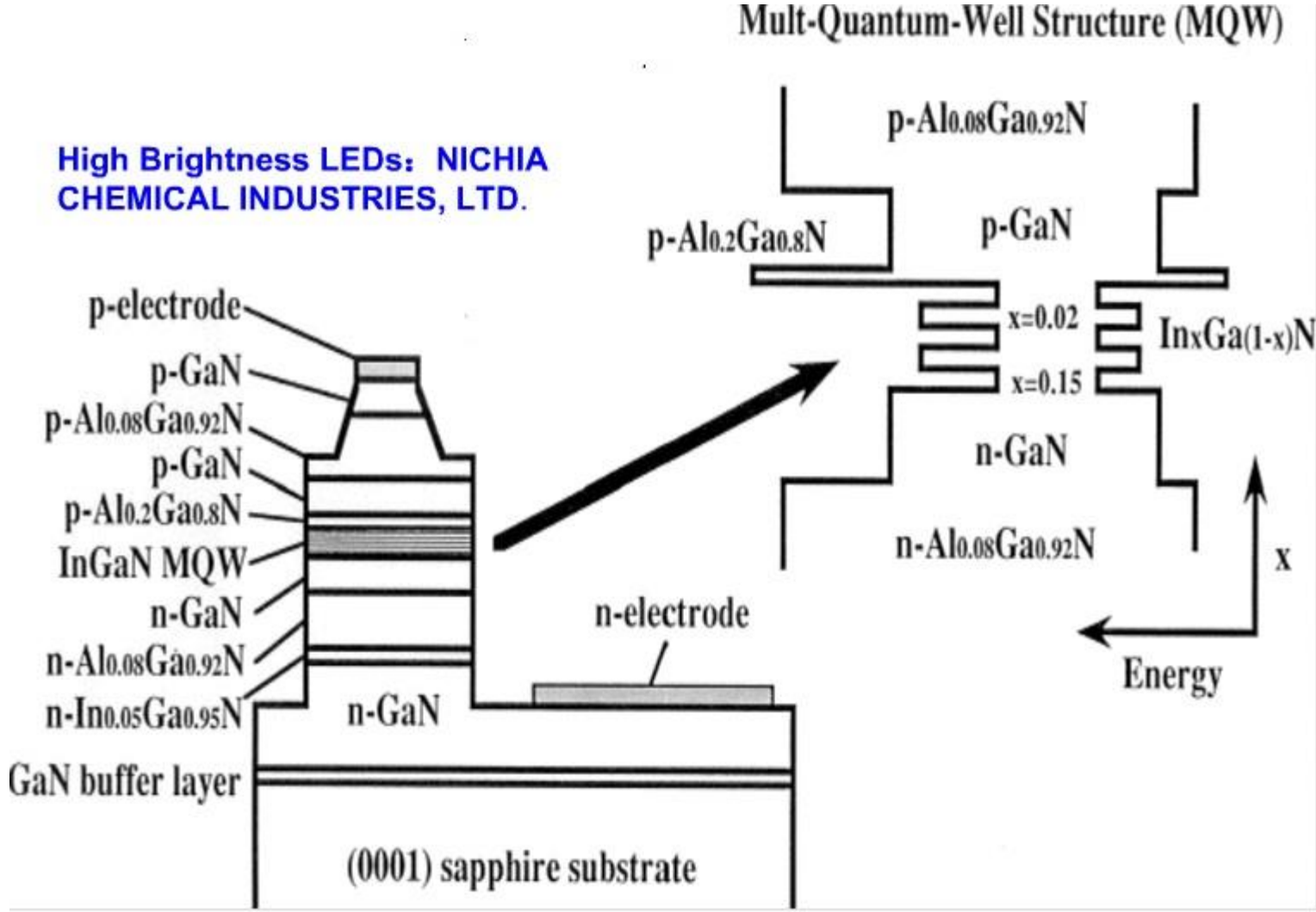


- MQW的溫度： 710°C 左右
- MQW的作用：**LED**的主要發光層。**PGaN**和**NGaN**提供的輻射復合載流子主要在這層輻射復合發光。**LED**的發光波長和強度由這層來決定。
- 該層晶格質量至關重要，基本上對產品的各項性能都有較大影響。



含MQW多量子阱的蓝光LED

High Brightness LEDs: NICHIA CHEMICAL INDUSTRIES, LTD.





How much the Maximum LED efficiency

$$N_w = K_w \int_{400}^{700} \frac{\phi_w(\lambda)\lambda}{hc} d\lambda$$

● 假设蓝光芯片的外量子效率和荧光粉量子效率均为1，则白光光子数等于蓝光光子数，等于注入的电子-空穴对数，即：

$$N_w = N_{eh} = 2.7 \times 10^{18}$$

工作电流为 eN_{eh} ：由工作电压就可以计算出产生1 W 白光辐射光功率消耗的电功率：

工作电压为2.8-3.0V时，
白光LED的发光效率极限值为：

$$\eta_{\max} = \Phi_{\max} / eN_{eh} V$$

$$\eta_{\max} = 250 - 300 \text{ lm/W}$$



150lm/W Target has been Overcome

Table 3.2: Summary of LED Package Price and Performance Projections

Metric	2010	2012	2015	2020
Cool White Efficacy (lm/W)	133	166	197	215
Cool White Price (\$/klm)	13	6	2	1
Warm White Efficacy (lm/W)	95	133	179	211
Warm White Price (\$/klm)	18	7.5	2.2	1

Table 5.1: Summary of Warm White pc-LED Luminaire Efficiencies and Efficacies

Metric	2010 Status	2020 Target
Diode Efficiency	49%	77%
Phosphor Conversion	47%	62%
Spectral Efficiency	82%	95%
LED Package Efficiency	27%	53%
LED Nominal Efficacy (lm/W)	92	183
Luminaire Efficiency	62%	79%
Luminaire Efficacy (lm/W)	57	144
High Current Luminaire Efficacy (lm/W)	44	144

Note: Luminaire efficiency only includes driver, fixture, and thermal effects.



未来2年要突破200lm/W

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Note: Luminaire efficiency only includes driver, fixture, and thermal effects.



3.2.1 透明电极技术

P电极研究简介

由于p-GaN导电性能不佳而且不宜生长太厚，必须使用辅助电流扩展的透明电极材料。

功率型LED对电极性能的要求如下：

- 低电阻率
- 低接触电阻
- 高透过率
- 良好的热稳定性能
- 与GaN基LED加工工艺兼容



透明导电氧化物——ITO

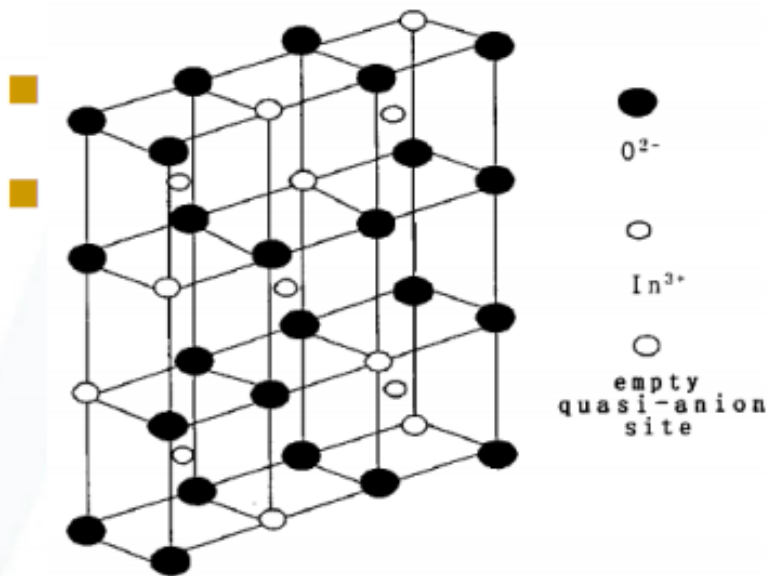


图2.1 In_2O_3 晶体结构

Fig.2.1 Crystal structure of In_2O_3

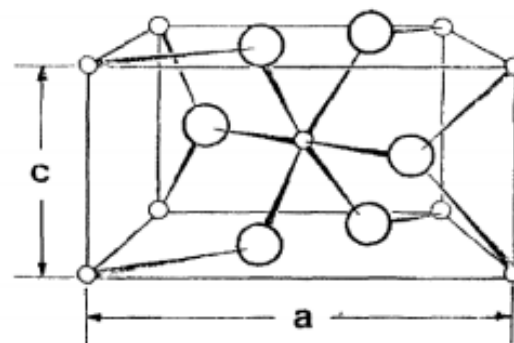


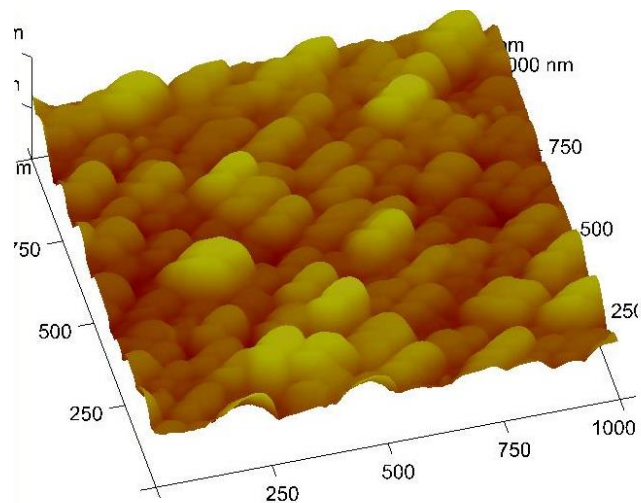
图 1-1 氧化锡的晶胞结构

Fig. 1-1 Unit cell of the crystal structure of SnO_2 , large circuits indicate oxygen atoms and the small circuits indicate tin atoms.

- 常用ITO薄膜靶材一般使用氧化铟、氧化锡90:10的重量比，在晶体结构中Sn元素主要作为代位离子，晶体结构仍为氧化铟的体心立方结构。



- ITO为什么会导电：ITO薄膜的禁带宽度接近4eV，其导电依靠附加能级上的电子和空穴的激发，在 In_2O_3 中掺入少量 SnO_2 后， Sn^{4+} 取代 In^{3+} 后产生一个正电子中心，释放一个自由电子。
- ITO为什么透明： In_2O_3 中的 In^{3+} 的最外层电子为 $4d^{10}$ ，d电子亚层全充满， In_2O_3 的能隙较宽约为3.75eV，用波长大于330nm的可见光照射ITO薄膜时，光子能量不足以使In的 $4d^{10}$ 满带的价电子跃迁到导带，所以ITO薄膜表现为透明状态。





透明导电氧化物——ITO

- ITO薄膜在LED中的应用：
 - 电流扩展层（电阻率 $10^{-2} \sim 10^{-4} \Omega \text{ cm}$ ）
 - 欧姆接触层（P-GaN/N-GaN欧姆接触）
 - 减反膜（折射率2.0左右）
- ITO薄膜设计要求：
 - 透过率与串联电阻均衡；
 - 减反膜设计：复合膜系设计
渐变折射率ITO薄膜



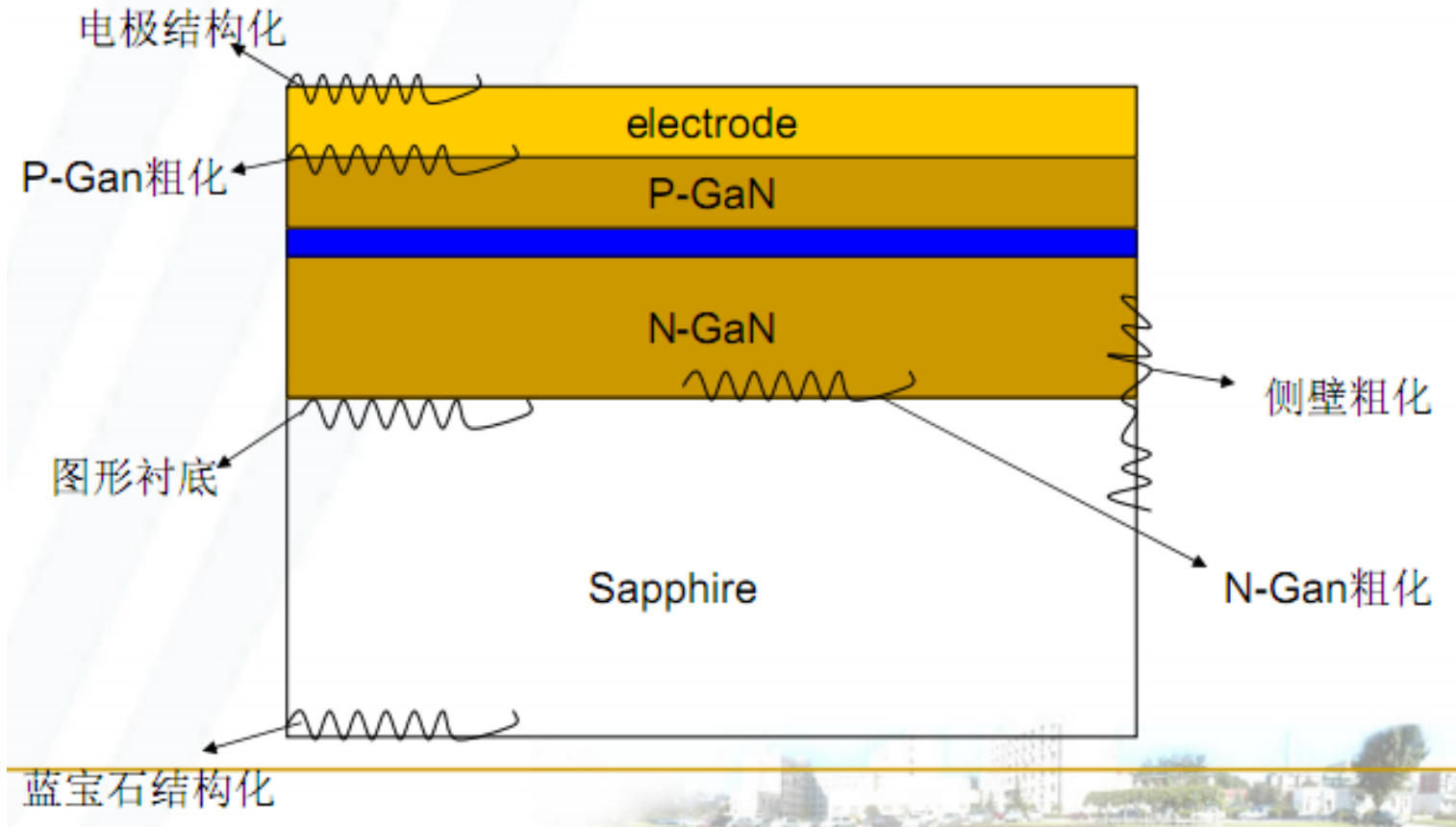
透明导电氧化物——ITO

■ ITO可靠性

- 在还原气氛下，尤其是有游离态氢存在的环境中，ITO材料中的金属组分被还原，形成亚微米金属颗粒从而降低ITO材料的透过率但同时电导率得到了提高，这种效应在多种TCO材料中都存在。
- 在空气和高温（ $>200^{\circ}\text{C}$ ）环境中，氧在ITO薄膜中的表面到内部的扩散会导致ITO层电阻率的上升。从表层扩散到内部的氧占据了氧空位和晶界上对氧的化学吸收作用引起的载流子密度下降和迁移率下降导致的。
- 在高温退火（ $>700^{\circ}\text{C}$ ）下，在光伏器件或LED中作为电极的ITO会产生In组分扩散通过缺陷进入材料活性区导致漏电甚至短路的情形。

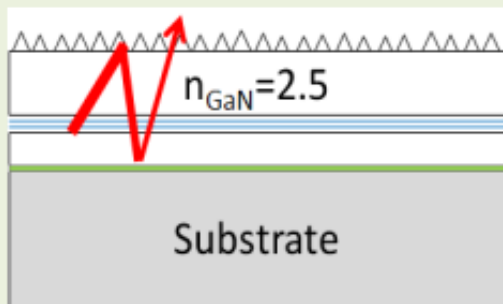
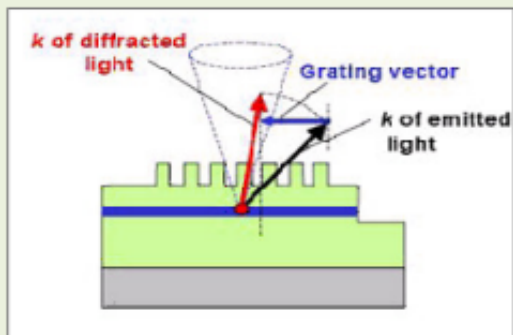


3.2.2 粗化技术





表面粗化的类型



有序结构

采用掩膜版

有序微结构、光子晶体

干法刻蚀

成本高、难度大、易造成损伤

无序结构

无掩膜技术

无序纳米结构

湿法腐蚀

设备简单成本低、无损伤



表面粗化的类型

形貌选择

形状 \ h/D	0.01	0.05	0.1	0.5	1	1.5
圆锥	37.1%	49.1%	53.6%	58.5%	59.8%	60.1%
六角锥	44.6%	84.9%	94.5%	96.1%	96.2%	96.2%
四角锥	35.8%	80.2%	94.8%	70.9%	96.1%	96.2%

- 六角锥形最有利于出光。
- 锥体高度与底面外接圆直径比值0.1,提取效率即可达到90%以上。



表面粗化的工艺实现

➤ 湿法腐蚀 (加热腐蚀, UV辐照腐蚀, 光辅助电化学腐蚀)

- 低损伤
- 低成本
- 工艺较简单
- 选择性腐蚀

➤ 干法刻蚀 (ICP刻蚀、RIE刻蚀)

- 形貌控制
- 离子损伤, 引入反向漏电流
- 成本较高

➤ 纳米压印

➤ 自组织纳米掩膜技术 (金属缩球、聚合物、微球、石英纳米颗粒)

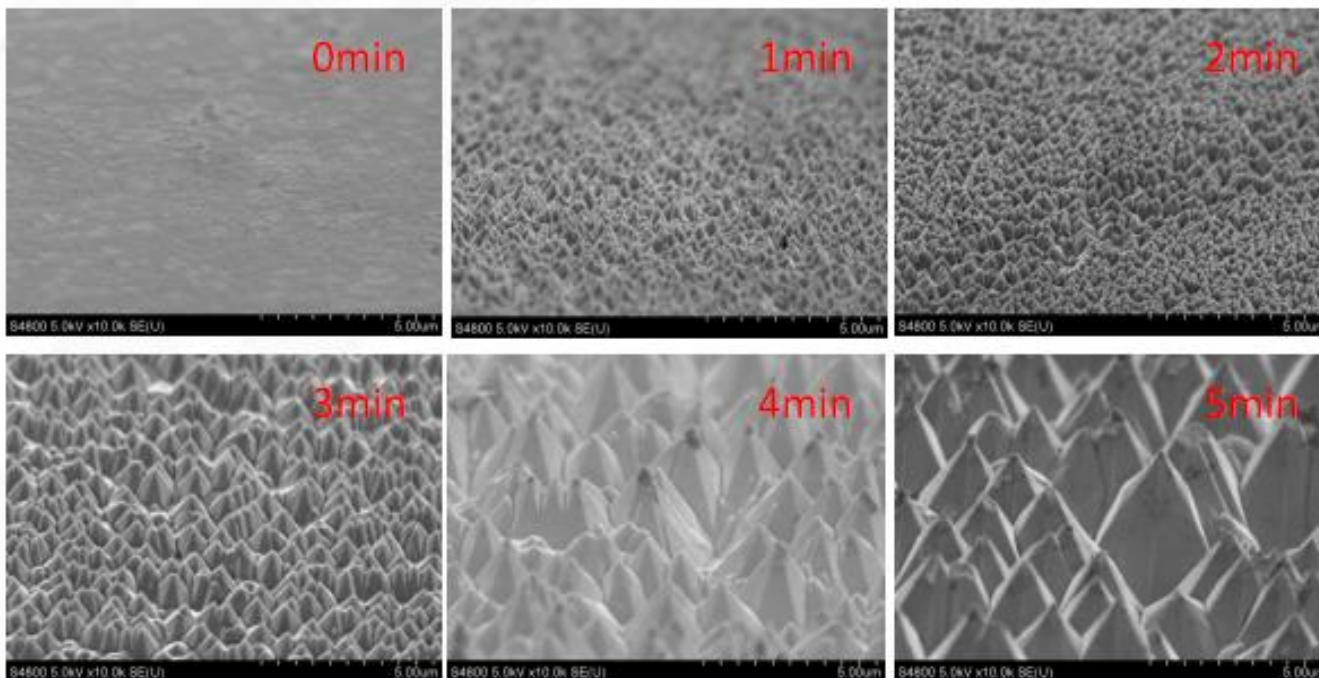
➤ 原位生长

➤ 阳极氧化铝.....



表面粗化对器件效率的改善效果

N-GaN表面粗化

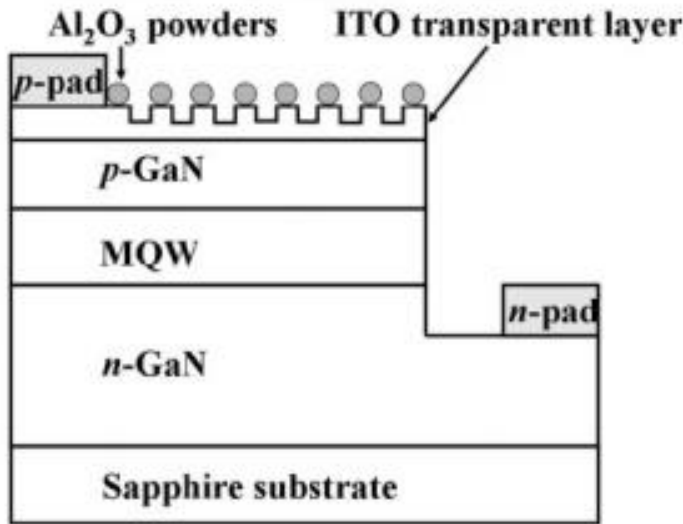


腐蚀时间	0min	1min	2min	3min	4min
roughness (nm)	9	78	158	216	292

The SEM photograph of roughing GaN after different etching time



电极粗化



300nm Al₂O₃ 粉末作为刻蚀掩膜。

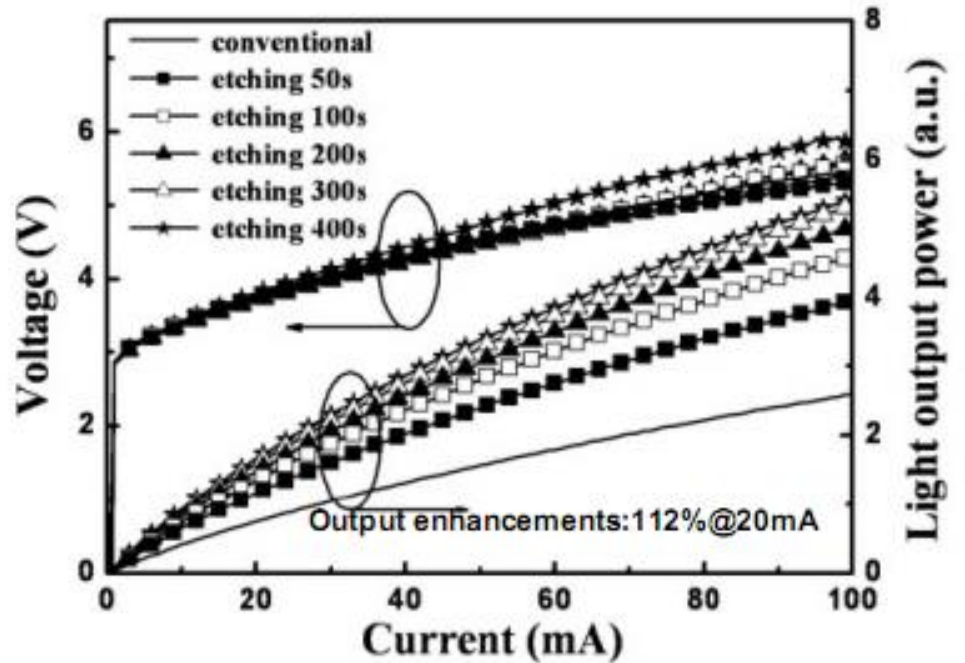
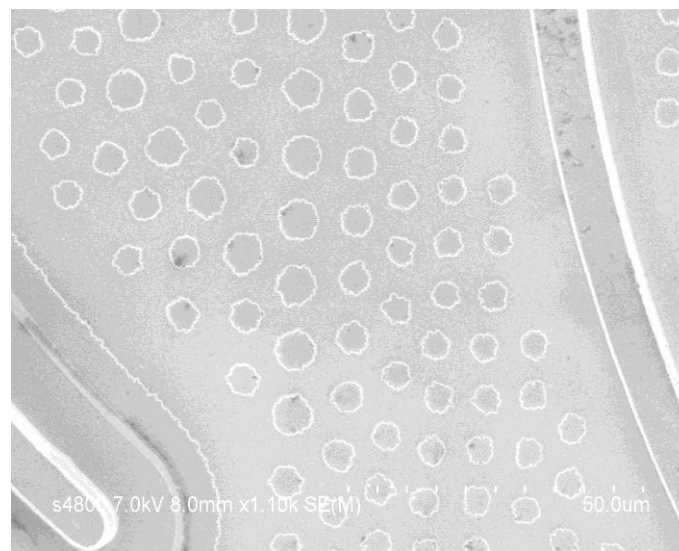
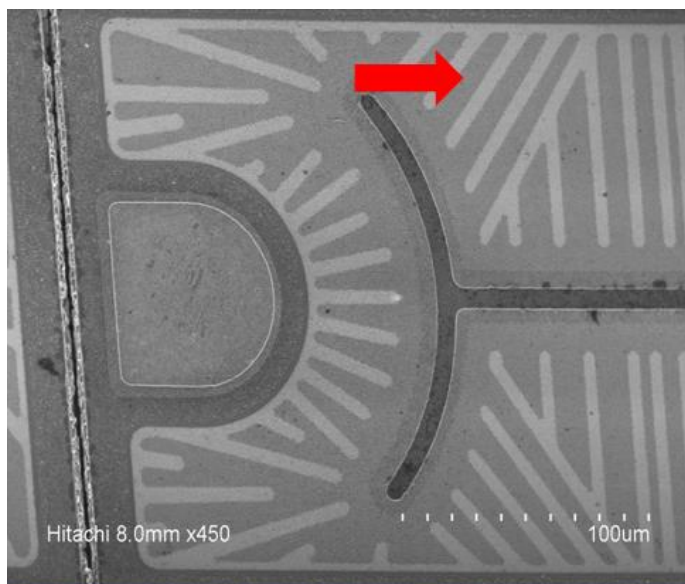


FIG. 3. *L-I-V* curves of surface-textured LEDs coated with Al₂O₃ powders for different ITO-etching times.



ITO网状结构



- ITO网孔结构可以增加表面光的逃逸路径，缩短光程，使亮度增加，但由于有效的欧姆接触面积减少，会使电压略有增加
- ITO网孔的尺寸、密度不同，亮度提高程度也有所不同，较好的设计可以使亮度提高25%，外量子效率提高5%



N-GaN表面粗化

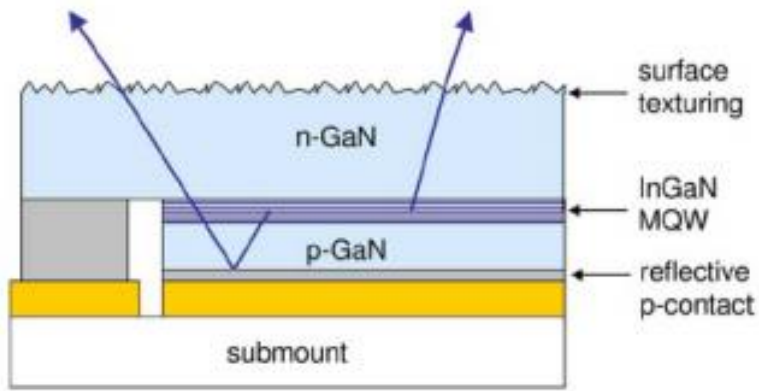
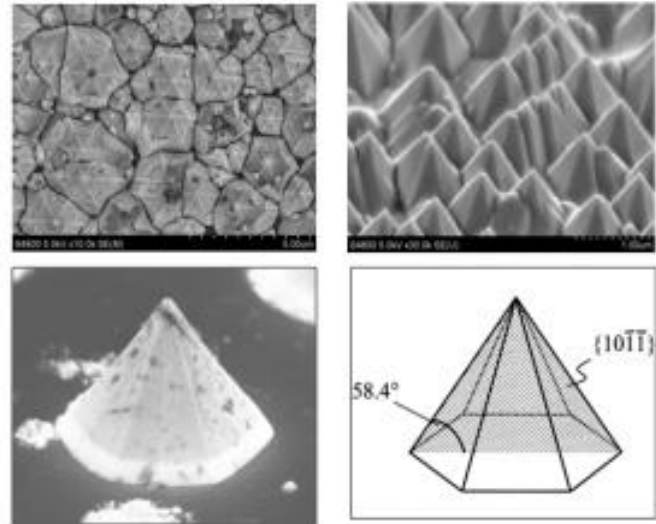


Fig. 9. General design of TFFC InGaN LEDs. Enhanced light extraction is achieved through substrate removal, n-GaN surface texturing, and use of a reflective p-contact.

extraction efficiencies as high as 80%

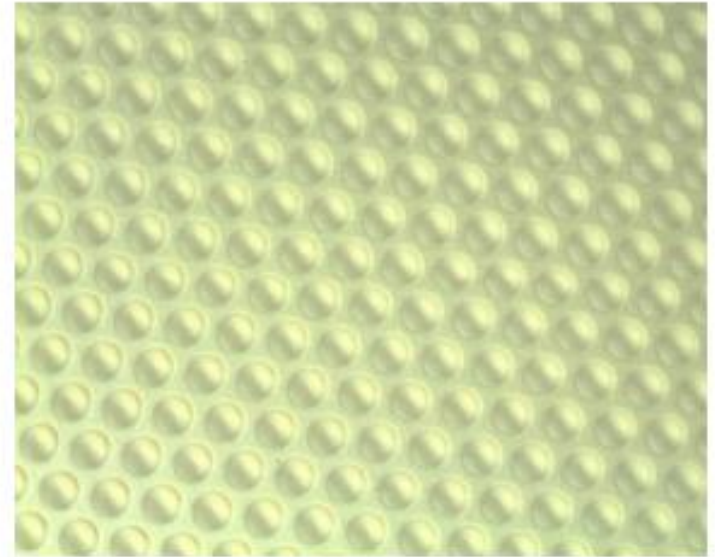
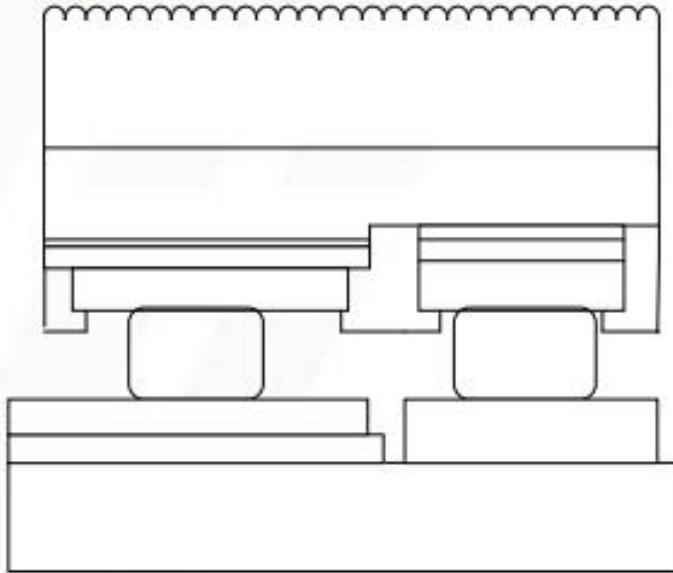


N面粗化容易实现，粗化密度高，粗化尺寸合适。



蓝宝石衬底粗化

蓝宝石微透镜阵列

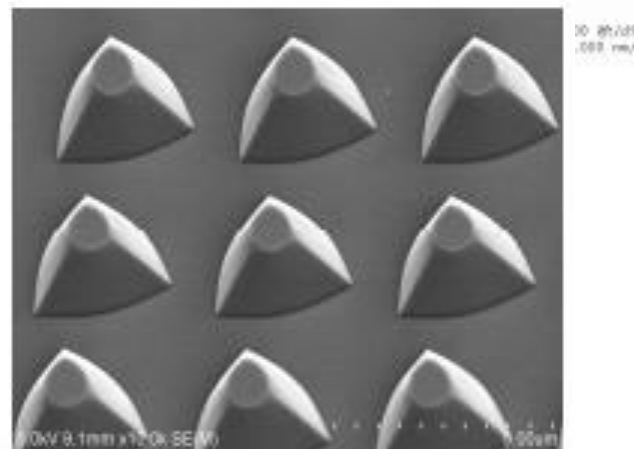
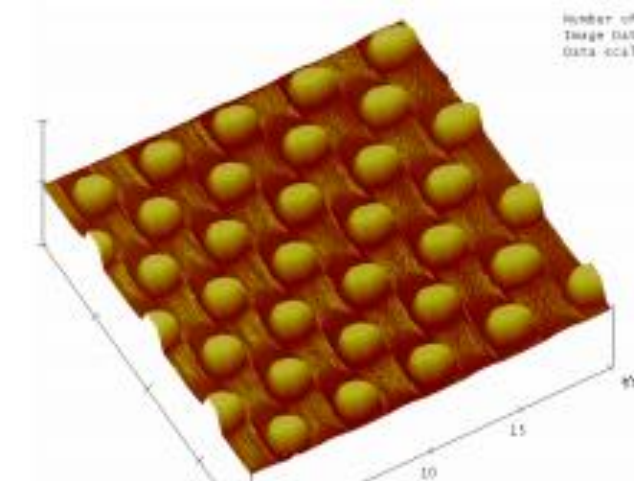
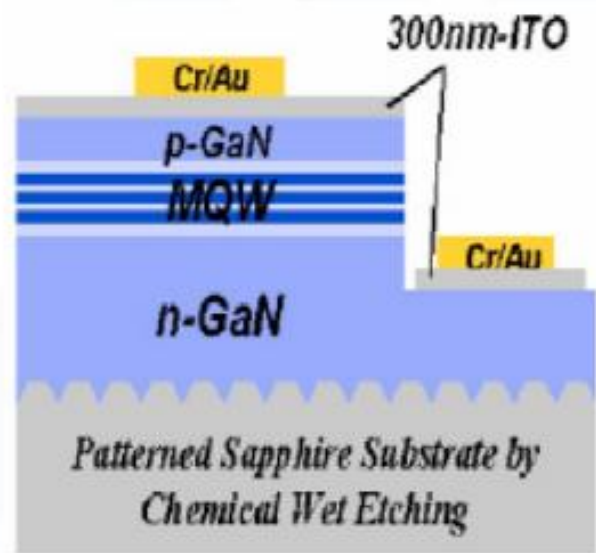


提取效率: improved 75% without pkg, 19% after pkg.



图形衬底

图形衬底技术:



侧壁粗化

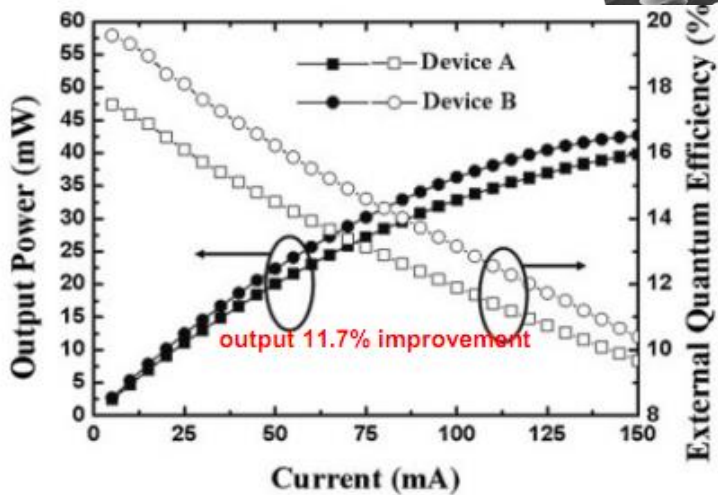
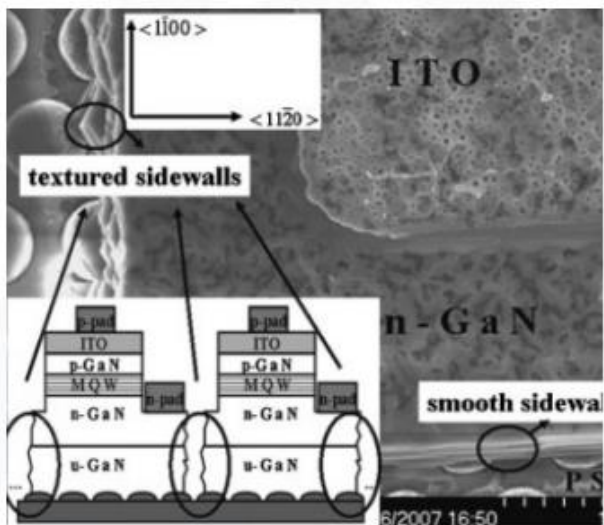
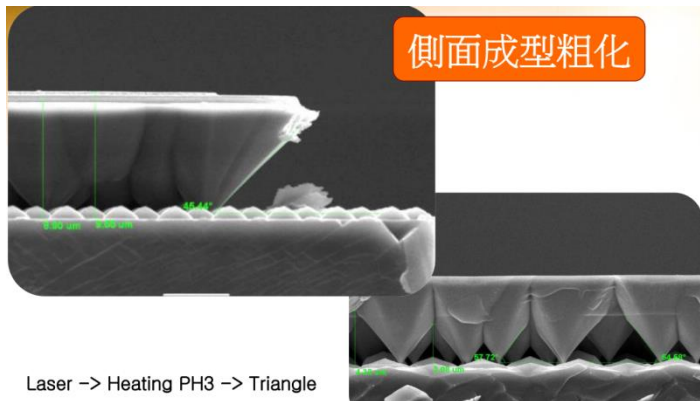


Fig. 8. The output power and EQE as a function of operation current for device A (without textured sidewall) and B (with textured sidewalls).



ZnO

透明导电氧化物——ZnO

■ ZnO基透明导电材料—AZO膜(ZnO: Al)和GZO膜(ZnO: Ga)

- 本征吸收小（禁带宽度为3.2eV左右）
- 折射率较高（2.1左右）
- 易掺杂（n-ZnO掺杂浓度 10^{19}cm^{-3} ）
- 晶格常数与GaN材料近似
- 易加工、低成本

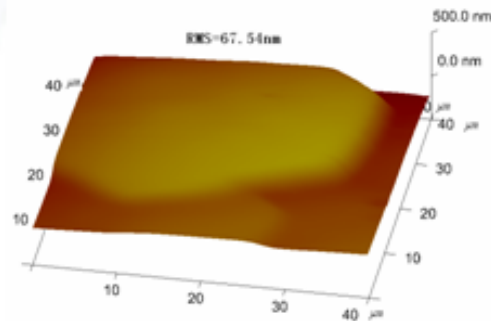
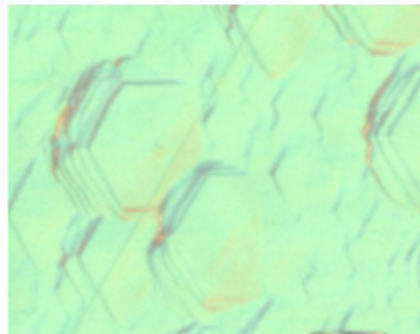
■ 用于GaN基LED的ZnO薄膜制备方法：

溅射、电子束蒸发、热解法、MBE、LPE、MVPE。

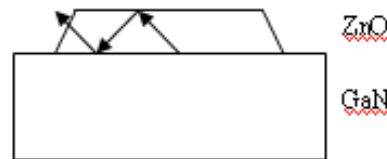
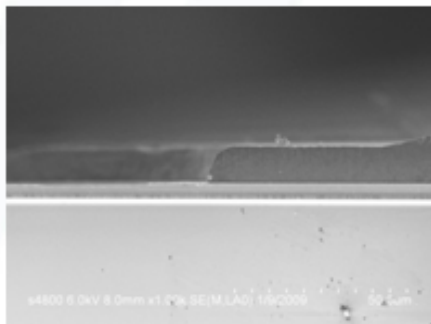


ZnO作为透明电极层提高了光提取效率

- ◆ ZnO单晶膜层对光的吸收ITO和Ni/Au更小;
- ◆ MVPE生长的ZnO表面晶粒存在为六角形边界，晶粒约200um，同一晶粒表面起伏几纳米，不同晶粒高度差约100nm。ZnO腐蚀后得到倾斜侧面{10-1-1}面，与底面夹角约为27度。特殊的几何结构提高了出光效率。



ZnO表面形貌



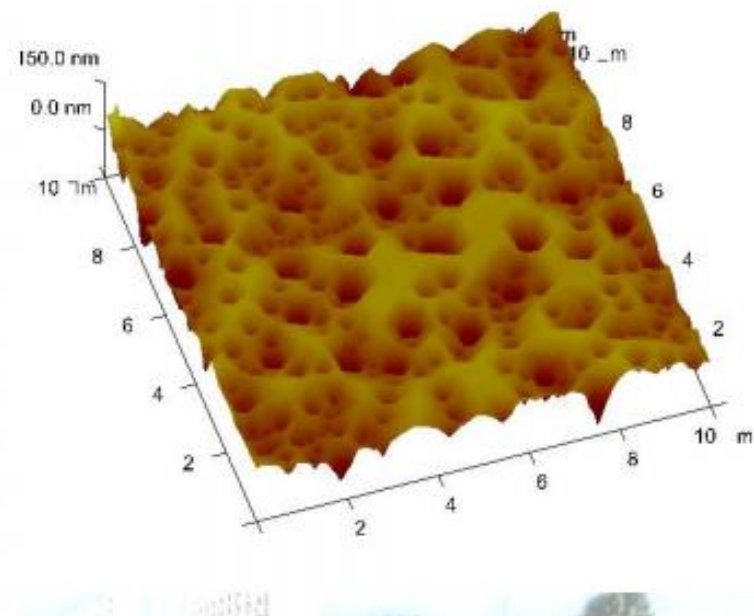
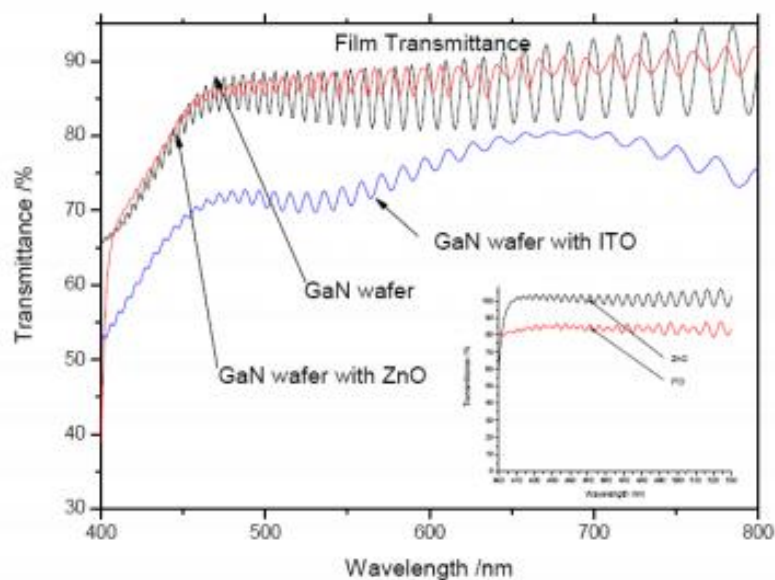
ZnO薄膜腐蚀截面

ZnO-LED的电压比ITO-LED高近一倍。
ZnO的材料生长工艺还有待进一步研究



透明导电氧化物——ZnO

在ZnO 薄膜中进行一定的元素掺杂电阻率 $10^{-1} \sim 10^{-4} \Omega \text{ cm}$ ，接近半金属的数值。
在可见光波长范围内的光透过率可达90%以上。
ZnO薄膜表面易于加工出各种微纳图形。





透明导电氧化物——ZnO

电流扩展层采用Ga掺杂ZnO薄膜，与ITO薄膜相比，外量子效率提高约30%。

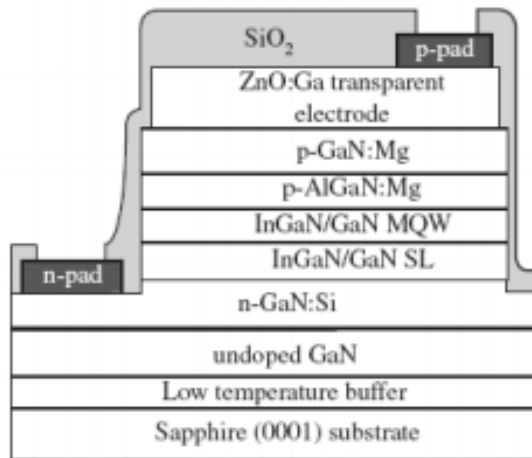
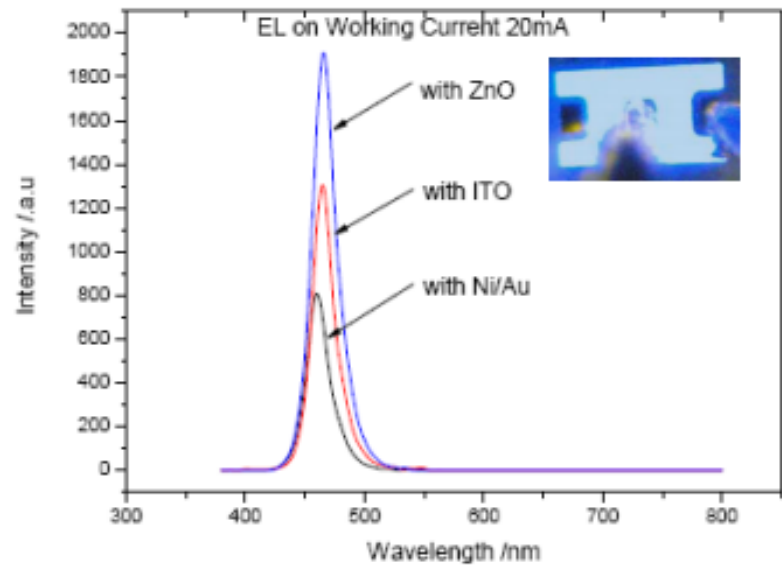


Fig. 1. Schematic cross-sectional structure of the InGaIn-based light-emitting diode-chip with use of Ga-doped ZnO (ZnO:Ga) film as a p-contact electrode.





透明导电氧化物——ZnO

wafer bonding技术

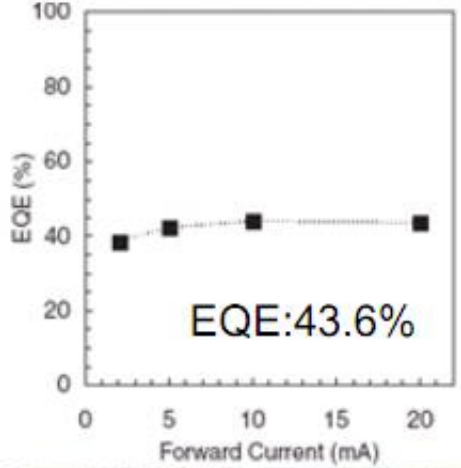
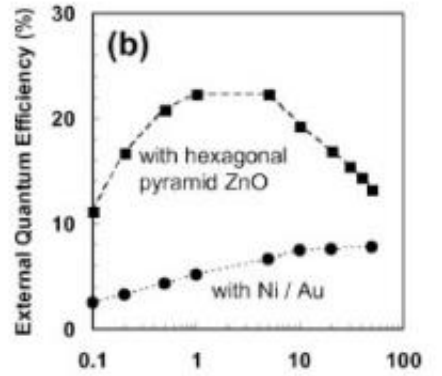
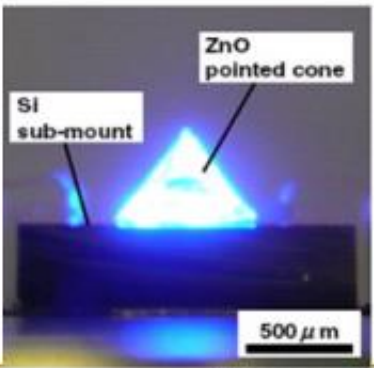
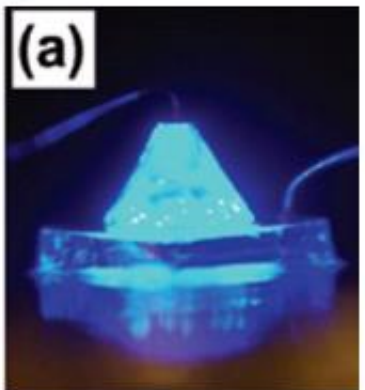
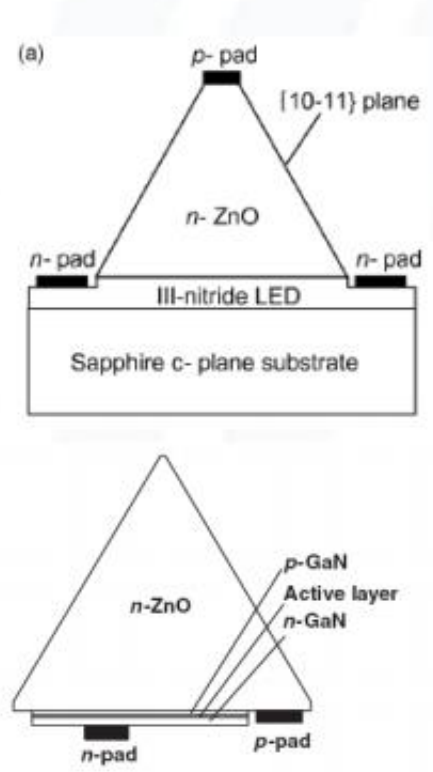
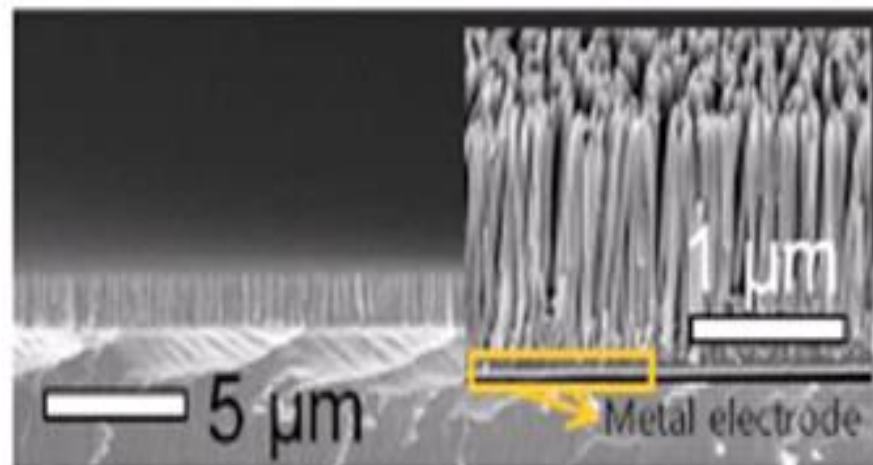
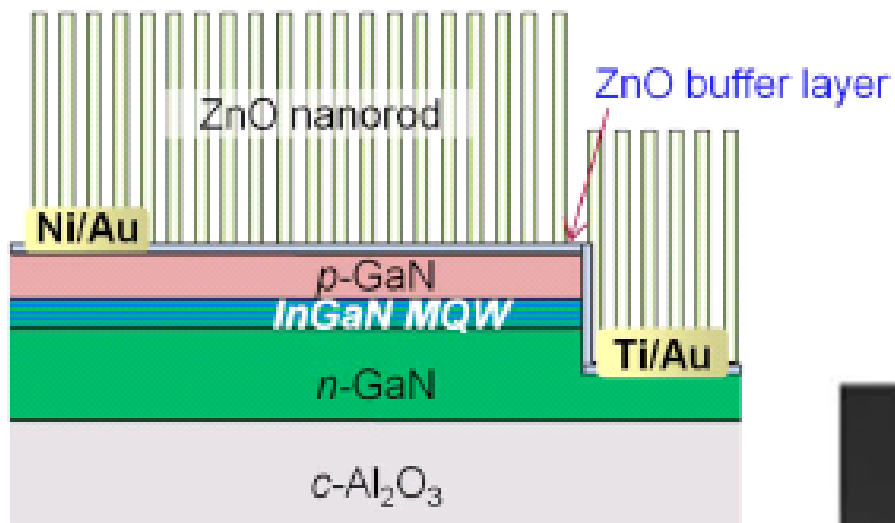


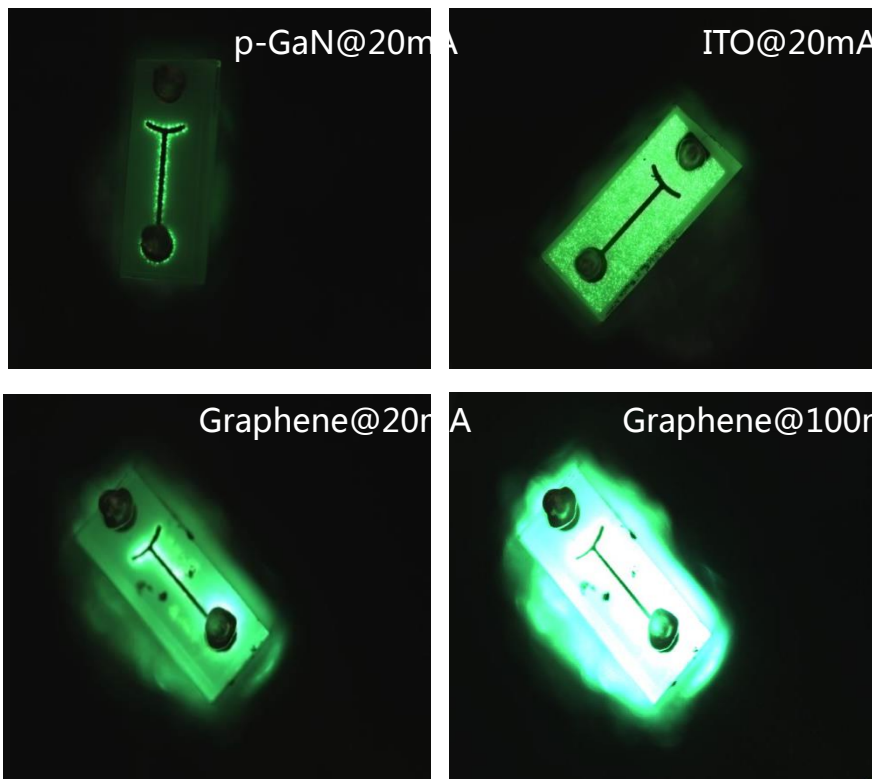
Fig. 1. Schematic cross-sectional structure of the pointed ZnO cone LED.



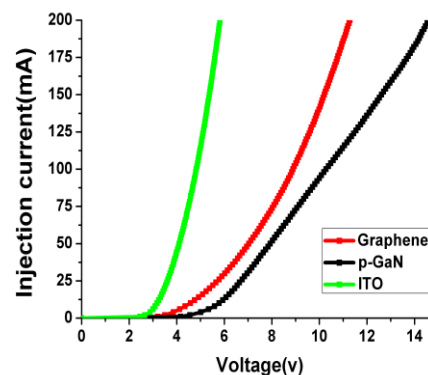


4.1.2 石墨烯

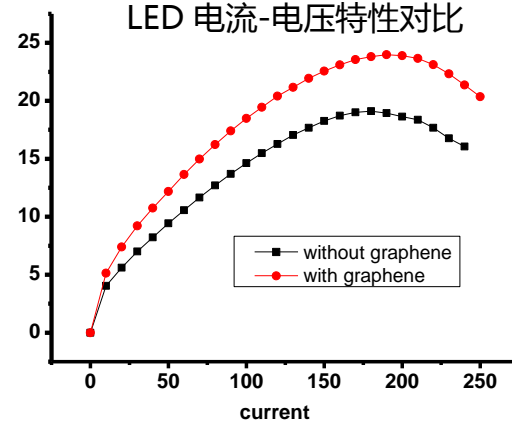
- 石墨烯用于LED透明电极



P-GaN、石墨烯(graphene)、ITO薄膜电流扩展能力对比



LED 电流-电压特性对比



LED 光功率-电流特性对比



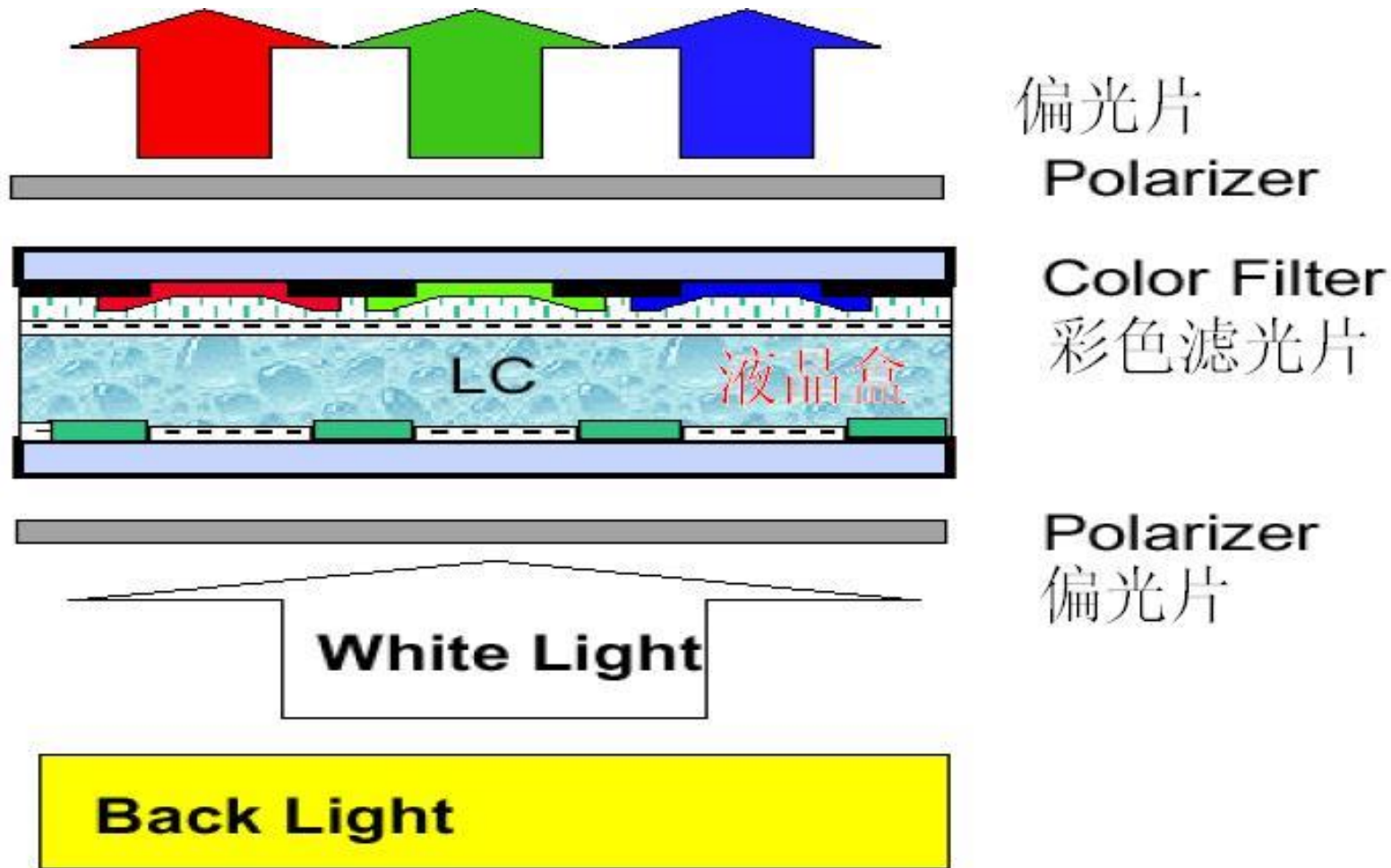
LCD Industry

液晶显示器



Panel基本结构

透过式LCD主要由背光模组、TFT模组两大部分组成





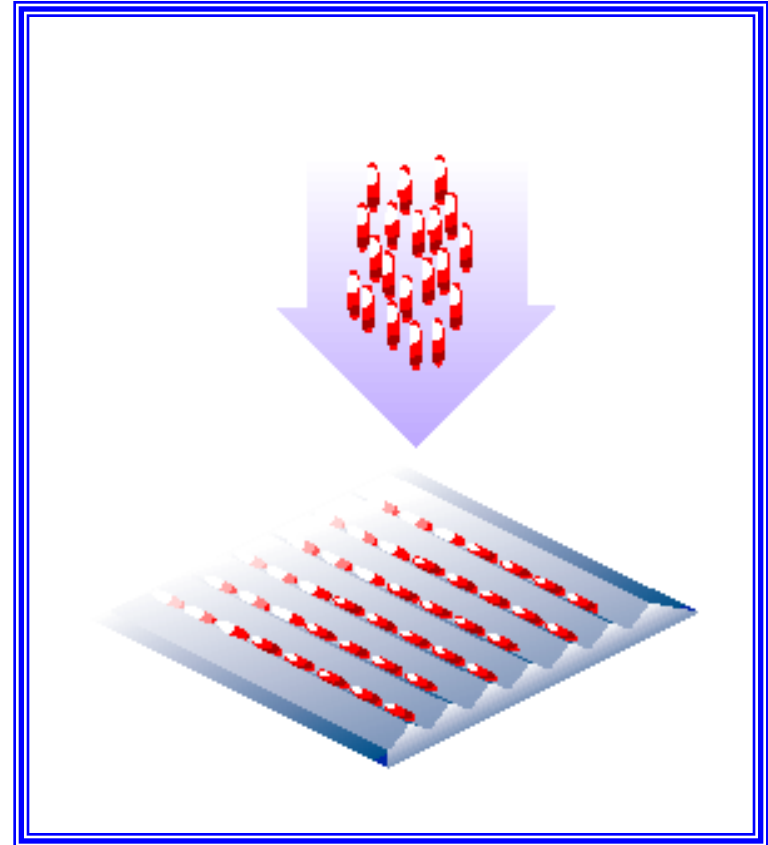
Panel基本结构

- 背光模组：提供光源
- 上下偏光片，**TFT Glass Substrate**，液晶：形成偏振光，控制光线的通过与否
- 彩色滤光片：提供**TFT LCD R/G/B(三原色)**的来源
- **ITO透明导电层**：提供透明的导电通路
- **Photo Spacer**：提供一个固定高度给彩色滤光片和**TFT Glass Substrate**，作为灌入液晶的空间，以及做为上下两层**Glass**的支撑



液晶基础

TFT-LCD使用的液晶为TN（Twist Nematic）型液晶，分子成椭圆状。TN型液晶一般是顺着长轴方向串接，长轴间彼此平行方式排列；当接触到槽状表面时，液晶分子就会顺着槽的方向排列与槽中



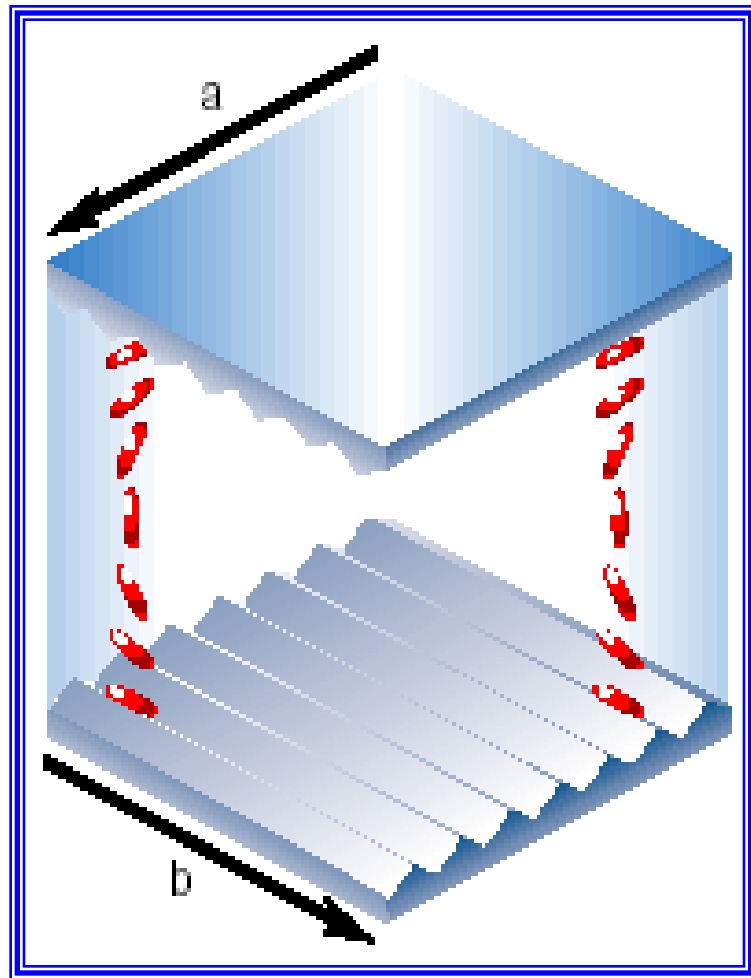


液晶基础

当液晶被包含在两个槽状表面中间，且槽的方向相互垂直，则液晶分子的排列为：

- a) 上表面分子：沿着a方向；
- b) 下表面分子：沿着b方向；
- c) 介于上下表面中间的分子：产生旋转的效应。

因此液晶分子在两槽状表面间产生 90° 的旋转

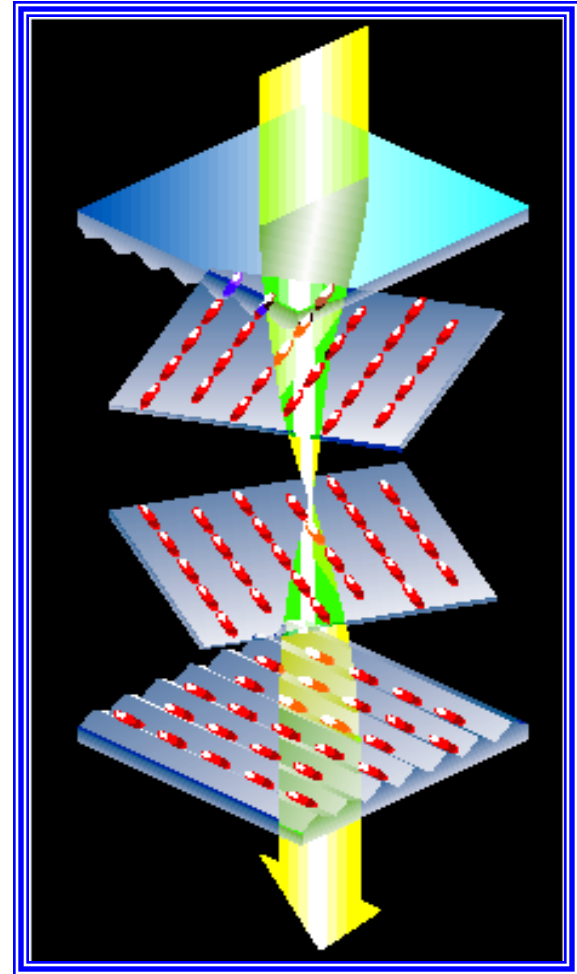




液晶基础

当线性偏极光射入上层槽状表面时，此光线随着液晶分子的旋转也产生旋转。

当线性偏极光射出下层槽状表面时，此光线已经产生了90度的旋转。





成像原理

偏光片特性：

将非偏极光（一般光线）过滤成偏振光。

当非偏极光通过a方向的偏光片时，光线被过滤成与a方向平行的线性偏极光

上图：偏振方向相同，线性偏极光继续前进，通过第二片偏光片时，光线通过。

下图：偏振方向不同，通过第二片时，光线被完全阻挡

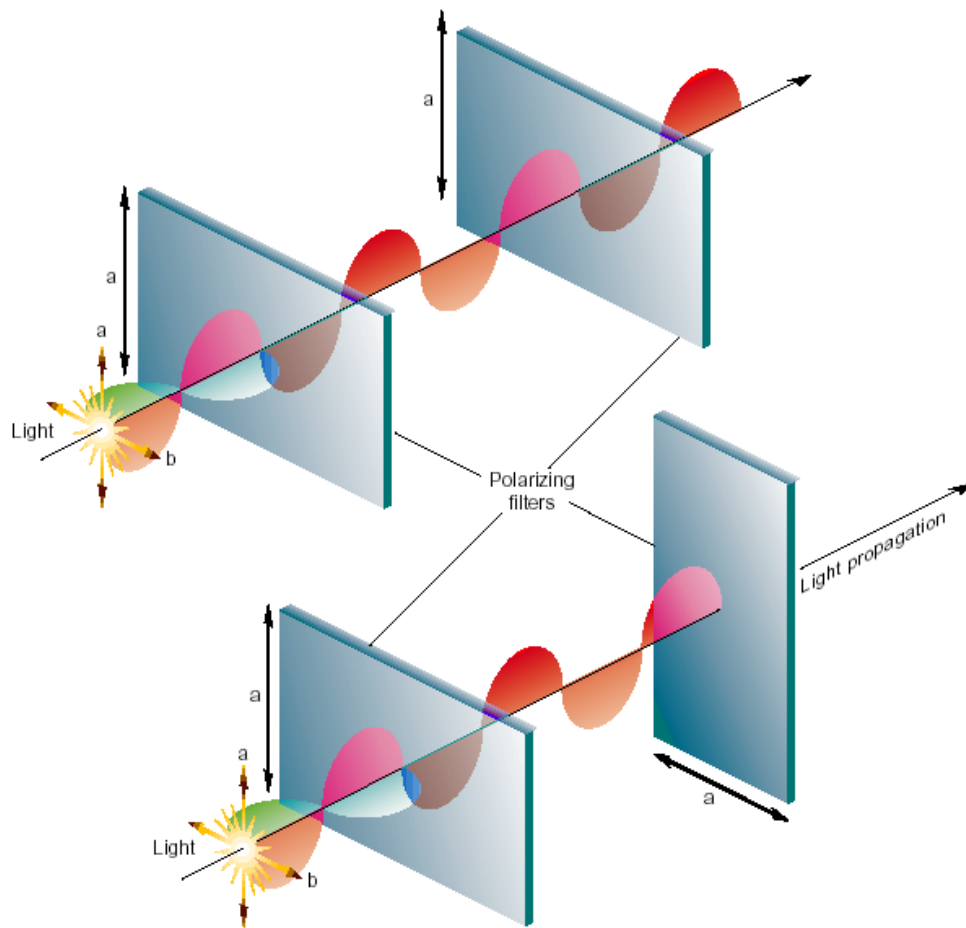
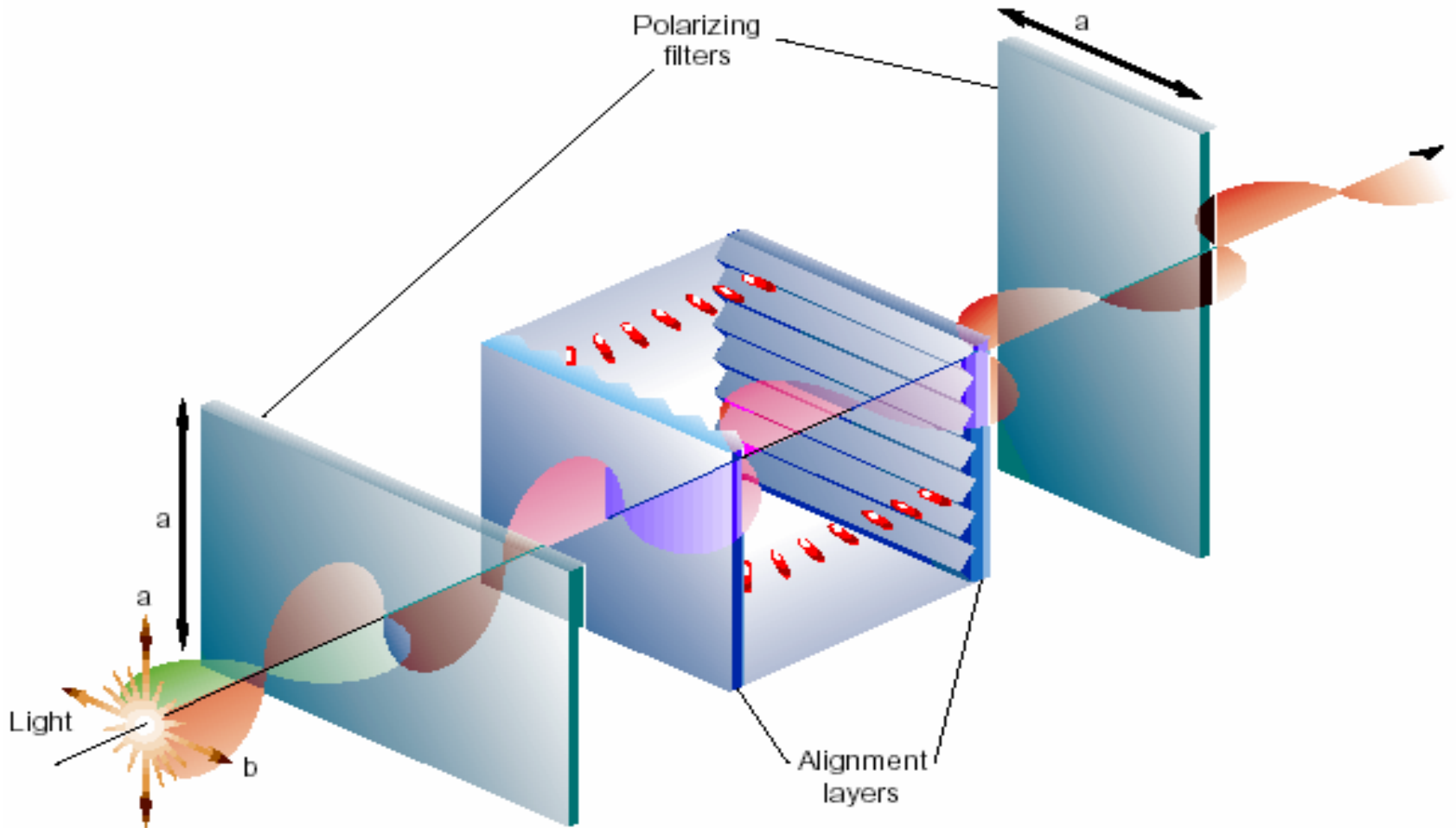


Figure 10. Interaction of Light with Linear Polarizers.



成像原理

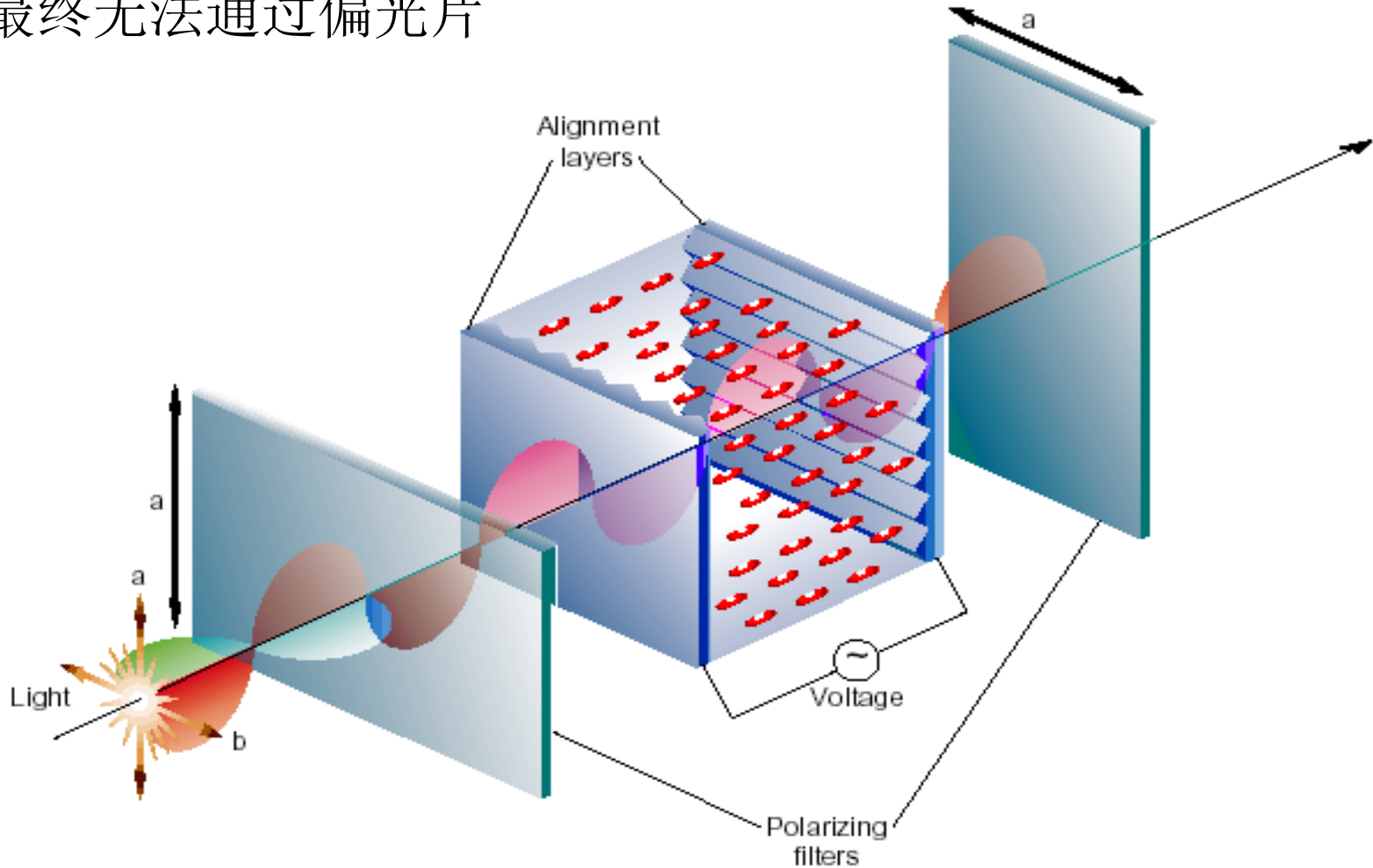
偏振光透过液晶分子，偏振方向发生旋转，光线可通过偏光片





成像原理

当液晶分子呈如图方向排列时，光线偏振方向将不再发生旋转，最终无法通过偏光片





成像原理

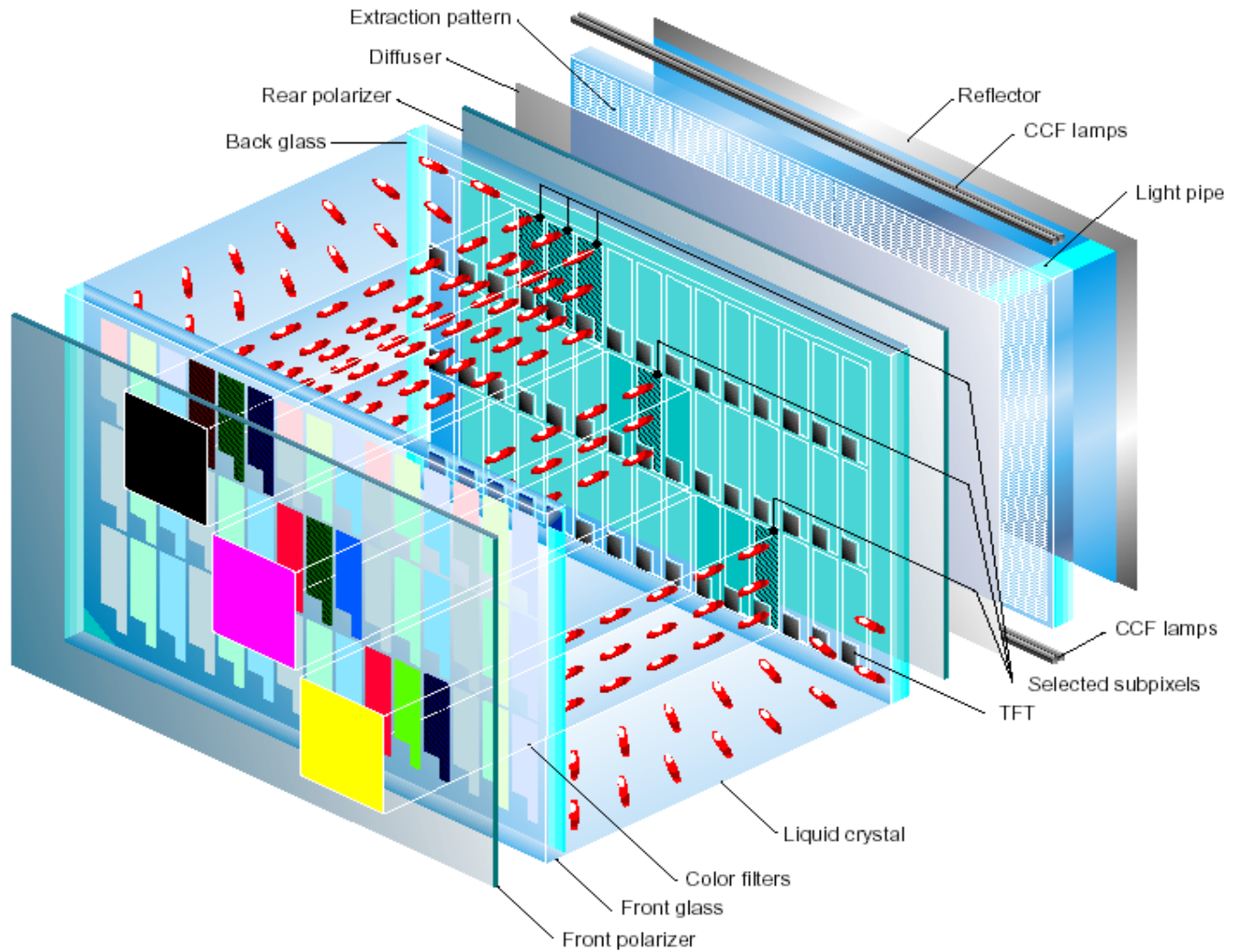
TFT上下各有一片偏振方向垂直的偏光片，背光板发出的光经背光模组散射后，先通过下层偏光片形成偏振光

之后通过液晶分子，并由液晶分子的旋转角度决定通过液晶分子后的偏振方向

在经过彩色滤光片产生红、绿、蓝三色光，最后通过上偏光片，并由偏振光偏振方向与偏光片偏振方向夹角决定最终输出的光强，以形成不同的色彩。



成像原理



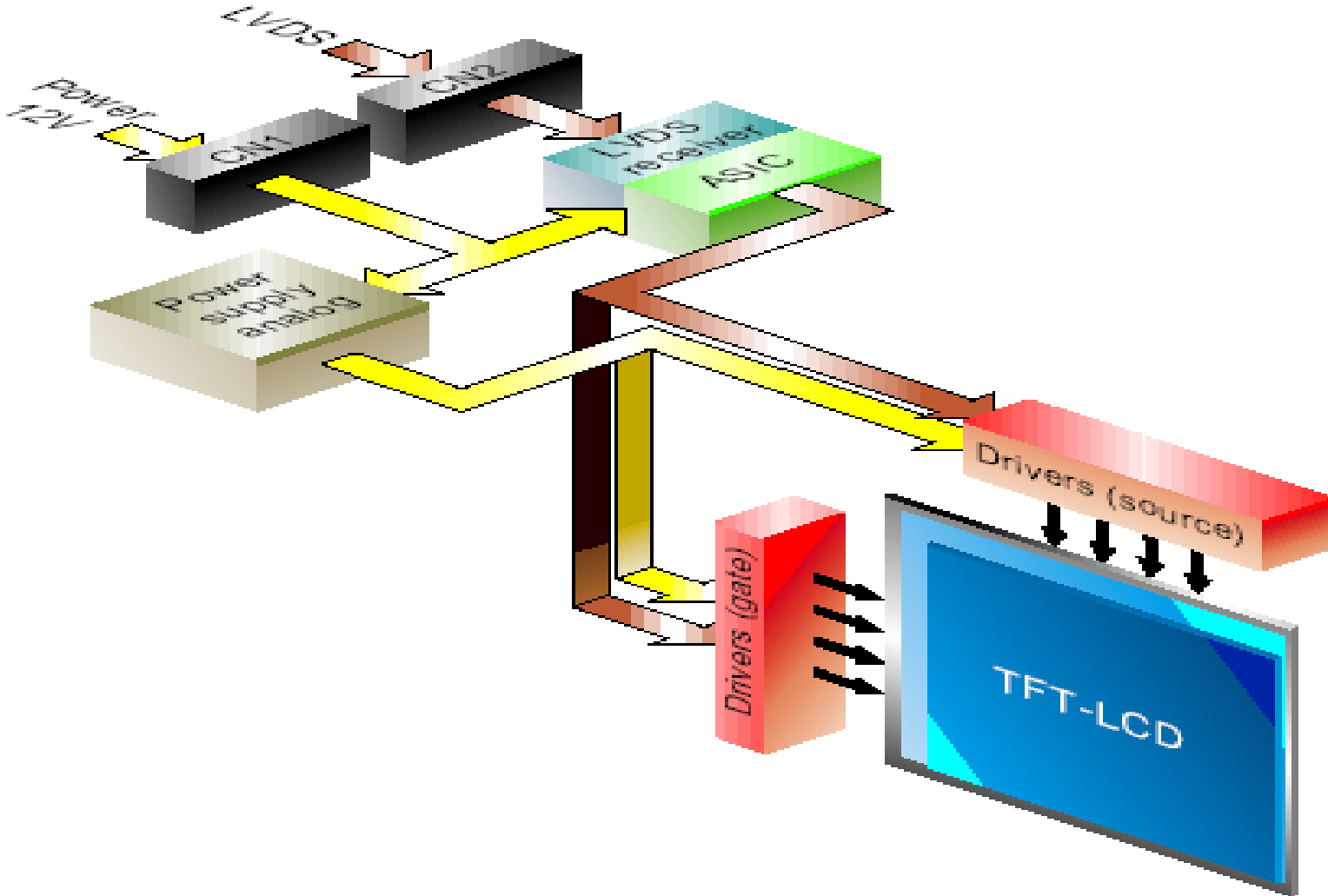


成像原理

- **Scaler IC**传送信号
- **Driver IC**传送控制液晶工作状态的信号
- 当某一**Sub-Pixel**导通时，该**Sub-Pixel**因无法透过光线而呈黑色
- 若该**Sub-Pixel**未导通，则因光通过**CF**而显示颜色
- 经过光的合成效果，显示器即可产生彩色效果



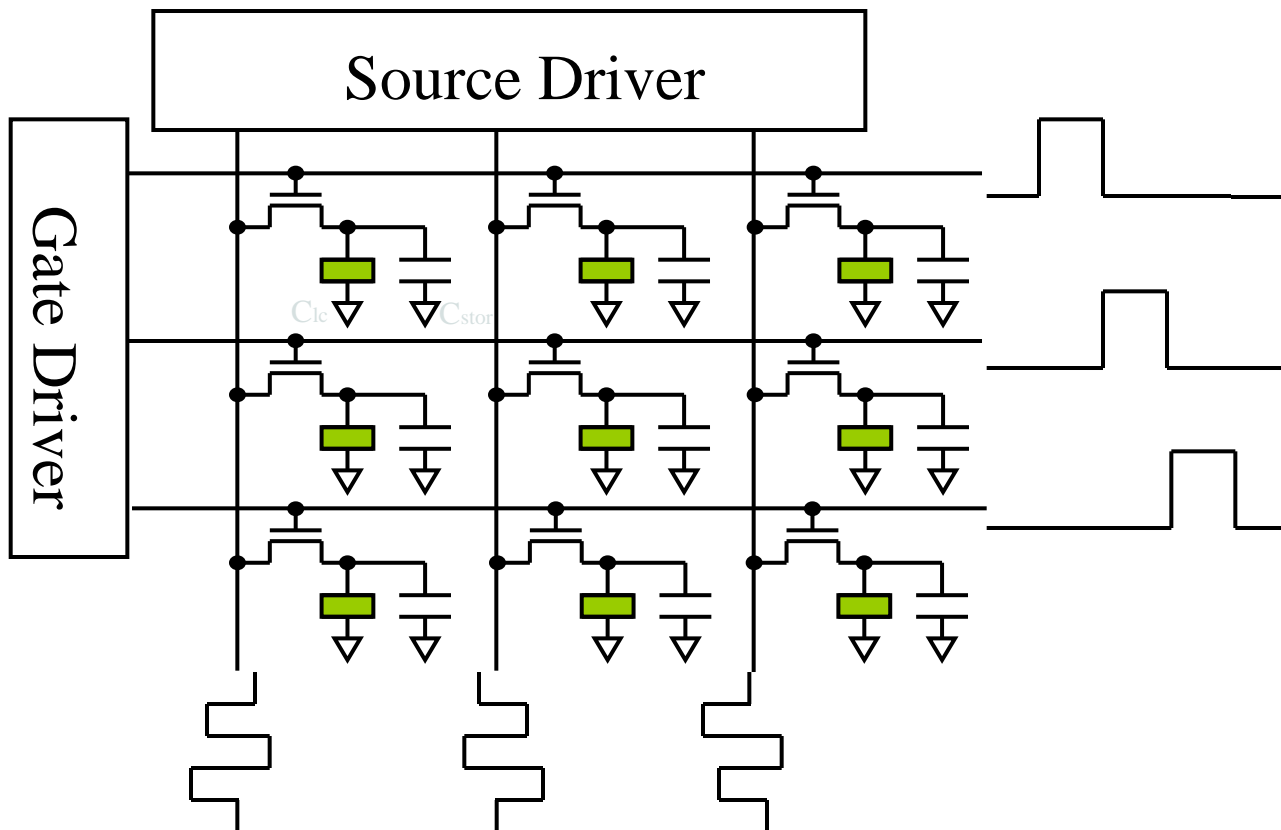
TFT结构





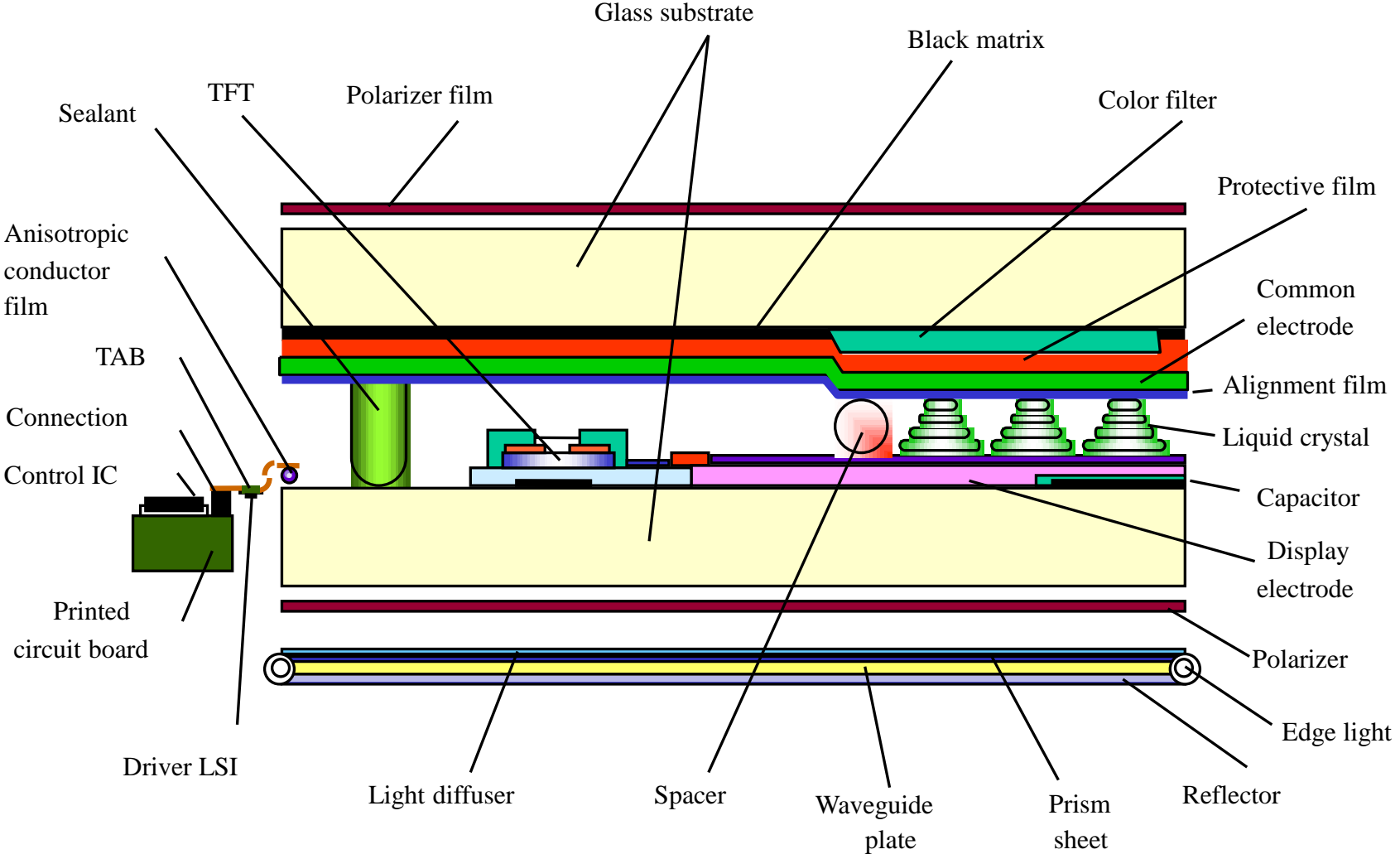
TFT结构

TFT-LCD 等效电路





Panel基本结构





合肥在LCD产业方面异军突起

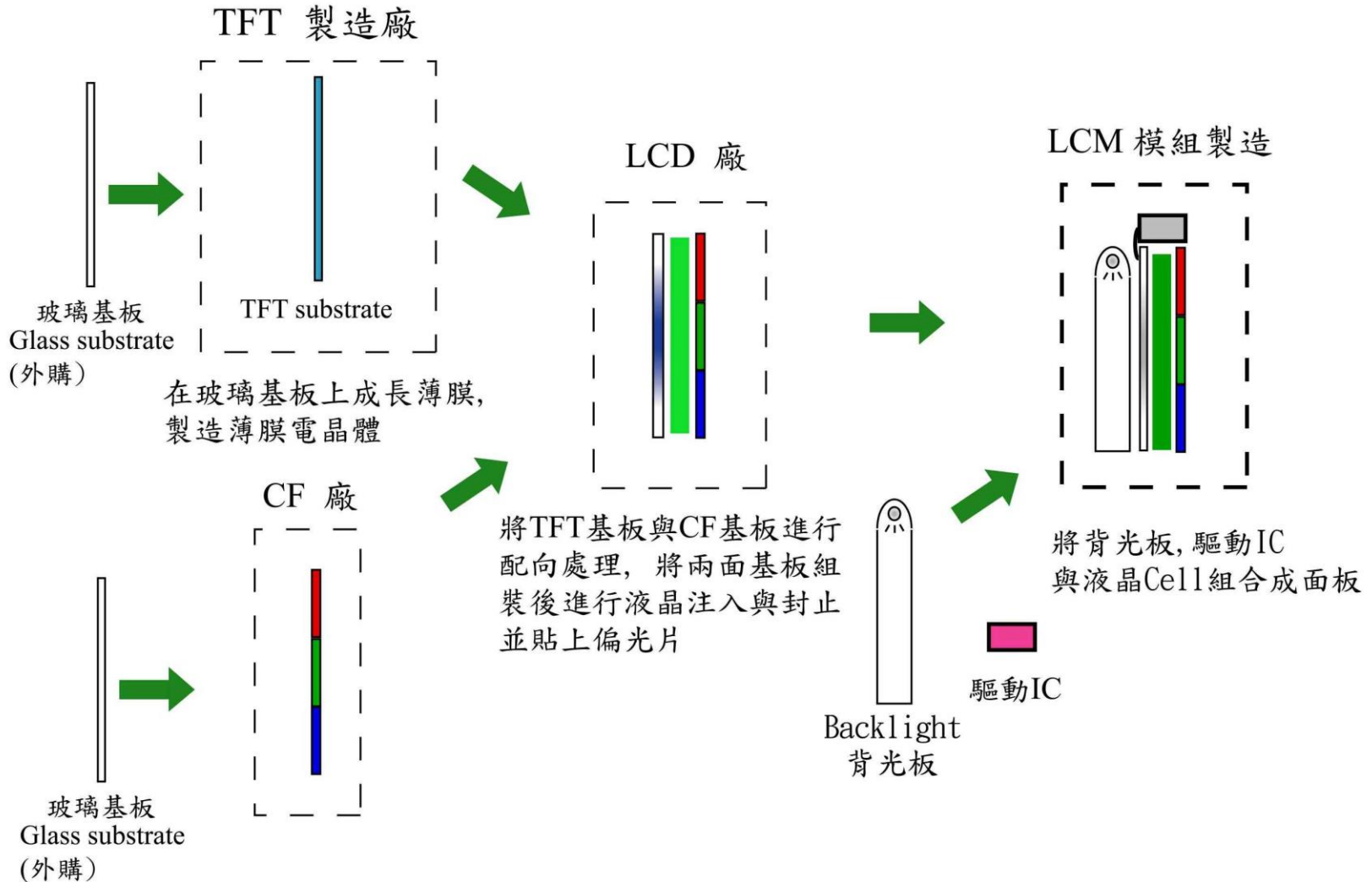


2017年12月20日，京东方合肥第10.5代TFT-LCD生产线提前投产，这也是全球首条投产的10.5代线（目前最高世代线），设计产能为每月12万片玻璃基板。建成后将奠定BOE在行业中的领导者地位。

8K成显示行业发展方向，8K显示屏分辨率高达 7680×4320 ，显示效果是4K显示屏的4倍，到2019年，65英寸及以上电视出货量将占到8K电视出货总量的八成。

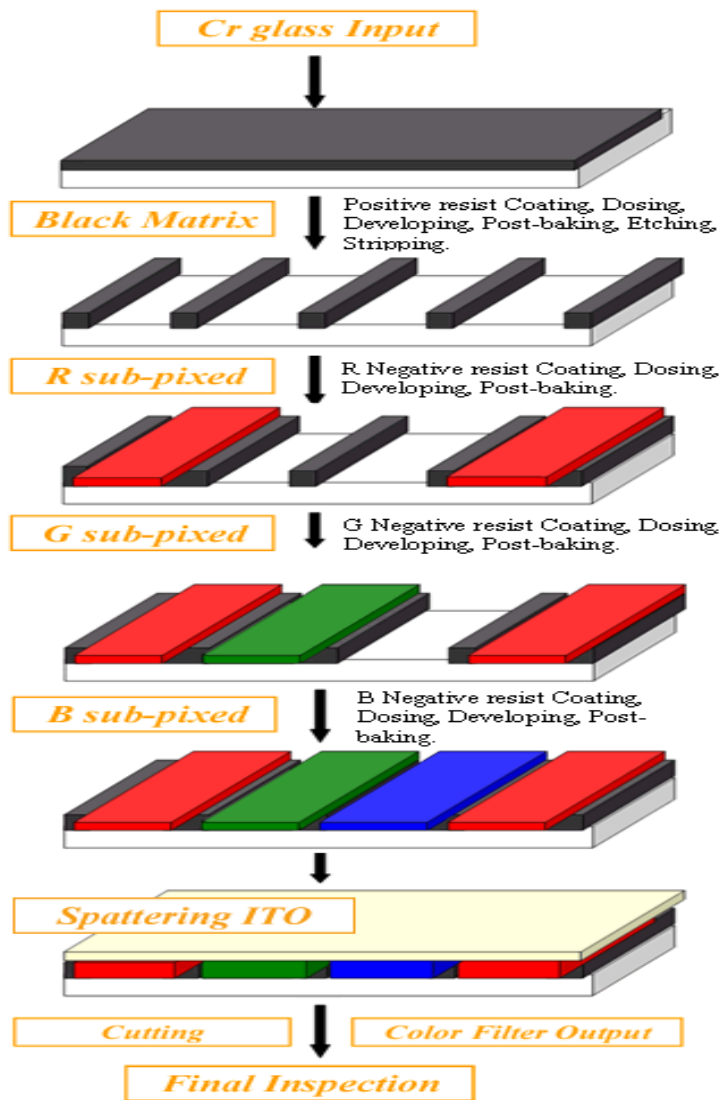
据了解，该产线采用的自动化和智能化水平的整体设备及核心工艺技术达业界最高水平，该产线投产将开启全球显示领域新的里程碑，引领大尺寸超高清显示新时代，届时BOE（京东方）将在液晶显示领域跃居全球第一。

TFT-LCD制程流程

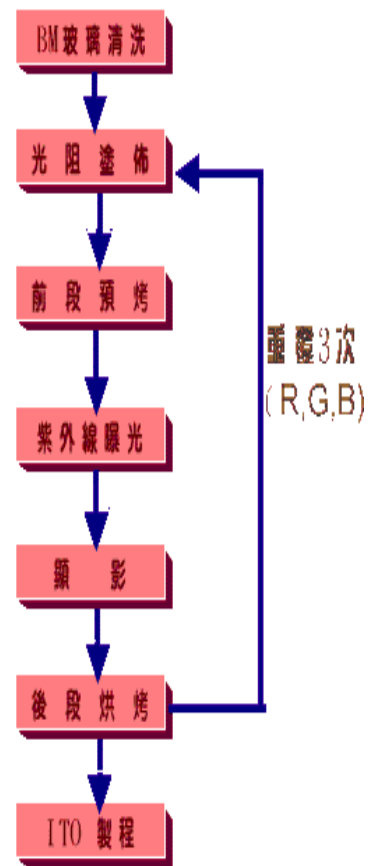
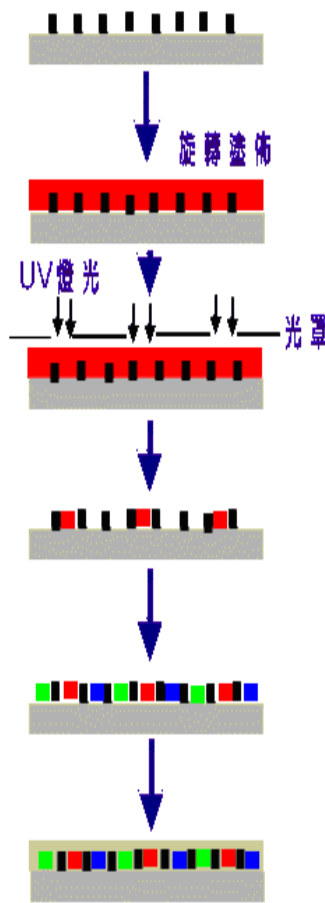




CF制作流程



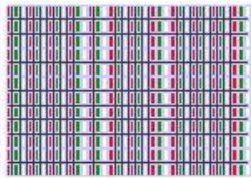
CF製程中RGB製作過程圖解



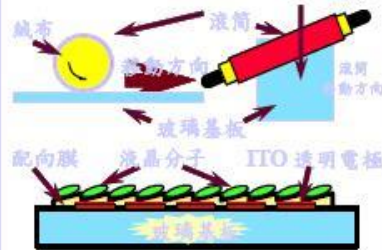


TFT-LCD Cell制程

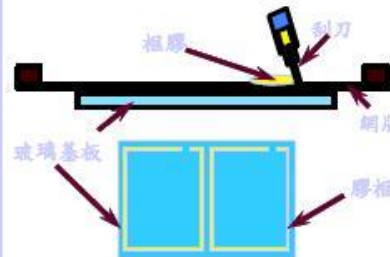
電極工程 PEP Eng.



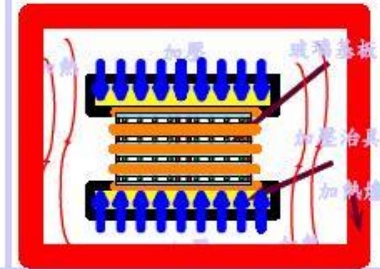
配向 PI Rubbing



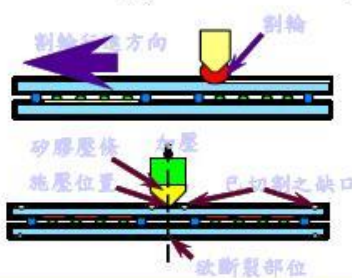
框膠印刷 Sealant Printing



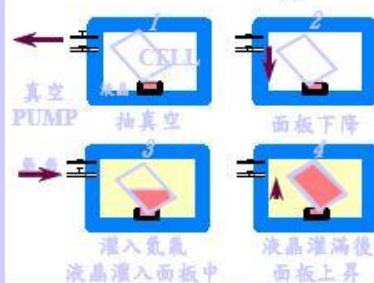
組立封著 Mounting & Sealing



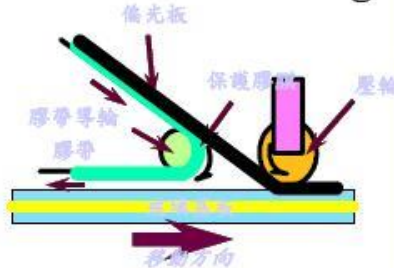
切割裂片 Scribing & Breaking



液晶注入 LC Filling

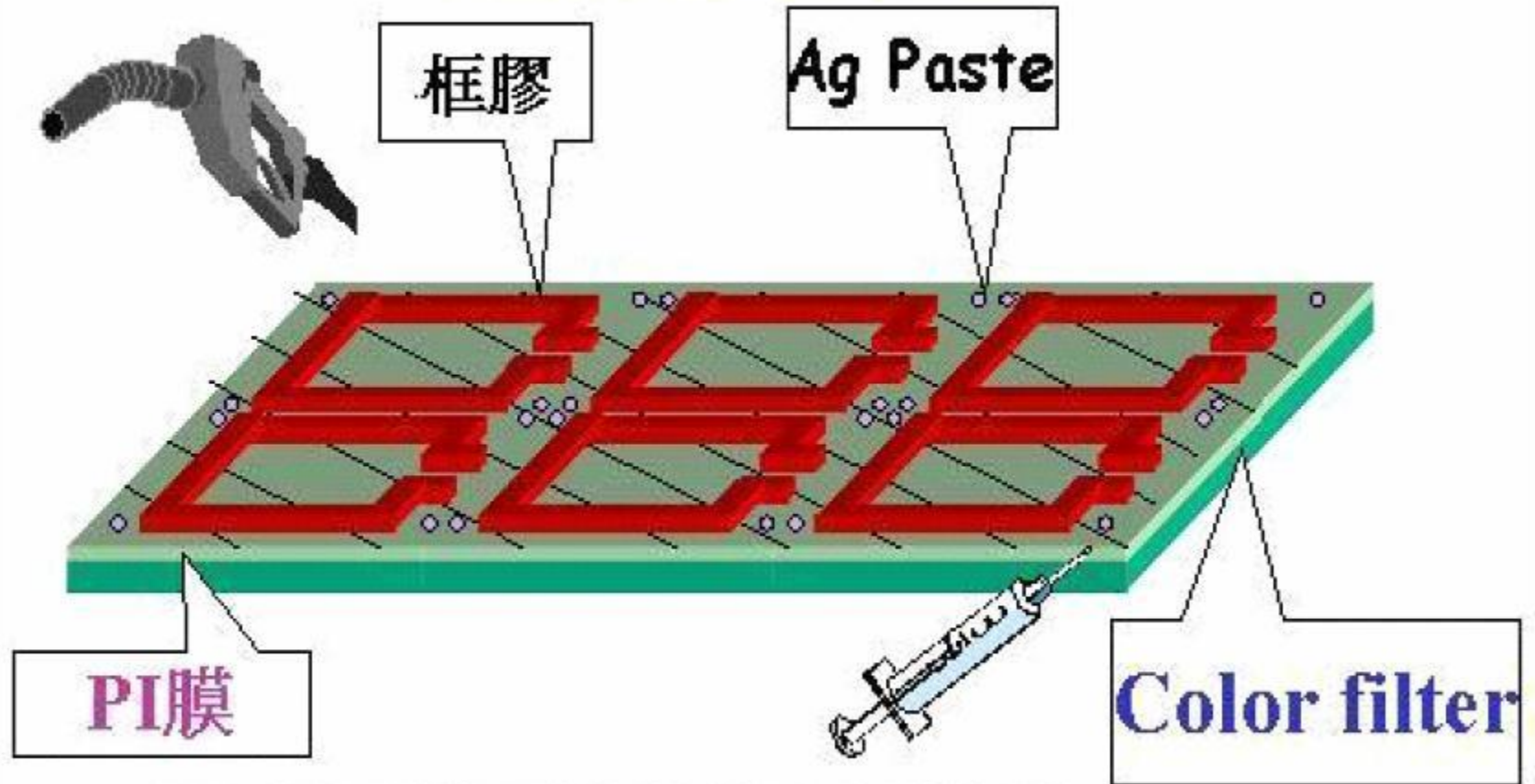


偏光板貼附 Polarizer Sticking



模組工程 MDL Eng.

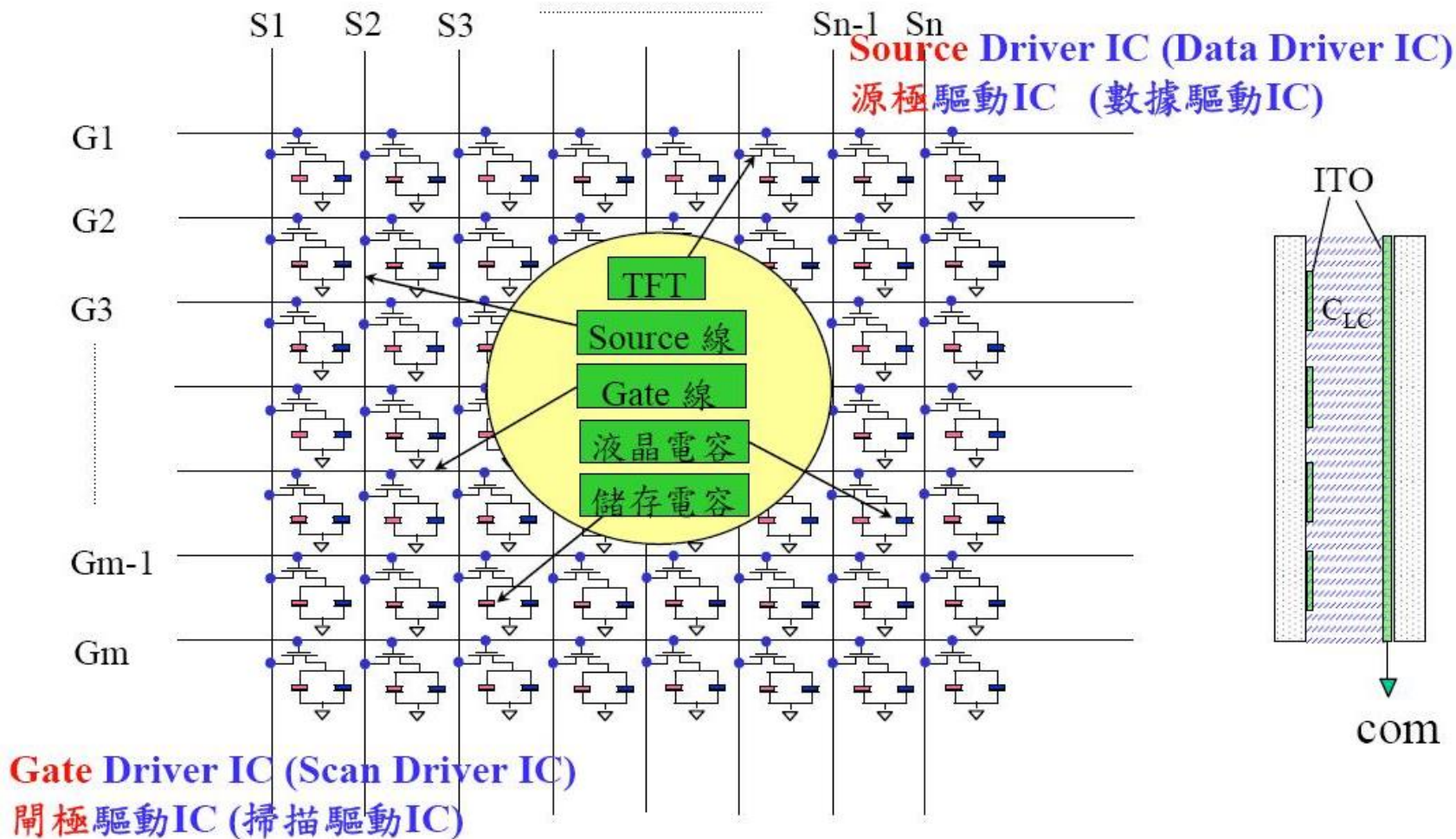




點銀膠是爲了尋通CF的共地極 (COMMON極)

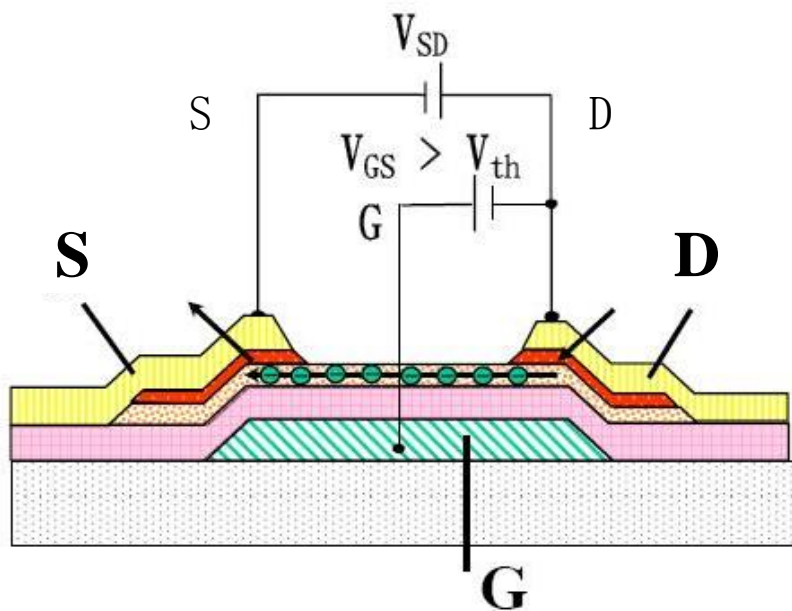


TFT面板示意图

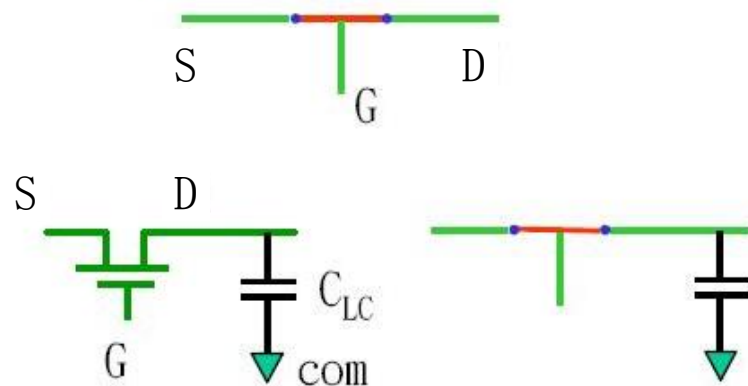




TFT的开关作用



(1) $V_{gs} > V_{th}$: 訊號讀取



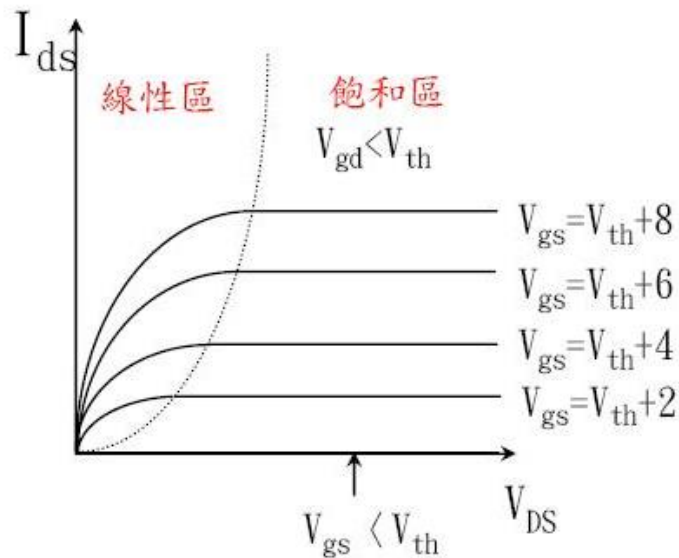
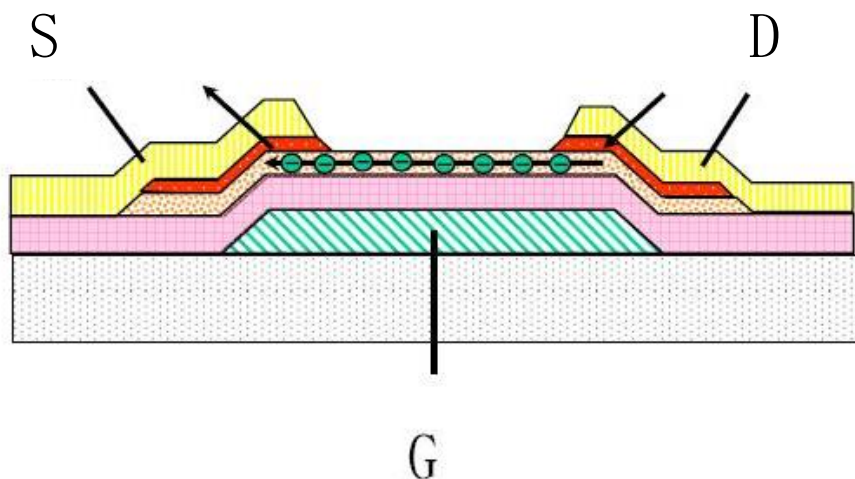
TFT元件在閘極(G)給予適當電壓 ($V_{GS} >$ 起始電壓 V_{th} 【註】)

使通道(a-Si)感應出載子(電子)，而使得源極(S)汲極(D)導通。

【註】： V_{th} 為感應出載子所需最小電壓



TFT的开关作用



(1) $V_{gs} < V_{th}$: 感應通道未形成

$$I_{ds} = 0$$

(2) $V_{gs} \& V_{gd} > V_{th}$: 形成感應通道

$$I_{ds} = 1/2 u_n C_{ox} (W/L) [(V_{gs} - V_{th}) V_{ds} - V_{ds}^2]$$

(3) $V_{gs} > V_{th} \& V_{gd} < V_{th}$: 進入夾止區(在 Drain側通道消失)

$$I_{ds} = 1/2 u_n C_{ox} (W/L) (V_{gs} - V_{th})^2$$

影響 I_{ds} 之重要參數 :

(1) V_{th}

(2) u_n : Mobility

(3) C_{ox} : Gate到Channel的電容

(4) W (Width) / L (Length)



谢谢大家，欢迎提问题讨论！

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