SUN YAT-SEN UNIVERSITY

中山大學

Sino-European Bilateral meeting on Material Aspects for Future Energy Supply

Research and Development of Solar Materials in Guangdong China

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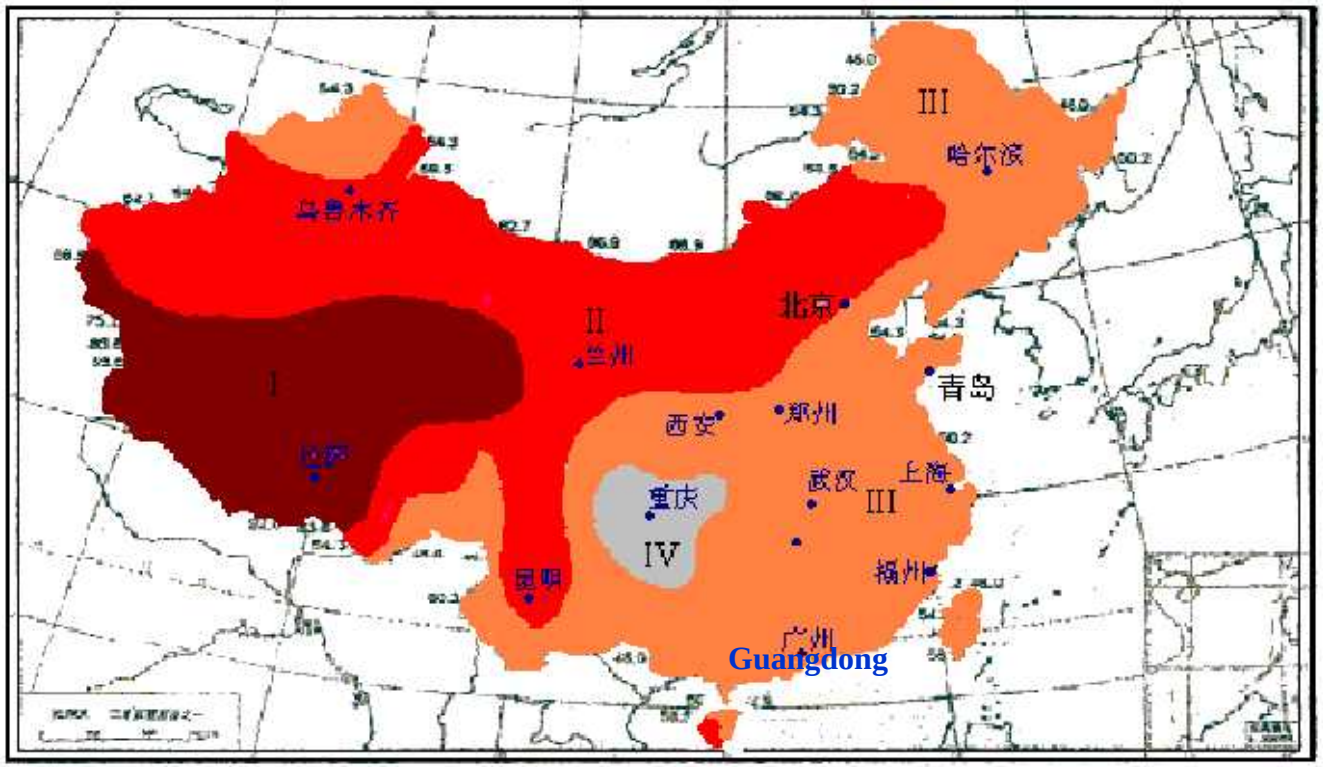
Introduction - Solar Energy Resources



The Distribution of Solar Energy Resources in China:
I ≥ 6700 MJ/m^2 · a , II 5400～6700 MJ/ m^2 · a ,
III 4200～5400 MJ/ m^2 · a (Guangdong) , IV< 4200MJ/ m^2 · a

Introduction

- Research, production and application of solar heating collectors and photovoltaics in China are speedy developed.
- Solar energy resources of China are very abundant and especially in the west regions of China, such as Tibet, inner Mongolia, Qinghai, Xinjiang provinces.
- Solar heating application in China is very useful and successful, especially in undeveloped regions in China.

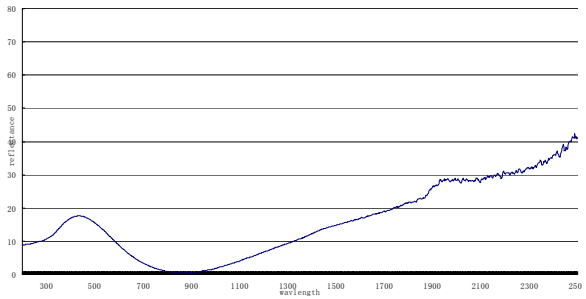
Introduction - Solar heating collectors

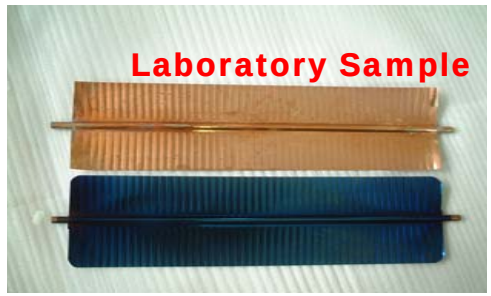
- China is the largest manufacturer and application country of solar heating collector in the world;
- In 2003, the installation area of solar collectors: 10 million m² and output value over 1000 million €;
- Until 2003, the total installed solar collectors in China over 40 million m²;
- Huang Ming Co., the largest manufacturer in China, output value over 70 million € in 2003;
- Five Star Co., the largest manufacturer in Guangdong Province, solar collector: 115 km², the output value over 1.6 million € in 2003;
- The total throughput of solar collector in Guangdong Province: 300 - 400 km².

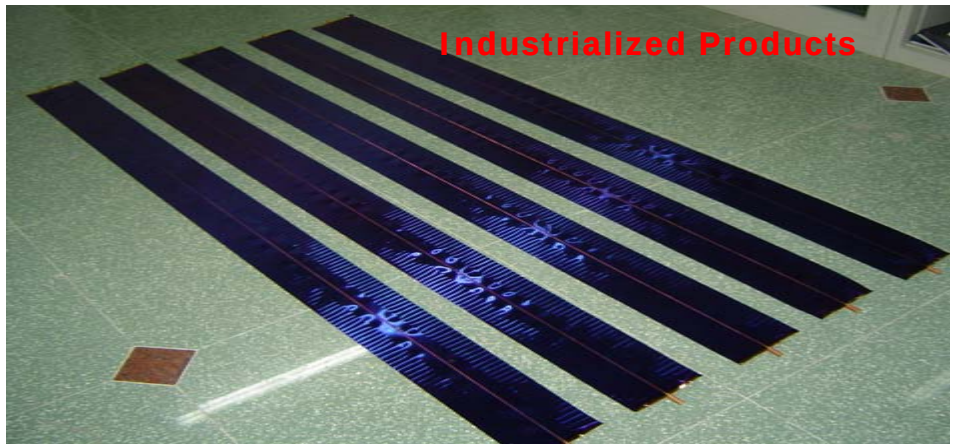
Solar Selective Coatings

- Substrate: copper sheet.
- Target: Ni-Cr alloy
- Reactive gas:O_2 and N_2 .
- Sputtering gas: Ar
- The pressure in the chamber before sputtering:7×10^{-3}Pa

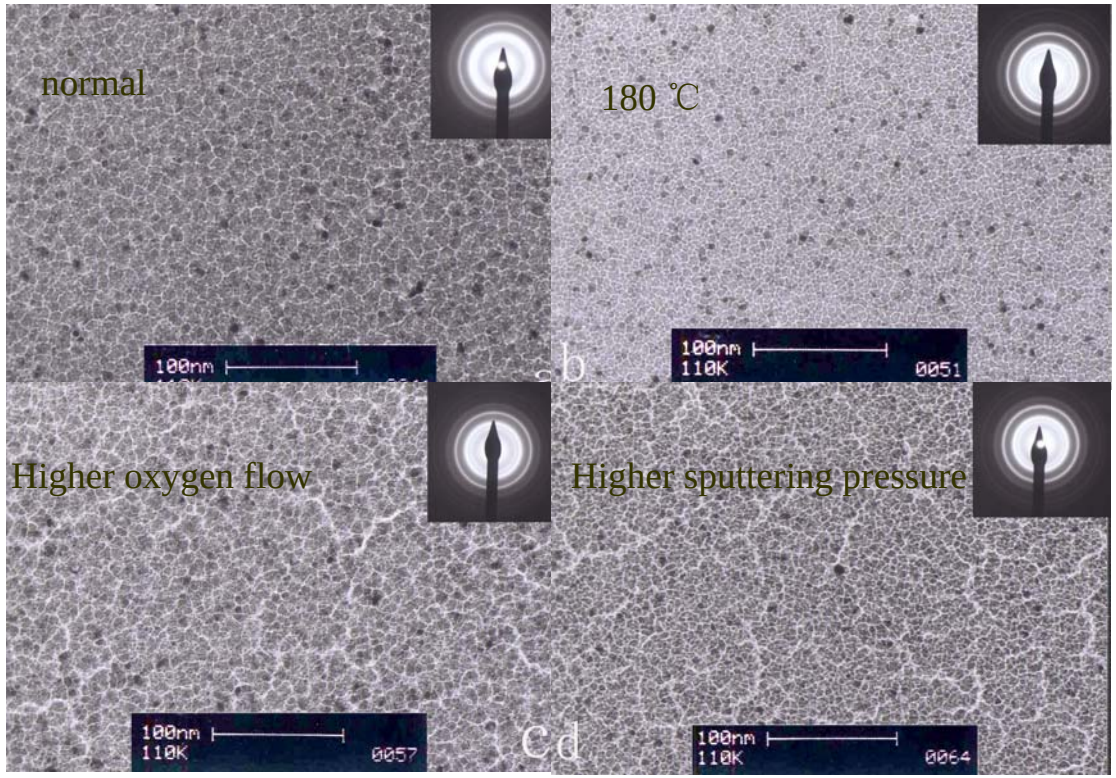
Solar Selective Coatings





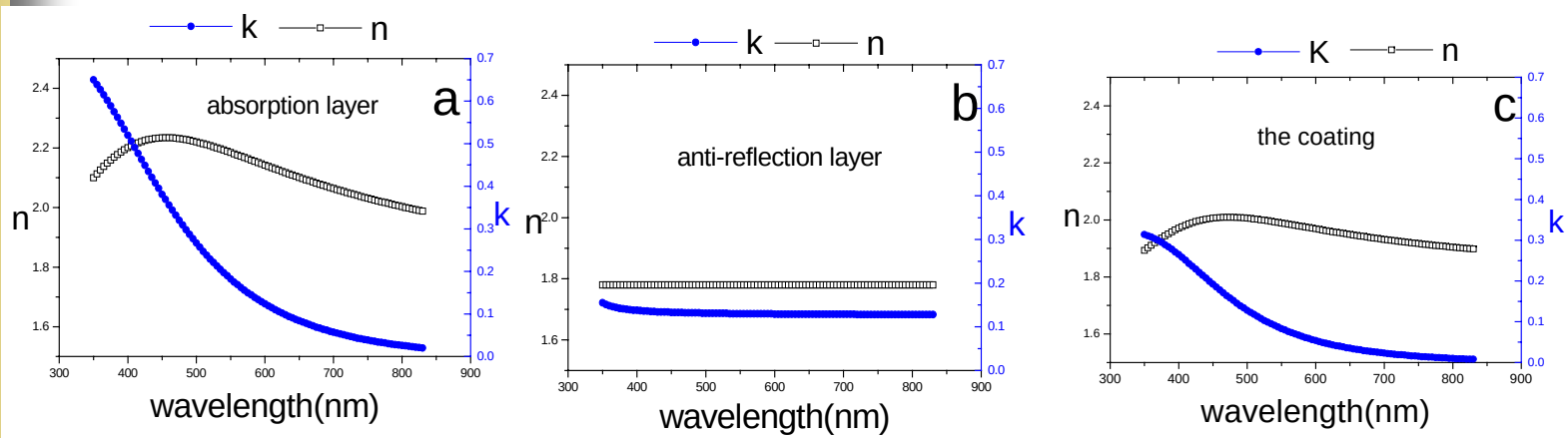


Solar Selective Coatings



- **The coatings consist of particles size of 5~20nm, the crackles, the particles size and the uniformities vary with the sputtering conditions, in the four cases, there are differences in the energy of particles and hence film growth, in all conditions, their diffraction rings were almost the same.**

Solar Selective Coatings



The coatings: copper / absorption film / anti-reflection film

a. The varied refractive index “n” led to a high solar energy absorption

b. The extinction coefficient “k” does not increase with wavelength, rather the opposite.

c. The coatings have non-metallic properties.

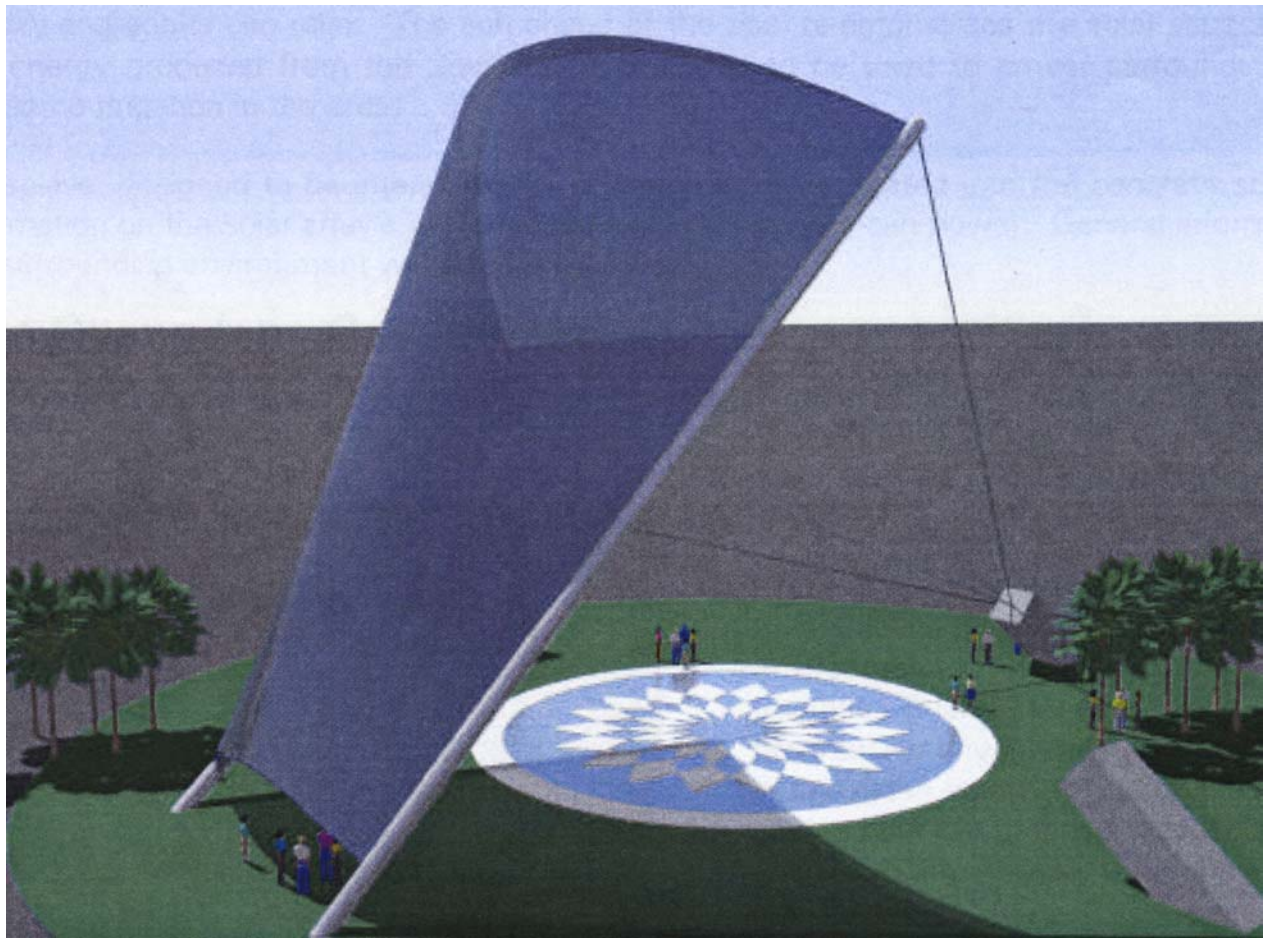
more work will put on the study of optical constants, they help us to determine the thickness of each layer.

Solar Selective Coatings

- Traditional process could result in pollution and could hardly produce high quality solar selective films.
- Magnetron reactive sputtering process is a good way to prepare thin solid films.
- Ni and Cr both has good solar selective performance in the range of solar spectrum.
- Ni-Cr system selective films were prepared on copper substrate.
- The $NiCrO_x$ layer had the effect of anti-reflection
- The film color has also a good decorative effect

Photovoltaics- introduction

The design of a 50 kW solar power generator - bp solar' a gift for Guangdong province government: an important signal – bp solar will enters China' PV market? (to be installed in 2005)



Photovoltaics - introduction

- **The present main PV market in China**
  - At first, west China electric power supply, In 2002 National Development and Reform Commission (NDRC) invested over RMB ¥ 2 billion for the “Electricity Transmission Program” in west provinces. (about **15 MW** solar modules installed)
  - Communication and traffic devices
    (3-5 MW solar cells per year)
  - Solar street light and garden light
    solar garden light for exporting, over 10 MW/year only in Guangdong province

    Small product can make a large PV market!
- **In the future Market**
  - PV can be combined with LED Lighting (Chinese National LED lighting Project starts from November 2003)
  - Solar module as solar building materials to build solar buildings

Photovoltaics - Throughput of main manufacturers for crystalline Si solar cells in China (in MW)

Name / Location	2001	2002	2003	2004	2005 (plan)
Suntech, Wuxi (Dr Shi Zhengrong) ? , Nanjing (Dr Zhaojianhua) Tianhe, Changzhou Jiangsu		3	7	38	100 ? 10
Boding Tianwei Hebai (Dr Wu Yan)			3	6	30?
Ningbo Solar Zhejiang	0.8	1.5	3	8?	10?
Tianda Kunming, Yunnan	0.5	1.3	1	2.5	8
Shaxi, Guangzhou Tuori, Shenzhen Guangdong			3 1	6 4	8 6
Shanghai Solar Sci. & Tech.					20
Motech Taiwan		8	17	35	88
Total	1.3	5.8 + 8	18 + 17	65 + 35?	200?

Photovoltaics - applications

Solar PV power generation in Tibet (100 kW) and PV supplied communication devices in Xinjiang

Photovoltaics - Lighting using hybrid of solar cell and LED (light emitting diode) installed in2003 (our project), we have a project to develop photovoltaic LED lighting from Chinese Commission of Sci. and Tech.

Photovoltaics - Solar garden lights producer in Guangdong, China

Company	Location	Garden lights (million units)	Solar cell Consumption (MW)	Export country	Other products
Jiawei	Shenzhen	5-6	6	USA	Module
Sunshine	Shenzhen	?	2	USA	Module
Chuangyi	Shenzhen	1	2	USA	a-Si & c-Si modules
Tuory	Shenzhen	2	?	USA	6MW a-Si + c-Si cells
Liqiao	Shantou	3	3	Europe	
Bailixing	Shunde	10	3	Europe	
Shaxi	Guangzhou	10	3	USA	6 MW Si solar cells
Aukaili	Zhuhai				
Fivestar	Dongguan	1			
Jiehong	Guangzhou	1	?	Europe	
Zhaotian	Guangzhou	?	?	Europe	
Jianlun	zhongshan	3	3	USA	
Shenhui	zhongshan	2	?	Japan	
Yulong	Dongugan	1			
New energy	Zhuhai	1			
Summary	Partial statistics of Guangdong	About 30 million units	Over10MW for garden lights		

Photovoltaics - applications

Demo of several solar garden lights from Guangdong province , popular in USA, Europe and Japan

Photovoltaics – The first invested BIPV project by private in the city, 2.56 kW, installed on September 2003 in Shenzhen, Guangdong province, (our project). Now we got a project from Chinese Commission of Sci. and Tech. that we will build 20 BiPV in Guangdong Province , the building cost do not over 5000 € / 1kW

Photovoltaics – Shenzhen Gardening Exhibition PV Power Generator (1MW) is the largest photovoltaic system in Asia, installed on October 2004 in Shenzhen, Guangdong province, the building cost over 6 million € (Prof. Xu Honghua' Project, cooperated with bp solar)

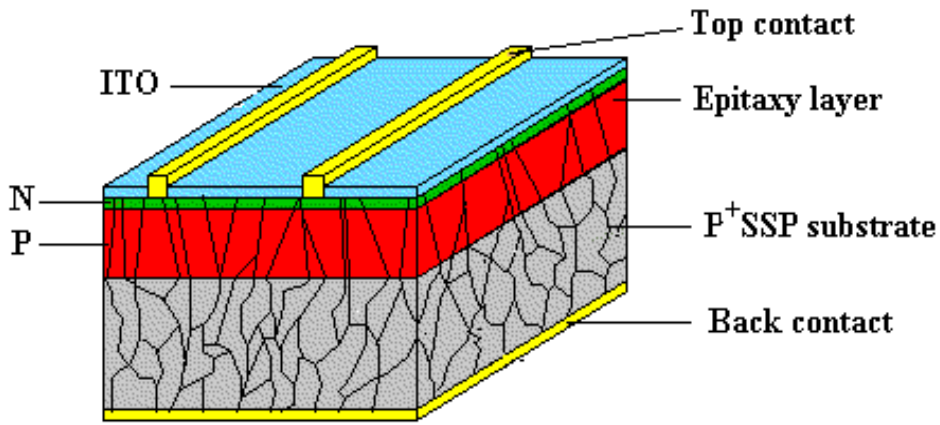
Photovoltaics - Poly- Si thin film solar cell

Motivation and Aim

- In order to prepare poly-Si thin film solar cells, at first, two problems must be solved: one is suitable substrate, another is poly-Si thin film deposition method.
- For this purpose, the **SSP** equipment (**silicon sheets from powder**) and **RTCVD** system (**rapid thermal chemical vapor deposition**) have been installed in Guangzhou in order to prepare SSP substrates and poly-Si thin films.
- China is the largest producer and exporter of industrial silicon powder (metallurgical Si powder), it is very beneficial if the low cost silicon powder can be used to prepare SSP substrate for poly-Si thin film solar cell (with interlayer)
- The solar cell with the efficiency of 8 -10% is also useful for the developing countries, if the cost-performance is more competitive with high efficiency solar cells.

Photovoltaics –

The structure of poly-Si thin film solar cell on SSP



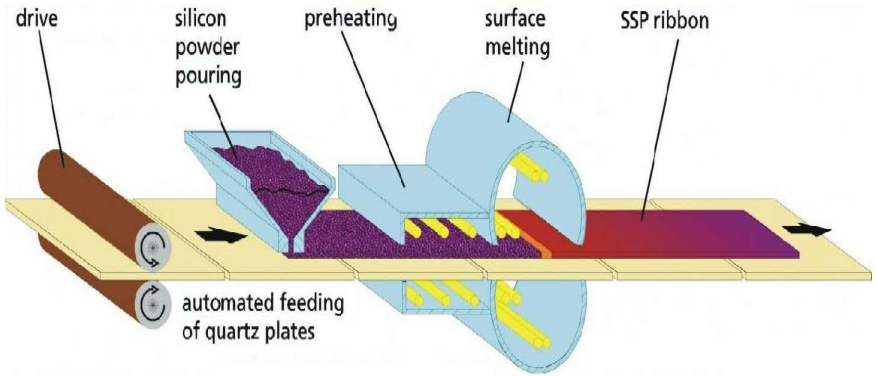
The SSP ribbon has three main functions: self-supporting of device, crystal growth seed for epitaxial layer and BSF (back surface field) to improve solar cells' properties (open circuit voltage V_{oc})

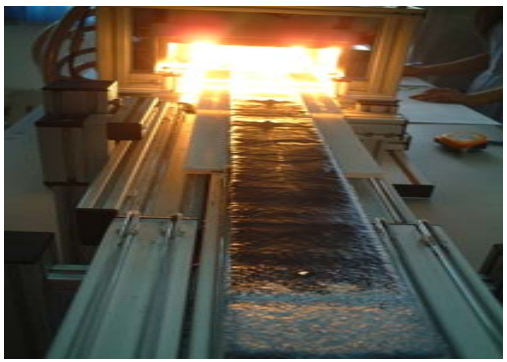
The technical route is as following; based on SSP substrate making epitaxial layer by RTCVD (in the coming work intermediate layers e.g. SiO_2 will be introduced to improve solar cells' performance) – then forming pn junction by diffusion process – depositing contact fingers by vacuum evaporation – finally coating SiN_x antireflection film by PECVD.

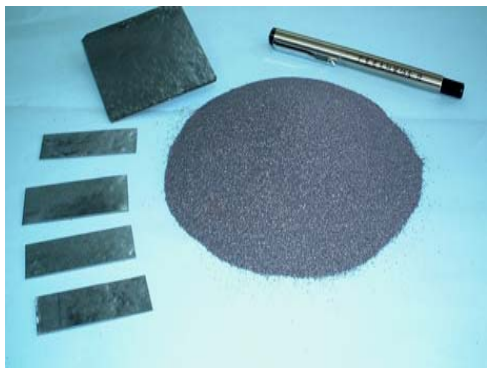
Photovoltaics - SSP-Process

- Silicon powders are poured continuously and tightly onto quartz carrier plates driven by electric motor.
- The upper surface of the powder layer is zone melted (over 1412℃) in Ar atmosphere by the heating of line focused halogen lamps.
- And the remain silicon powders are combined by the melted liquid during re-crystallization process.
- The ribbon is typically 0.6 -1.0 mm thick depending on the particle size of silicon powders, 60 -110mm wide and usually 1000-1500 mm long.

Photovoltaics - SSP-Process

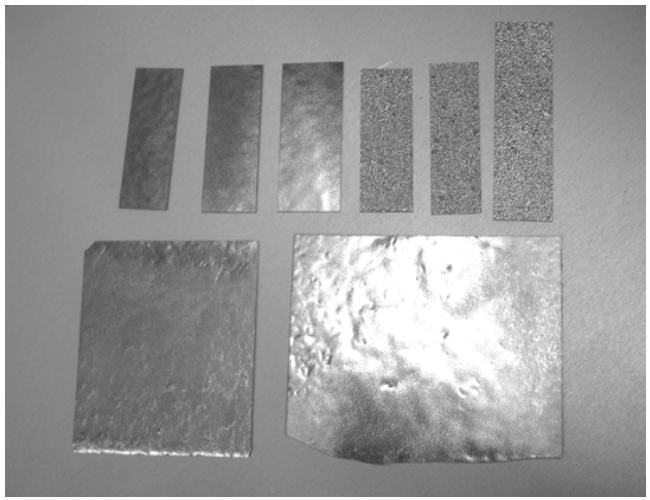


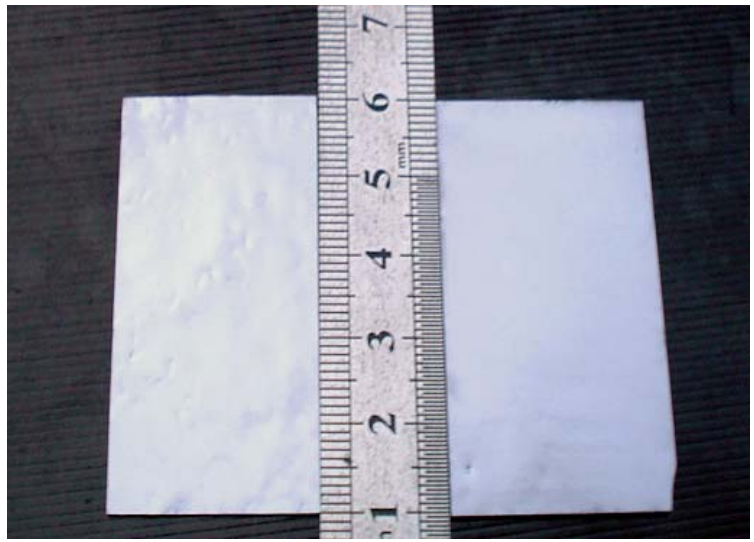




Schematic diagram of SSP Process, with optical heating, from silicon powder to ribbon

Photovoltaics - SSP-Process

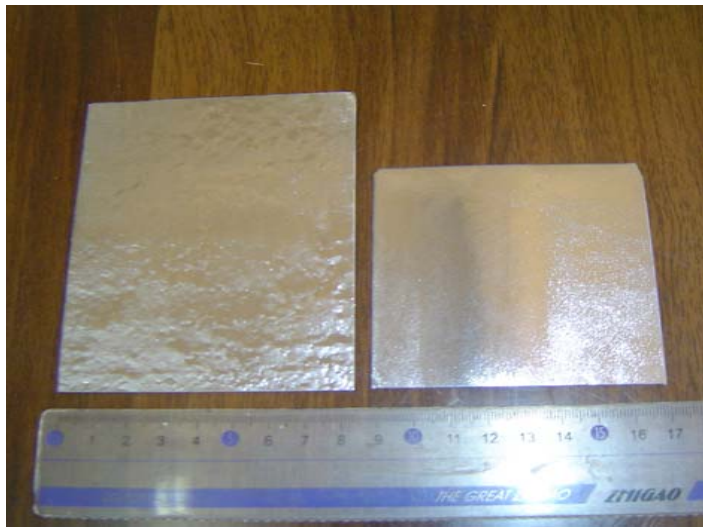




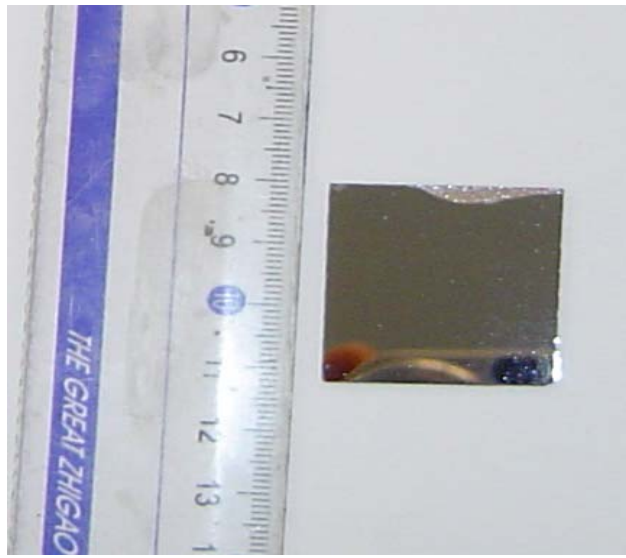
a. prepared Si-sheets b. right side: after re-melting

the surface of prepared SSP-ribbons are rough and the smooth surface after the re-melting process

Photovoltaics - smoothness improvement of SSP



Recrystallization of back side



Polished Surface of SSP

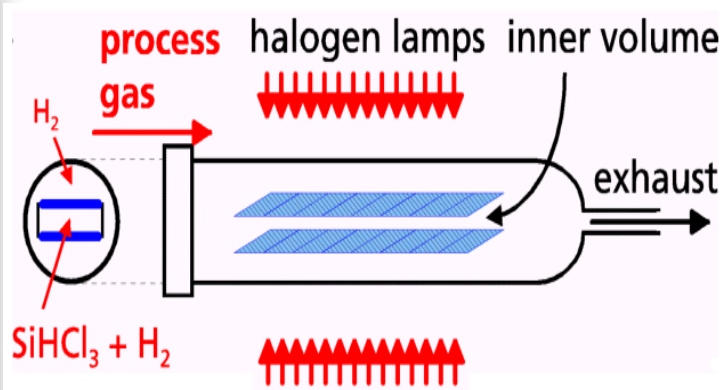
Photovoltaics - RTCVD Process

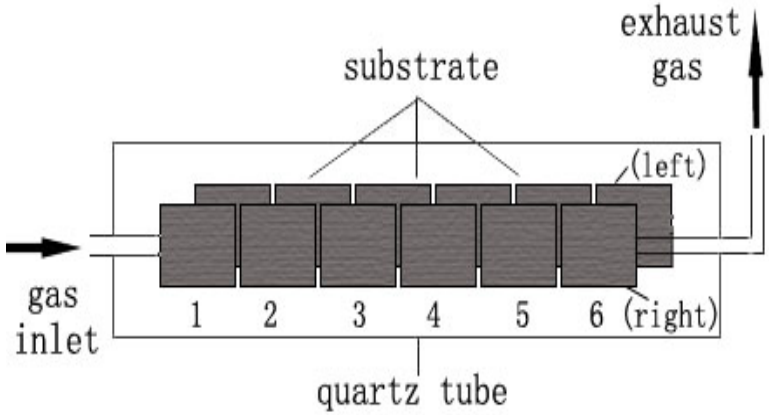
- **The deposition of silicon thin film is another key process** for high performance solar cells. Because we choose SSP as substrate and in order to obtain bigger grain size, RTCVD is preferred used for our researches.
- Trichlorosilane ($SiHCl_3$) is cheaper Si deposition resource to compare with silane and another.
- **The thermal chemical reaction process follows the equation: $SiHCl_3 + H_2 \rightarrow Si$**

- **Advantages of our RTCVD system:**

high deposition speed; large deposition area; easily getting bigger grain size and the cost reduction potential

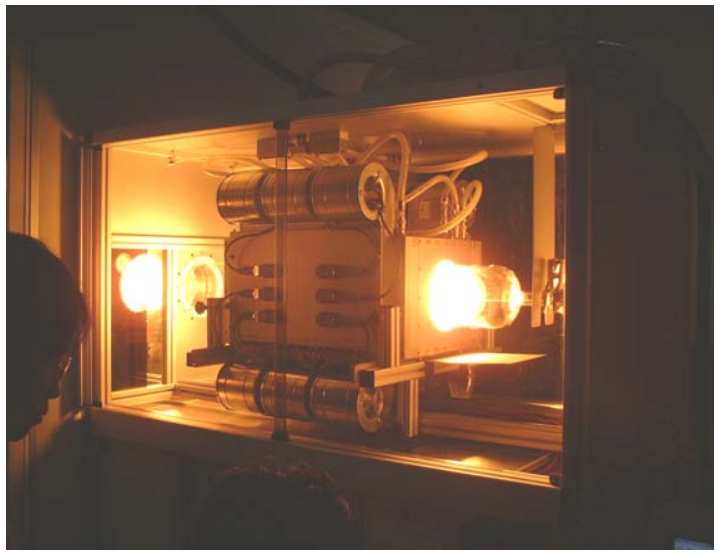
Photovoltaics - RTCVD Process

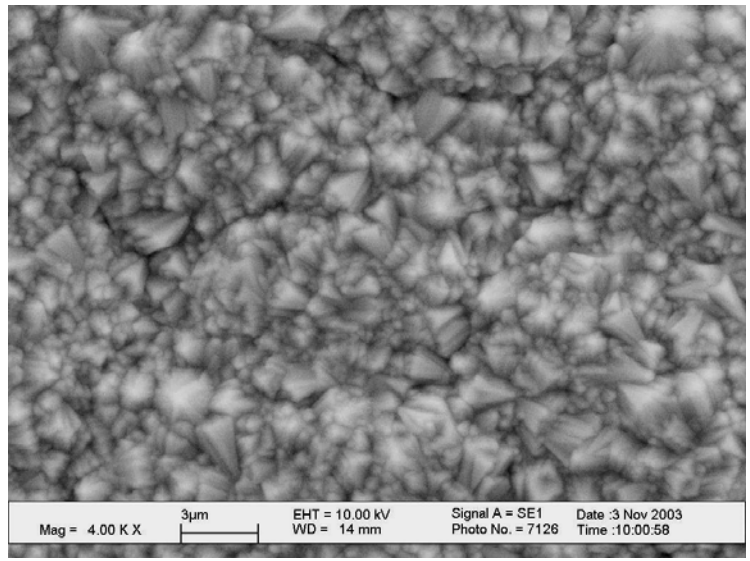




Schematic diagram of RTCVD process (with optical heating), substrate size can be 5×5 cm² each one， total 12 pieces, (max. size of 10×10 cm² each one, total 10 pieces). And substrate as follows: poly-Si wafer, mono-Si wafer, SSP ribbon and quartz plate,etc.

Photovoltaics - RTCVD Process



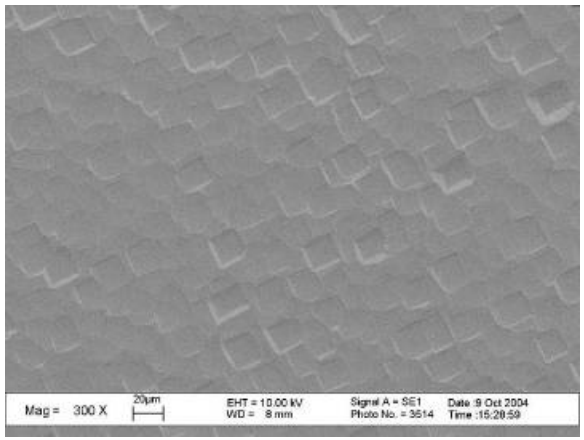


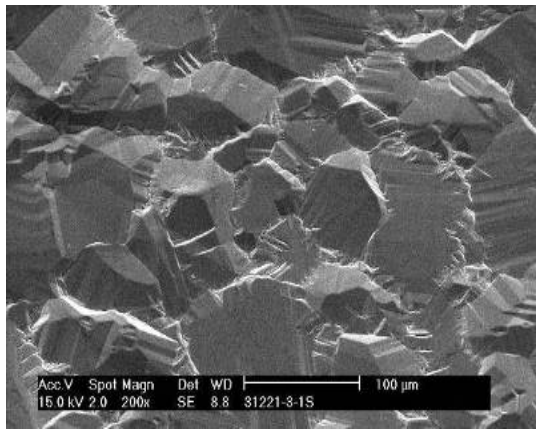
The typical parameters in our experiments as follows:

H_2: 8.0 slm, $SiHCl_3$: 15~20 g/min, Reaction temperature is 900 ～1170℃，heating rate is 100 ℃/min，the film growth rate is 3～7 μm/min and the thickness of film is 30～50 μm for the active layer of solar cell.

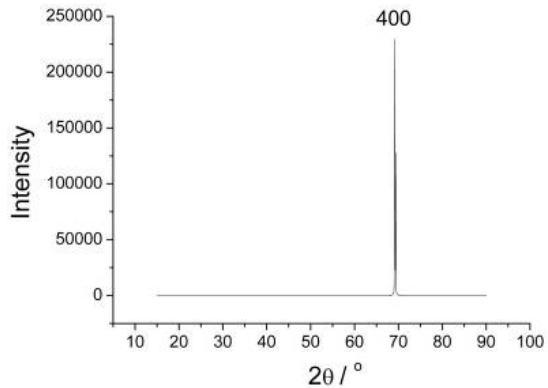
Photovoltaics - RTCVD Process

Surface morphology





Film on m-Si (left) and SSP (right)



XRD spectrum of film on (100) m-Si wafer

Photovoltaics - Poly-Si thin film solar cells on SSP

Samples of poly-Si thin film solar cells with (left) and without (right) anti-reflection coating, the size of all cell size is 1 cm^2

Photovoltaics - Results of poly-Si thin film solar cells

Cell	Area cm^2	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF	η (%)	
1	Norma-lized in 1 cm^2	14.7	246.6	0.3201	2.9	
2		16.51	288.2	0.3382	4.03	
3		15.82	271.6	0.34	3.65	
4		16.04	308.7	0.3191	3.95	
5		17.12	187.4	0.3517	2.83	
6		15.73	282.6	0.3296	3.63	
7		16.45	280	0.3604	4.15	
8		13.51	285.2	0.2919	2.8	
9		13.75	272.2	0.4639	4.35	
10		18.19	317.4	0.4893	5.66	
11		16.26	308.4	0.3195	4.0	
12		12.79	260	0.2683	2.38	
13	1	18.54	428.9	0.5657	4.5	
14	1	18.14	475	0.618	5.32	
15	1	17.53	497.4	0.6942	6.05	
19	1	26.69	506.8	0.6101	8.25	

Concluding Remarks

- As a prospective low cost technology route, in present there are several key points to study further: one is to solve the smoothness and defects of large area SSP ribbon, another is to increase the gas-solid conversion ratio during RTCVD reaction process.
- In the trudge of seeking a low cost practicable technology route fitting China's domestic market, there is still a long way to go.
- Guangdong province have very good condition to developing solar photovoltaic industry:
- Strong economics; much new market Information and many contacts from ; better Investing environment; and there are many islands (more than 400) need electricity by solar cells.

Concluding Remarks – my dreams

- To build a research center for PV, incl. solar cell test;
- To build 1-2 advanced solar cell & module manufacturers in Guangdong province;
- To develop the photovoltaic physics and a branch of learning for master and Ph D students in Sun Yat Sen University;
- To design a larger solar PV (1-2 MW) system for demonstration and test in Guangzhou City;
- To build a large "**solar park** " **with ecological and technological** demonstration near Pearl River;

Concluding Remarks – my dreams

Guangzhou lost many chances to made BIPV, such as in new Sport Holl, Olympic Hall, new Trade and Exhibition Center, now Guangdong Science Center, to be built in 2005, the roof area over 30 km^2, a good chance to using solar modules to made BIPV.

Acknowledgements

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Thank you!