Investigation on micro welding and nano joining with laser
激光微纳米连接技术

Jimin Chen

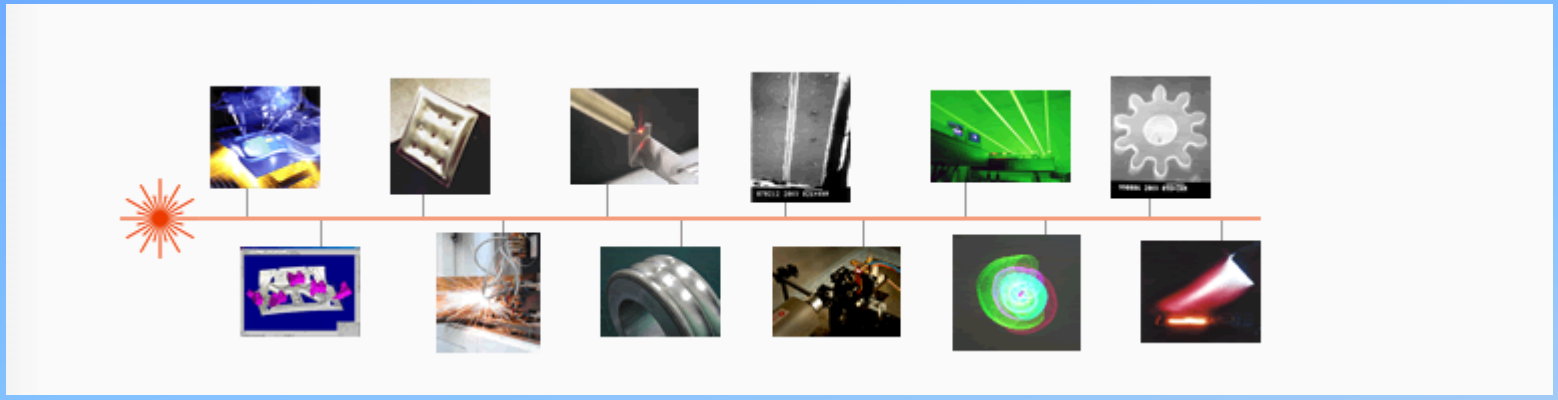
陈继民

Institute of Laser Engineering

Beijing University of Technology(BJUT)

北京工业大学激光工程研究院

We focus on LASER专注激光



Advanced laser manufacturing
激光制造技术
- Laser welding
- Laser cutting
- Laser cladding
- Laser sintering
- Laser drilling
- …….

How To Use Laser?
光制造

High power optoelectronics
能量光电子技术
- Laser device
- Ps Laser
- Diode Laser
- Fiber Laser
- …….

How To Produce Laser?
制造光

Laser micro/nano processing
微纳加工技术
- Micro sintering
- Micro STL
- Nano structuring
- ……

Bio-optronics…..
生物光子学

Contents目录

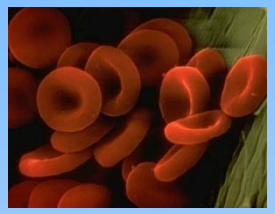
- Introduction简介
- Laser micro welding激光微焊接
- Laser Nano joining激光纳连接
- Conclusions总结

The Scale of Things – Micro/Nanometers微纳米尺度

Ant
~ 5 mm

Human hair
~ 60-120 μm wide

Red blood cells
(~7-8 μm)



DNA
~2-1/2 nm diameter

Atoms of silicon
spacing 0.078 nm

1 cm
10 mm
10^{-2} m

"The Macro World"

10^{-3} m
1,000,000 nanometers = 1 millimeter (mm)

Microwave

0.1 mm
100 μm
10^{-4} m

Micro-technology
"The Micro World"

0.01 mm
10 μm
10^{-5} m

Infrared

10^{-6} m
1,000 nanometers = 1 micrometer (mm)

Visible

0.1 μm
100 nm
10^{-7} m

Ultraviolet

0.01 μm
10 nm
10^{-8} m

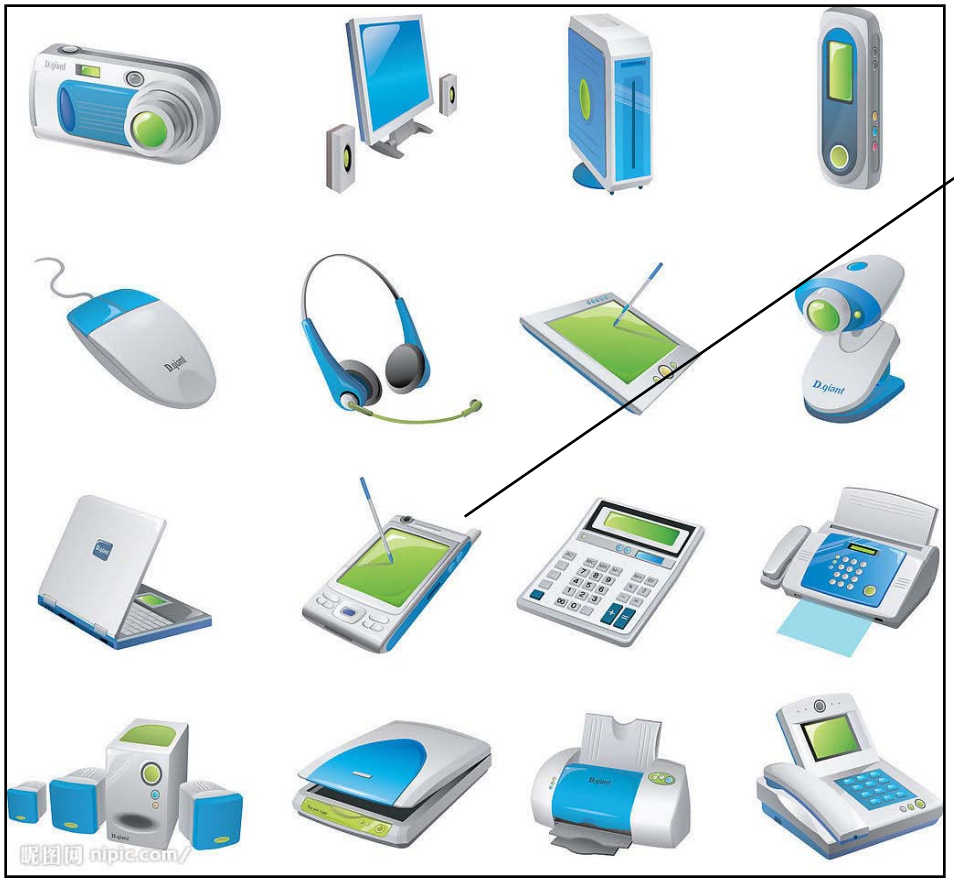
10^{-9} m
1 nanometer (nm)

Soft X-ray

Nanotechnology
"The Nano World"

0.1 nm
10^{-10} m

2、Microwelding in electronic device
电子器件微焊接



SMT

Reflow soldering

- infrared
- hot air
- vapor phase
- laser
- ...

Pb dose great harm to human health.
铅对人的危害

America: <H.R.2922>, <S.391>, <H.R.3554>,etc.
Japan: <The Japanese Home Electronics Recycling Law>.
Europe: <WEEE>, <RoHS>, etc.
China: Ministry of Information Industry regulation: the national key supervision within the directory of the electronic products can't contain lead and other harmful substances since July 1st, 2006 .

- Legislations: elimination of lead from electronic solders.

↓

Find suitable lead-free substitutes.

↓

New challenges: material, technology, equipment, detection.

Lead-free solders无铅钎料

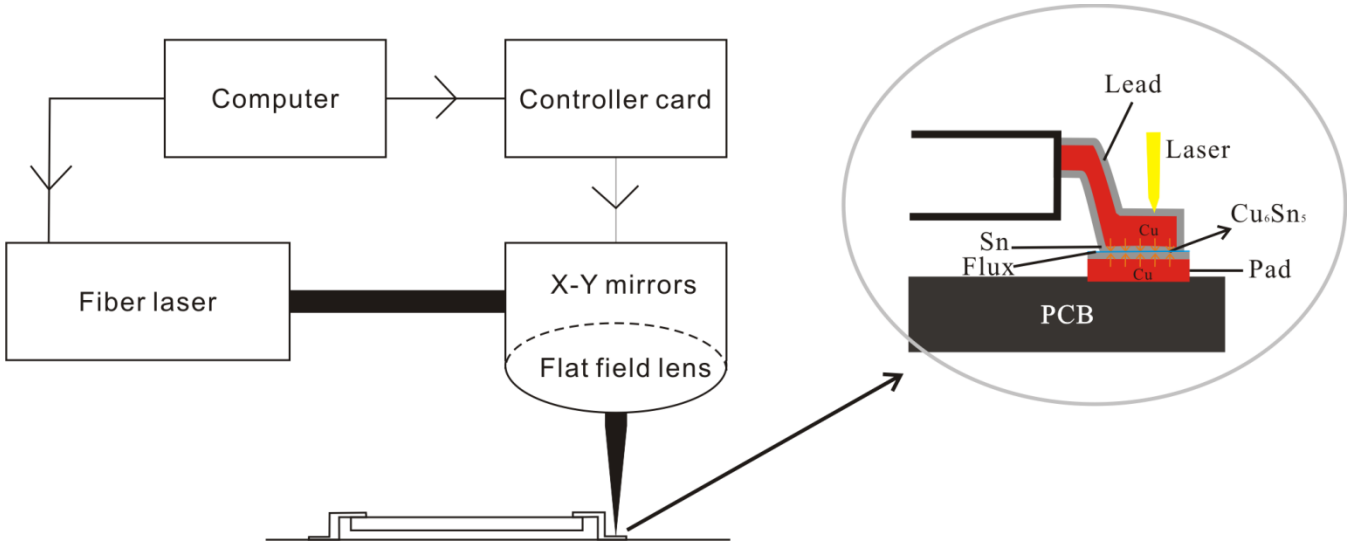
- Sn-Ag-Cu, Sn-Cu, Sn-Ag, Sn-Zn, Sn-Zn-Bi, Sn-Ag-Bi, etc.

- **Common faults compared with Sn-Pb solder:** short life, store in low temperature (0-10^{o}C), high melting temperature, low density, high cost, etc.寿命短、必须低温储存、熔点高、密度低、成本高

Not use solder → Chip connect with PCB

Laser welding directly?

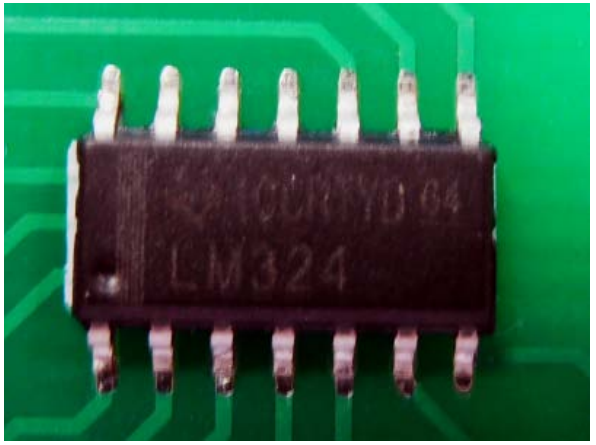
Laser welding without solder



Package Type	Chip Type	Pin Count	Lead width /mm	Lead pitch /mm	Lead length /mm	Lead thickness /mm
SOP	LM324	14	0.36-0.61	1.27	0.40-1.27	0.2
SSOP	HT1621	48	0.203-0.305	0.635	0.635-0.889	0.1
QFP	HT16512	44	0.30	0.80	0.73-0.93	0.20

Laser soldering parameters激光钎焊

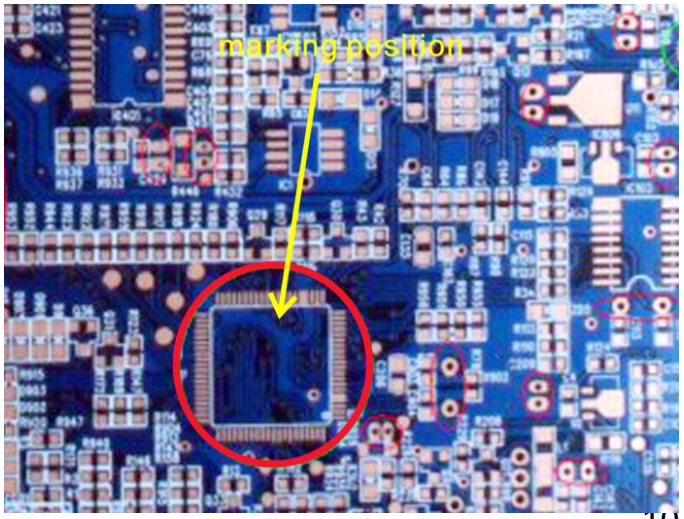
- Laser power: 10-20W;
- Scan speed: 10-50 mm/s;
- Pulse repetition frequency: 20-80 kHz;
- Welding path



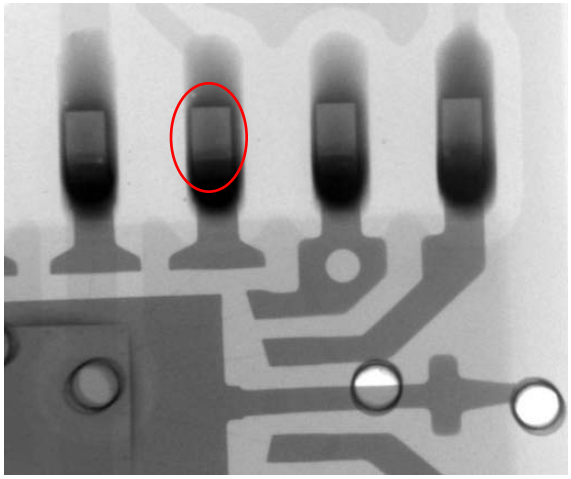
18 W, 20 mm/s, 20 kHz

Laser welding microchip without solder
无钎料激光焊接芯片

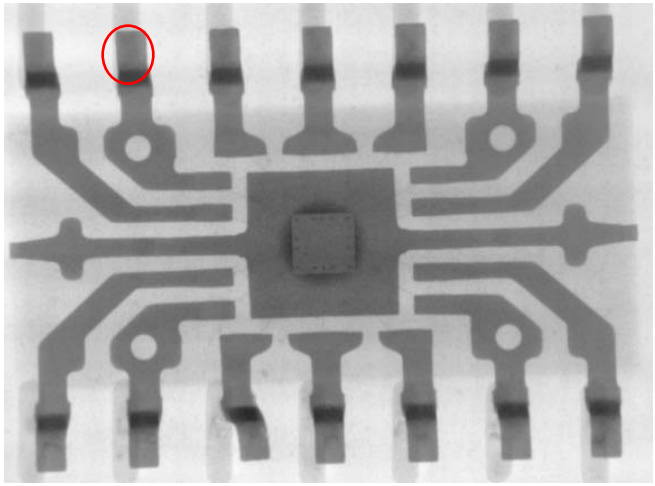
- Firstly it will remove solder and screen printing process, which can greatly lower the cost.
- Secondly superfine lead laser soldering will get rid of the limits of printing technology. It can make the lead width less than 0.1mm rather than generating bridge defect.
- Thirdly it will be more flexible to weld chip at any position on the PCB.



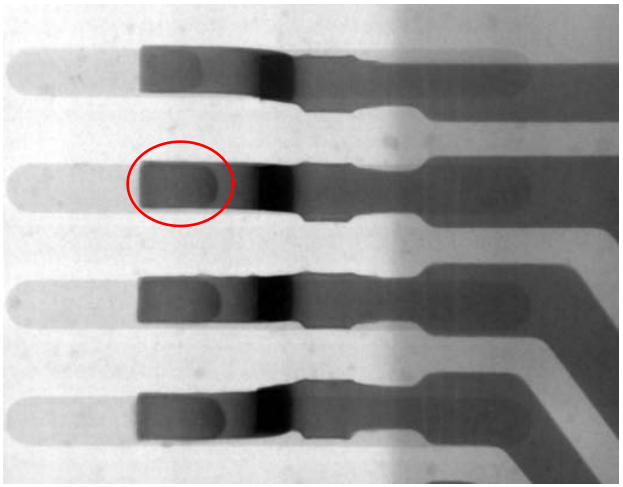
X-ray nondestructive test



IR reflow soldering with Sn-Pb



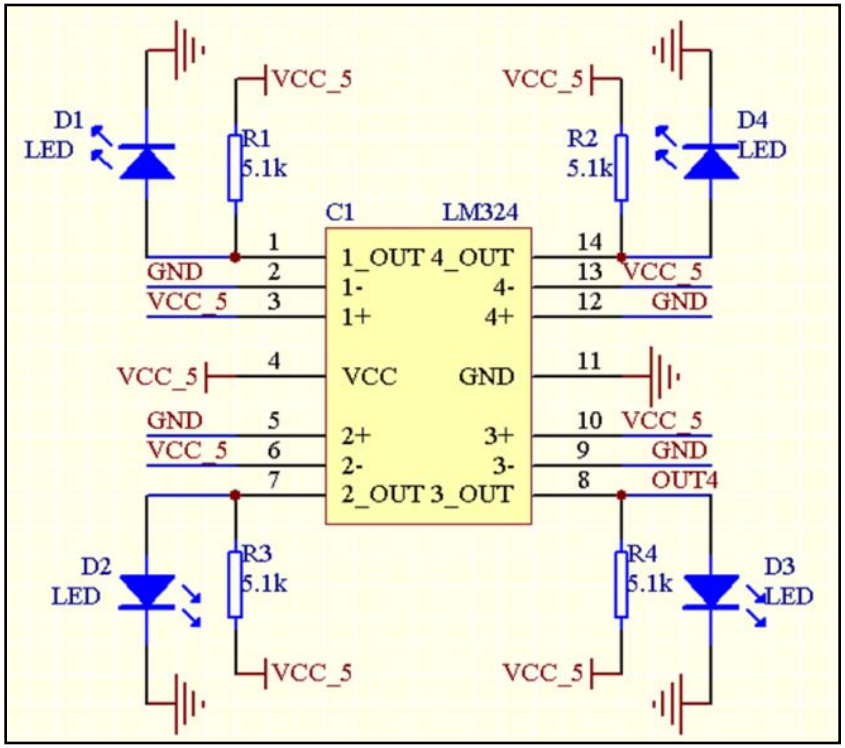
Chip put on PCB without welding

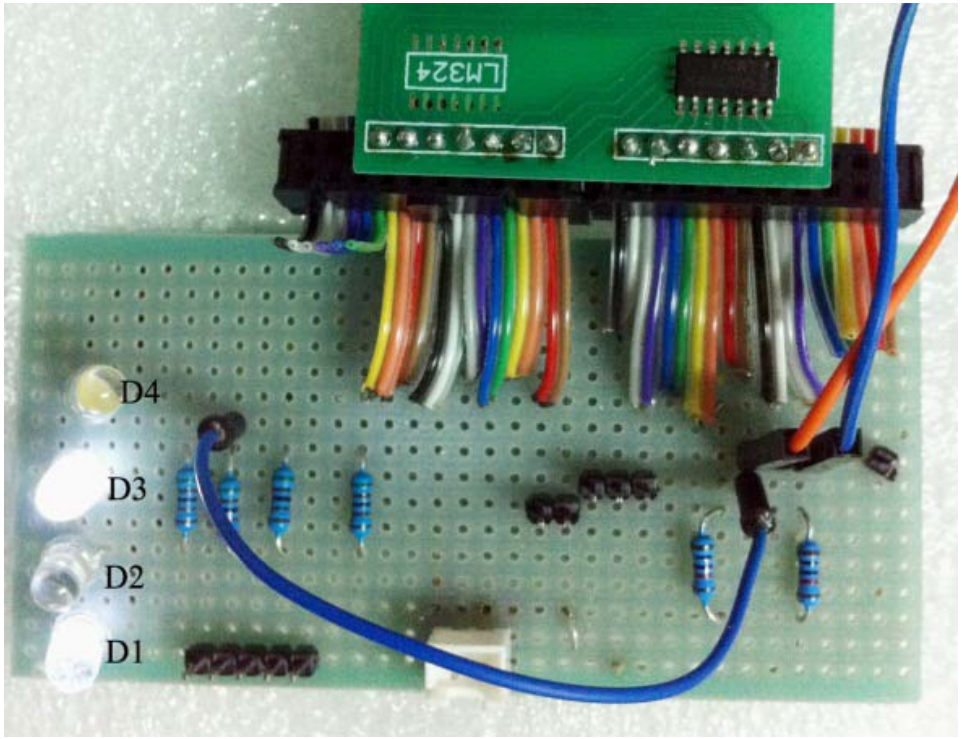


Laser welding without solder

Achieve solder joints between chip leads and PCB pads and not have bubble or crack defects.

Electric property test电路测试

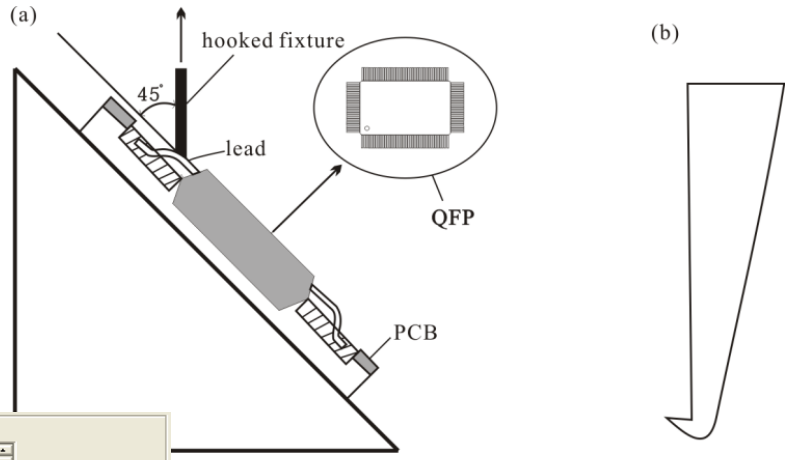


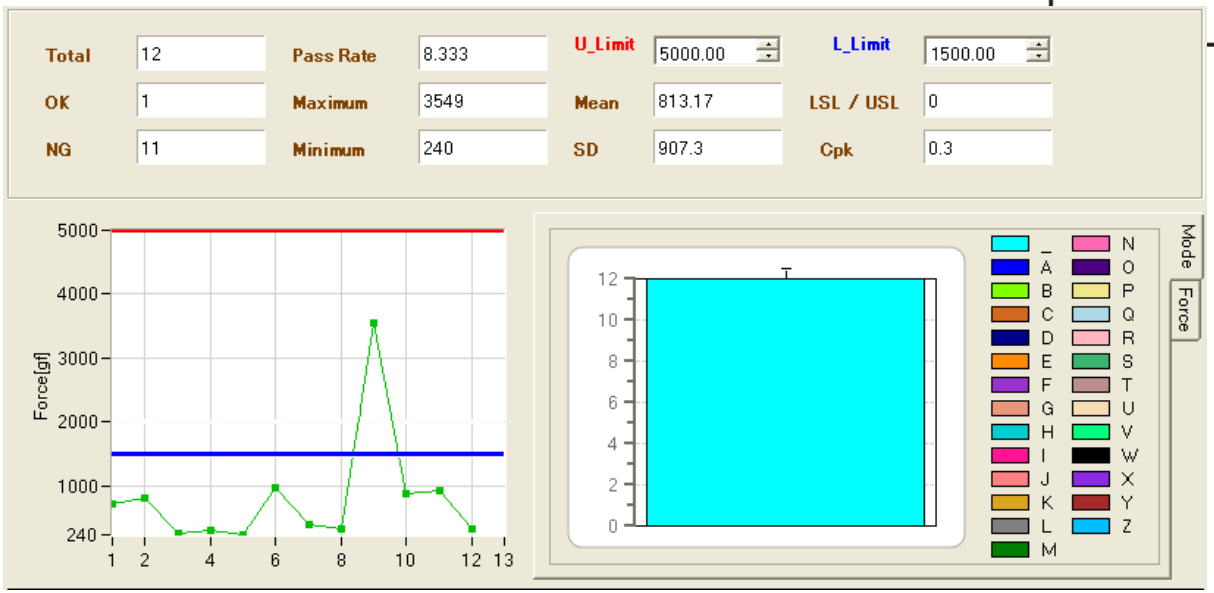


The solder joints can achieve good electric property and the chip wasn't damaged by laser energy.

Tensile strength test拉伸测试

Japanese industrial standards (JIS) Z3198 about test methods for lead-free solders, part 6: methods for 45º pull test of solder joints on QFP lead.





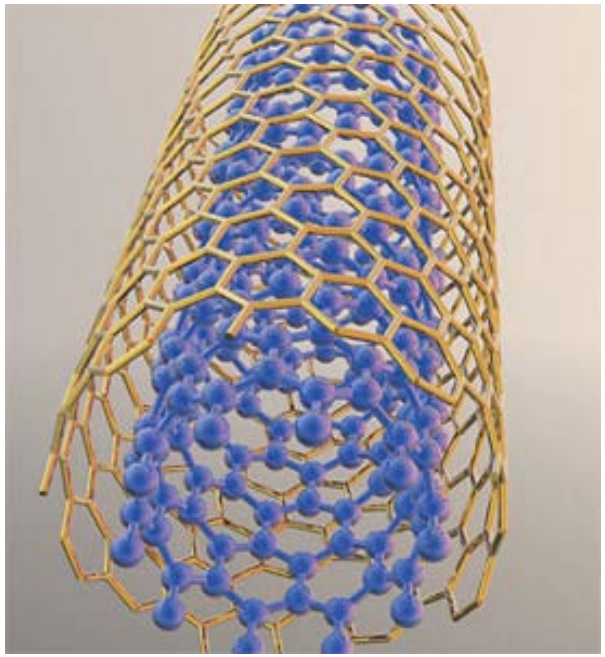
result:
The tension is greater **than 10N.**

laser microwelding激光微焊接

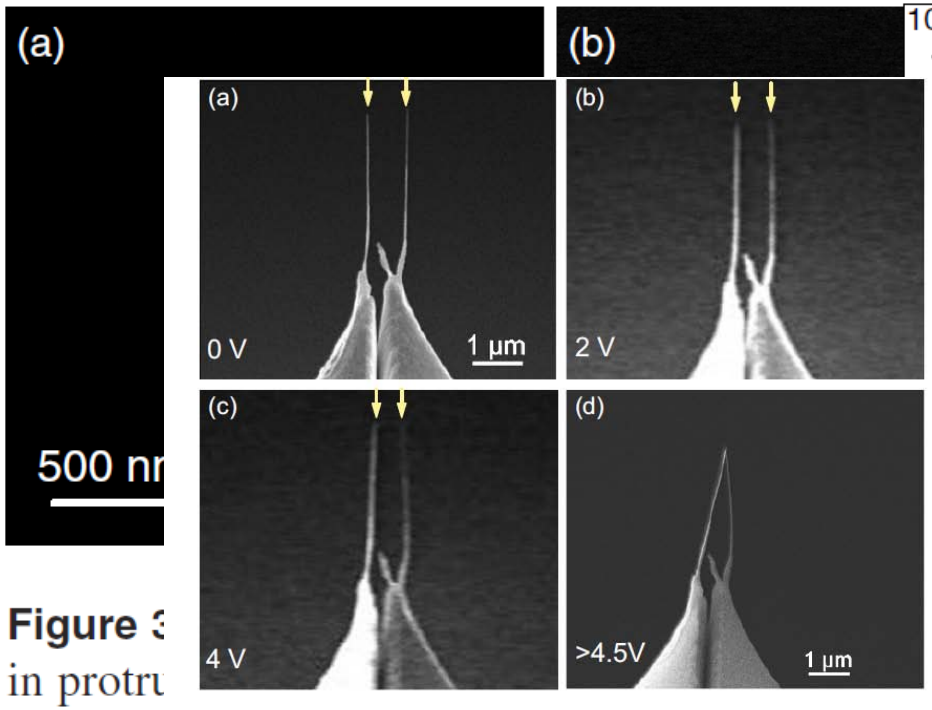
- The SOP、SSOP、QFP devices have been welded to PCB pads by laser welding without solder, and achieved good solder joints.
- Through electric property device test, it proved the solder joints can enforce good electric properties.
- Under the soldering parameter of 18 W, 20 mm/s, 20 kHz, the tensile strength of SOP devices reached 52 MPa (SSOP 72 MPa, QFP 57.3 MPa), which was equal to the tensile strength of IR reflow soldering with Sn-Pb solder.

3、纳米连接背景介绍

- 碳纳米管（Carbon nanotubes）
- 碳纳米管是1991年被日本NEC公司Iijima博士发现的一种新型碳结构，它是由石墨烯片层卷曲而成的无缝、中空管状结构。按照层数的不同，碳纳米管可分为单壁碳纳米管（single-walled carbon nanotubes--SWCNTs）与多壁碳纳米管（Multi-walled carbon nanotubes--MWCNTs）,其中SWCNTs直径为0.6nm-6nm 多壁碳纳米管直径为6nm-200nm.



纳米线连接的应用



纳米镊子 -------Kim P, Lieber CM. Science. 1999,286:2148

米探针------Hafner H, Cheung CL, eber CM. Nature. 1999,398:761

宏观体:

Figure 3 ... otube (200 nm in protru ... a single one at the very ... f the nanotubes are abou ...

Figure 5. SEM images of nanotube tweezers at different applied voltages: (a) 0 V, (b) 2 V, (c) 4 V and (d) >4.5 V.

纳米

晶体管

纳米探针

Research on the joining of MWCNTs by different wave length laser

国内外研究现状

EBID方法------Florian Banhart. Nano Letters. 2001, No.6 329-332

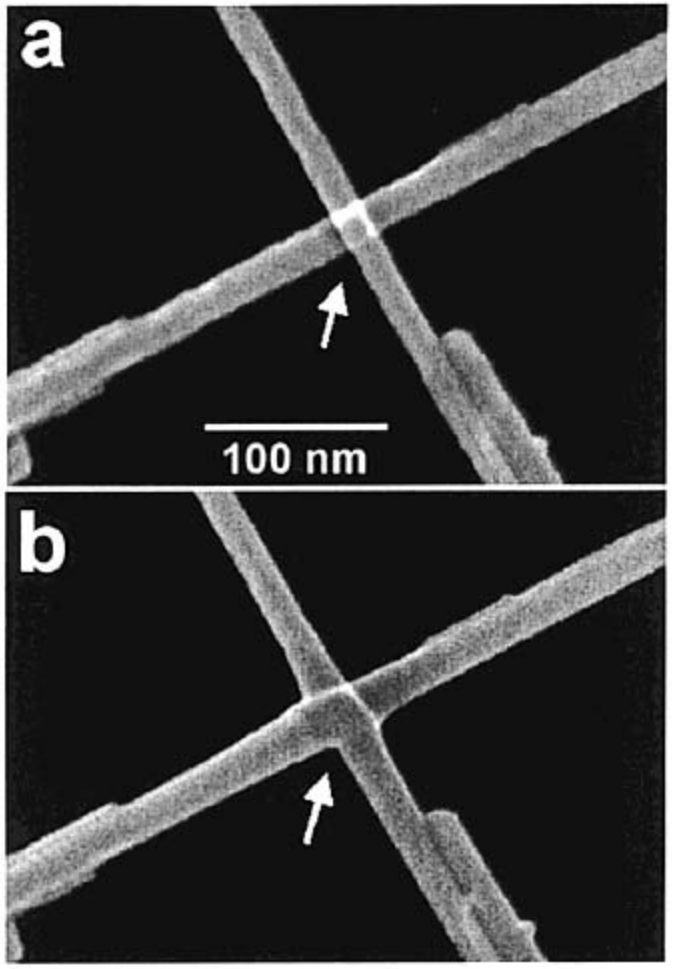


Figure 2. Nanotube junction treated as described in Figure 1 but with a small deposit (low contamination rate)

CNTs定向连接------Mingsheng Wang, Jingyun Wang, Qing Chen, and Lian-Mao Pang. Adv Func Mater, 2005, 15: 1825-1831.

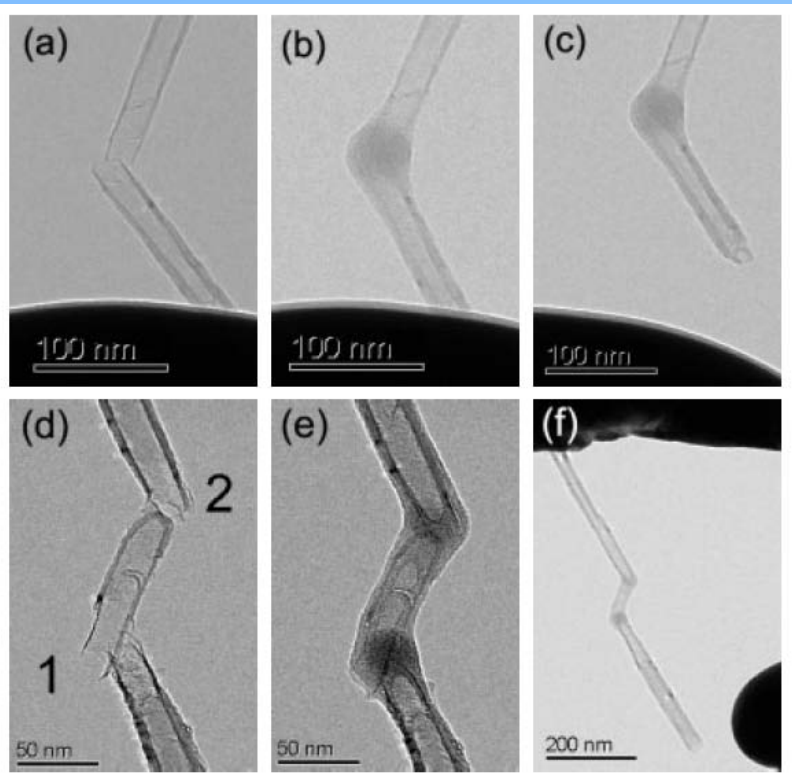


Figure 4. TEM images showing the fabrication of bent and zigzag CNT structures. a) Contact near the end of the two ruptured nanotube segments with a controllable angle. b) Deposition of a-C on the junction. c) Detachment of the bent structure from the W tip. d) Construction of a zigzag structure with two controllable bends (a straight tube was cut at bend 1 and partly broken at bend 2). e) Deposition of a-C on the junction.

利用化学改性法连接-------Seung I.Cha, Kyung T.Kim, Kyong H.Lee. Carbon 46 (2008) 482–488

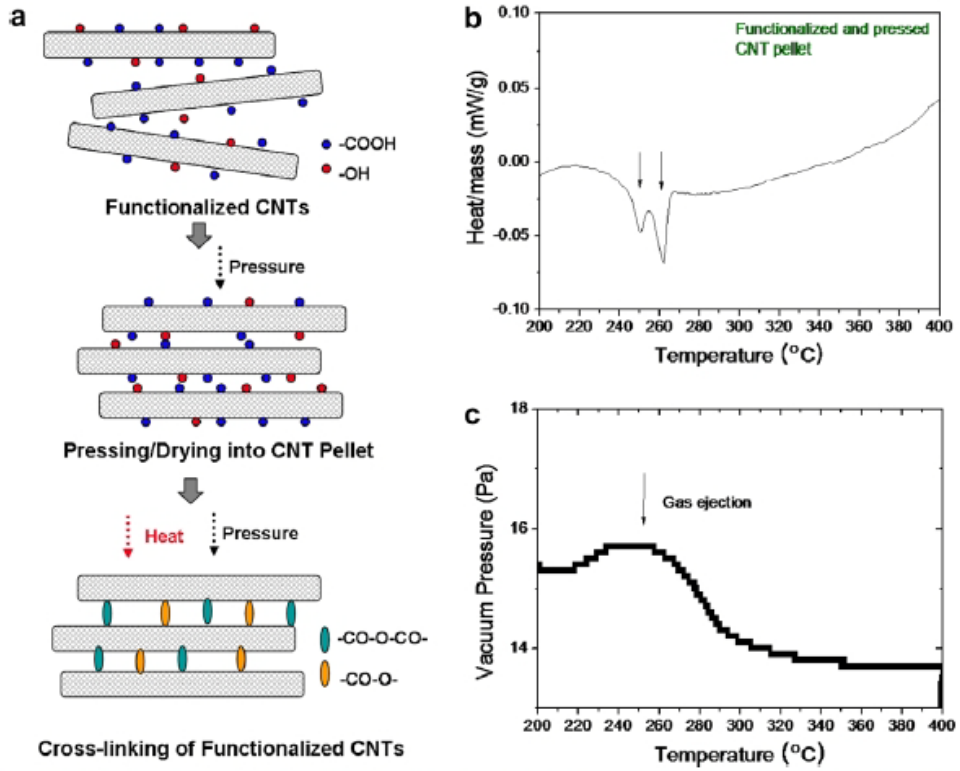
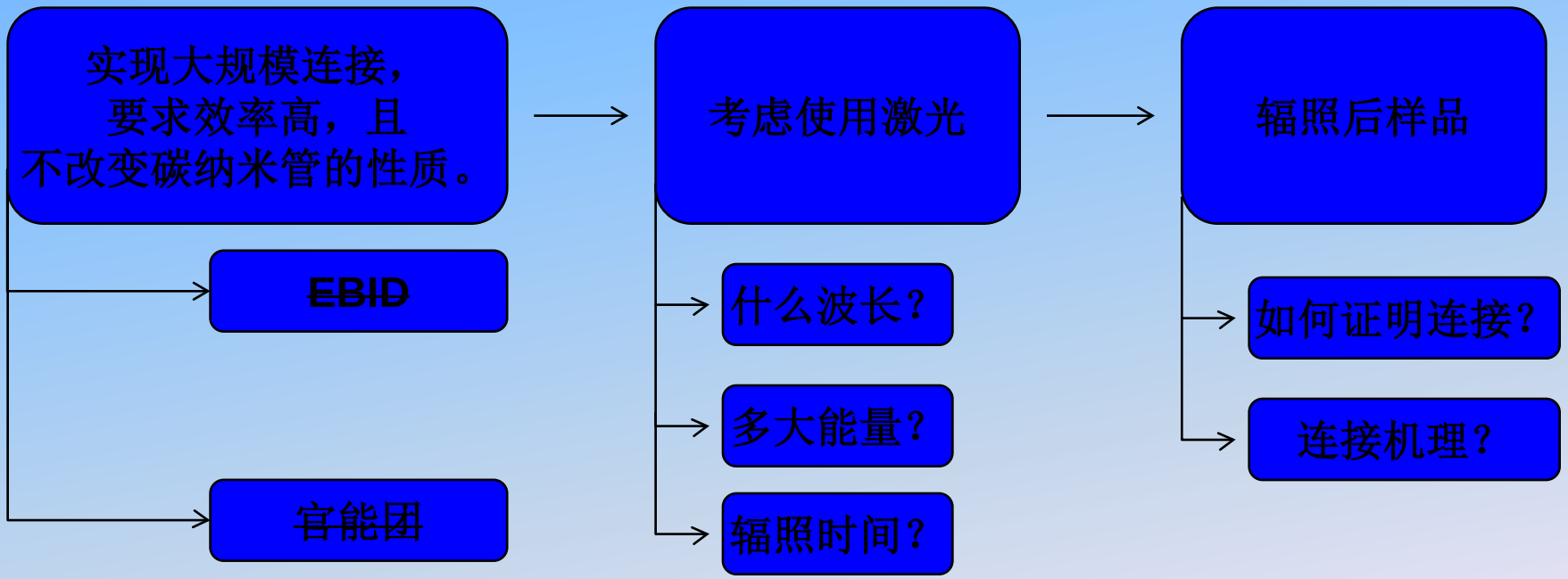


Fig. 1 – (a) Schematic of the process used to fabricate CL-CNT. The functionalized CNTs are compressed to keep them in close contact with each other, and this is cross-linked using spark plasma sintering to form chemical bonds between the functionalized CNTs. (b) DSC analysis of an as-pressed CNT pellet before spark plasma sintering and (c) the changes in the vacuum pressure during spark plasma sintering of a pressed CNT pellet. The arrows indicate the peaks from ejection of gas in cross-linking during spark plasma sintering.

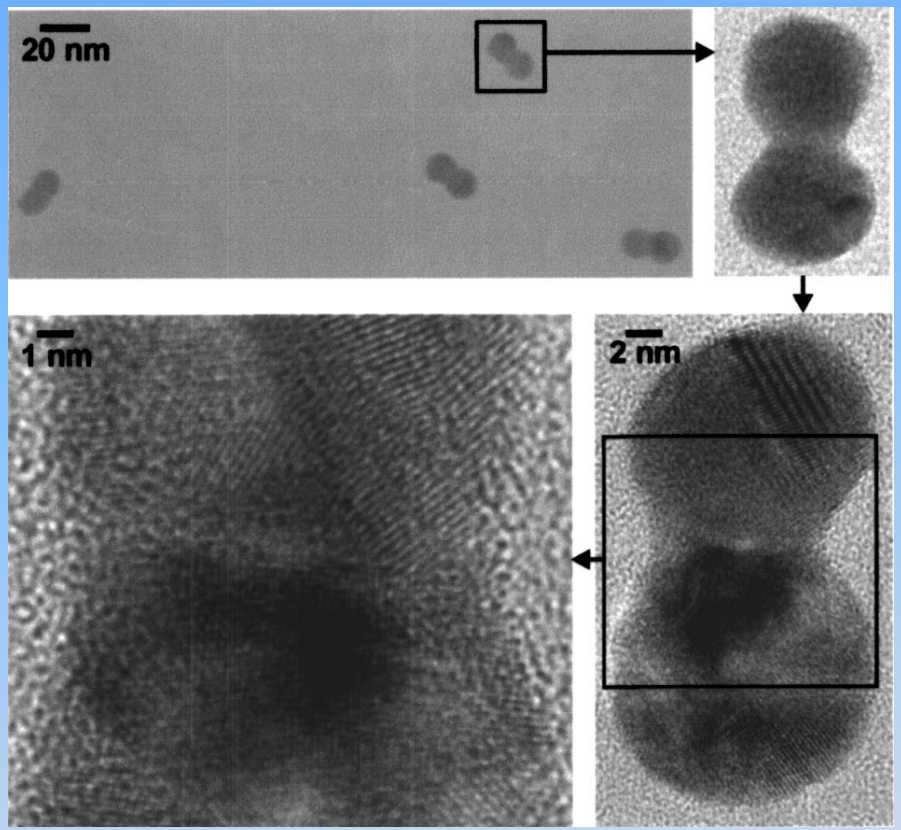
Research on the joining of MWCNTs by different wave length laser

高效、大规模纳米连接途径



Research on the joining of MWCNTs by different wave length laser

Nano joining with Laser 激光纳米连接现状



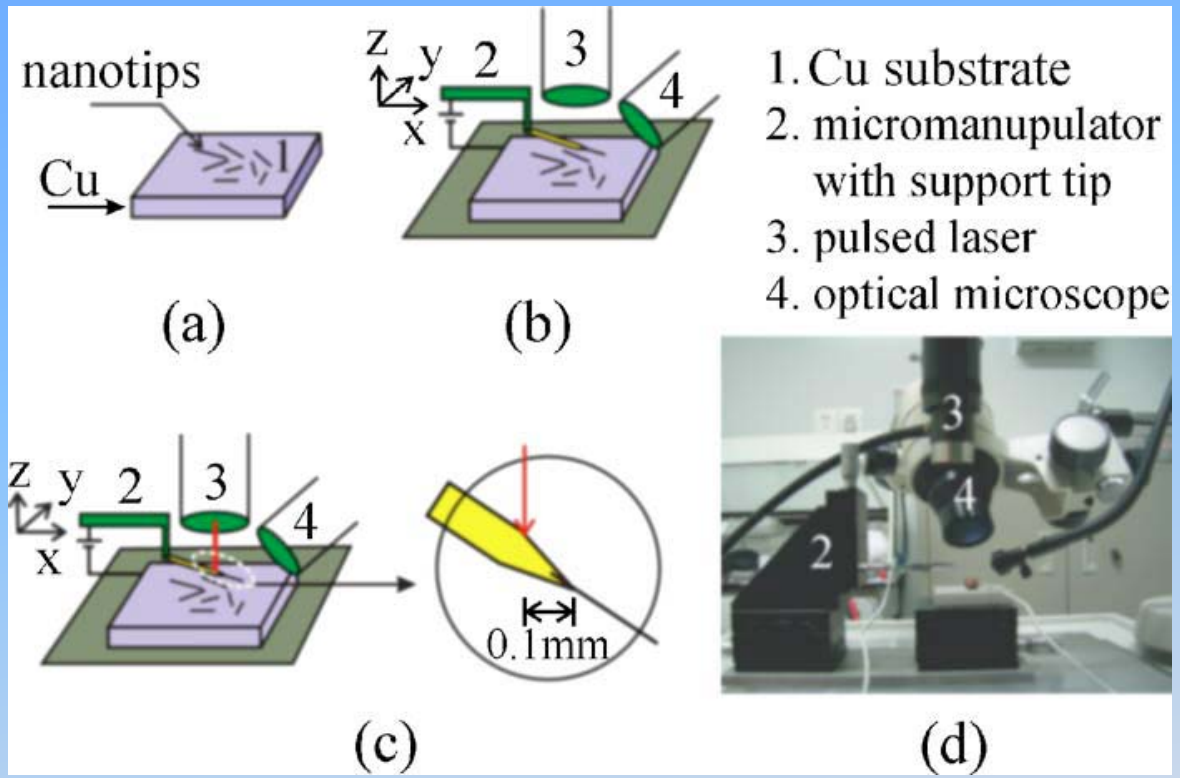
Surfactant-free gold nanospheres of 9.3 nm dispersed in water, having an average diameter of 13 nm The gold nanoparticles were irradiated to weld by using the second harmonic pulses of 532 nm having a duration of 30 ps from a mode-locked Nd:YAG laser sQuantel, run at 10 Hz. The spot diameter of the irradiation beam was 4 mm.

532nm绿激光
30皮秒

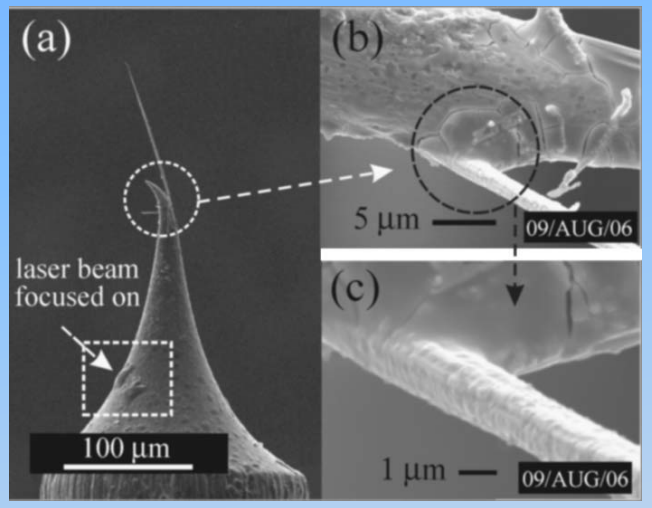
Courtesy of Seol Ji Kim et.

Laser-induced nanowelding of gold nanoparticles

Laser spot welding(YAG 1064nm.1ms)

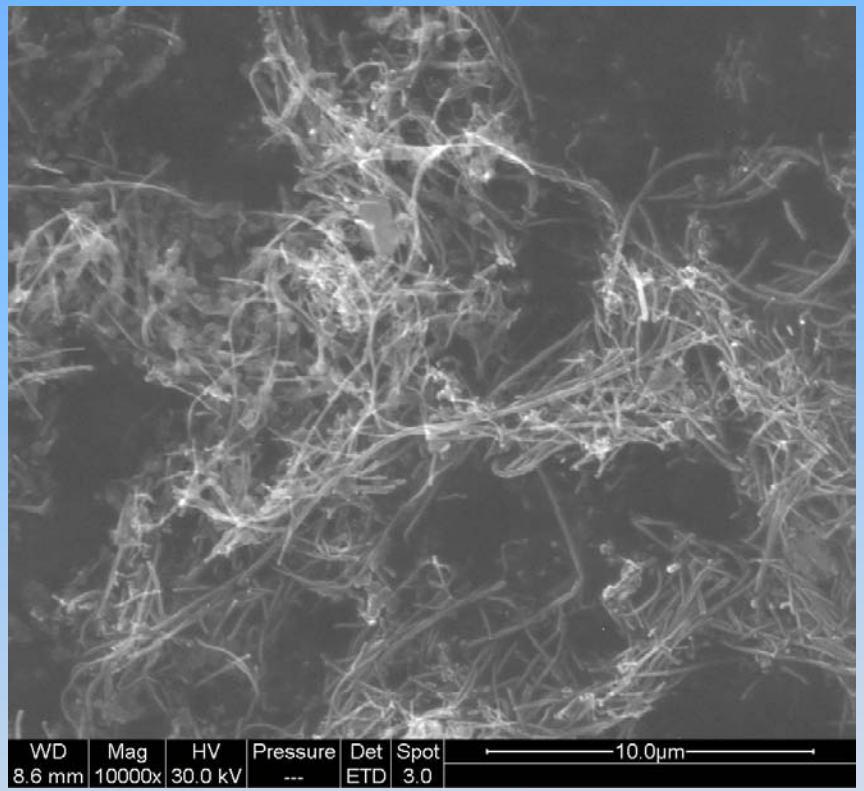


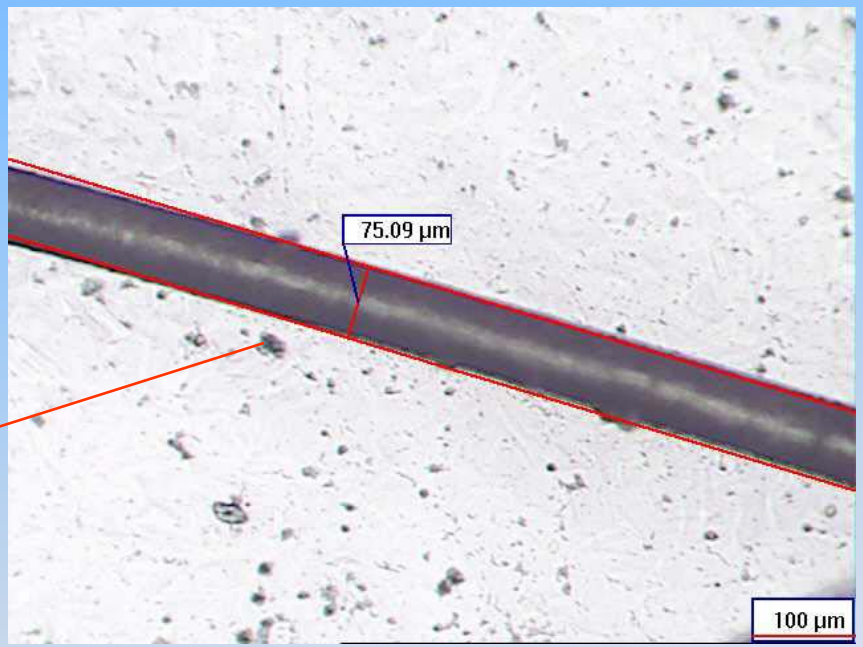
Courtesy of J.C.She et.



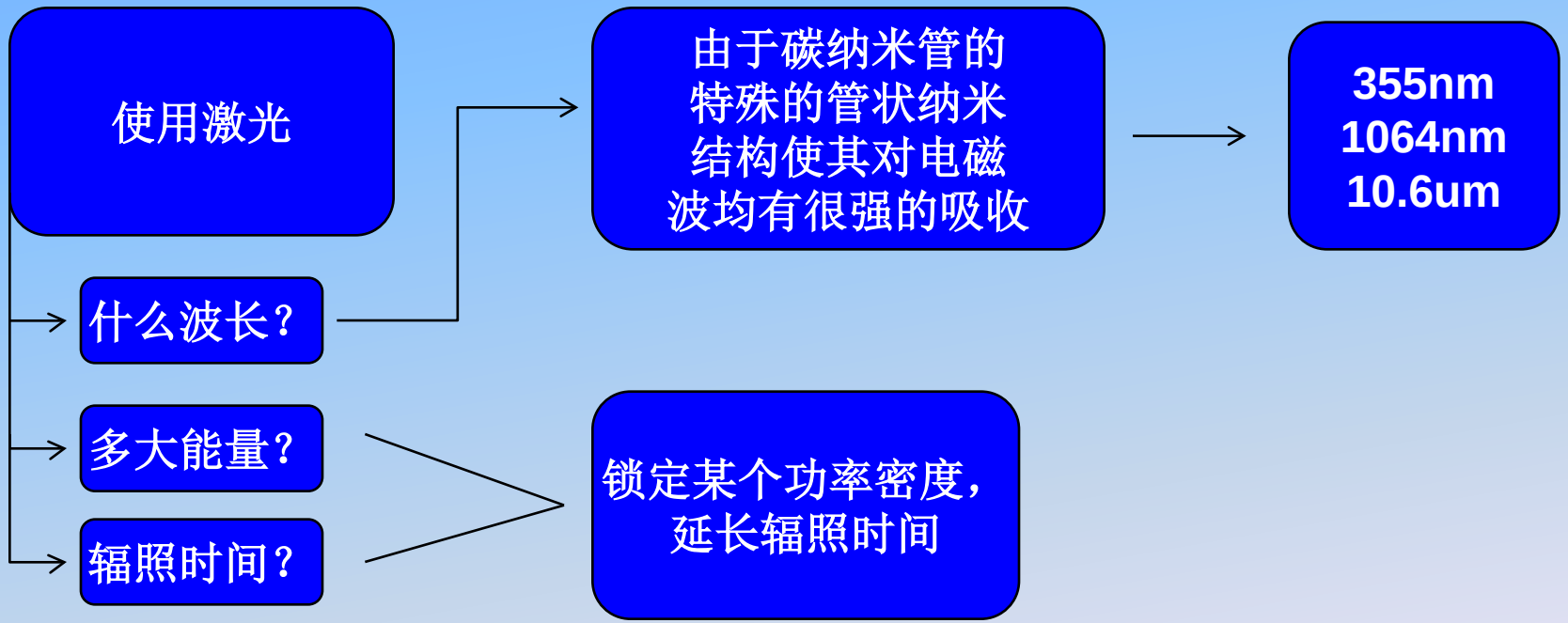
Illustrating how to laser weld a W18O49 nanotip on to the apex of a W microtip and the photography of the central part of the micro assembly facility.

How about Carbon nanofiber?
纳米碳纤维



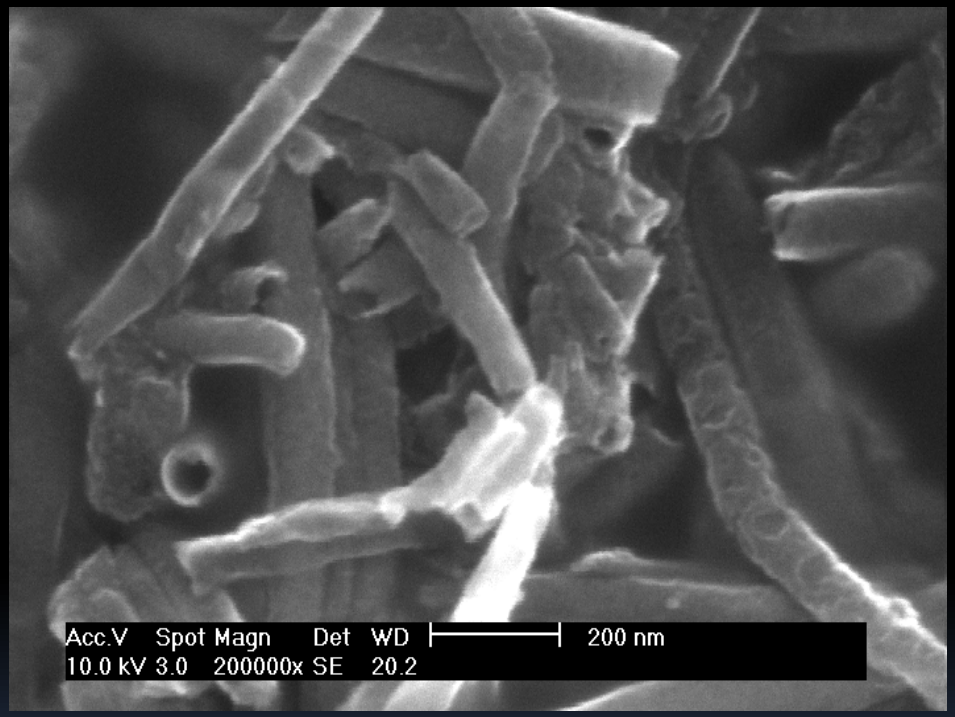


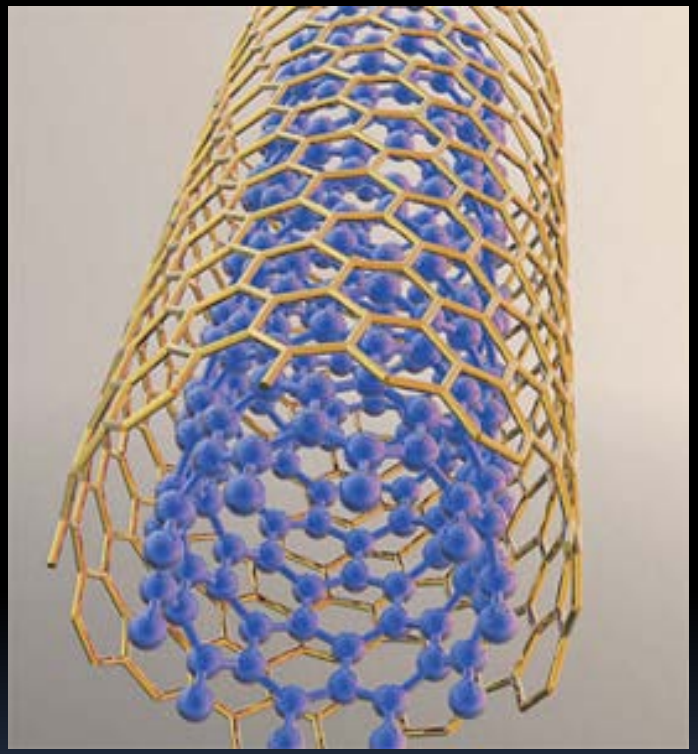
高效激光纳连接？



Research on the joining of MWCNTs by different wave length laser

They are MWCNTs

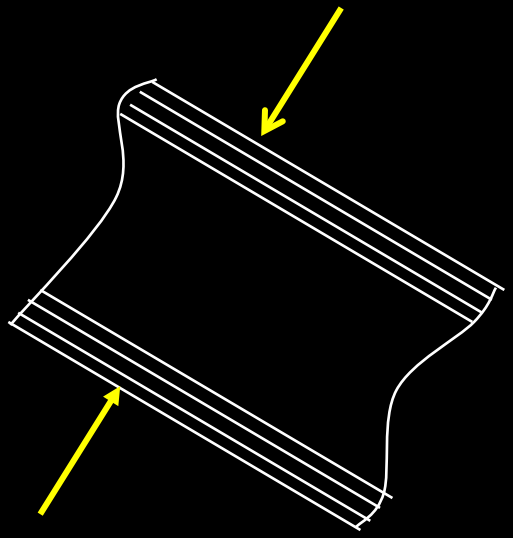


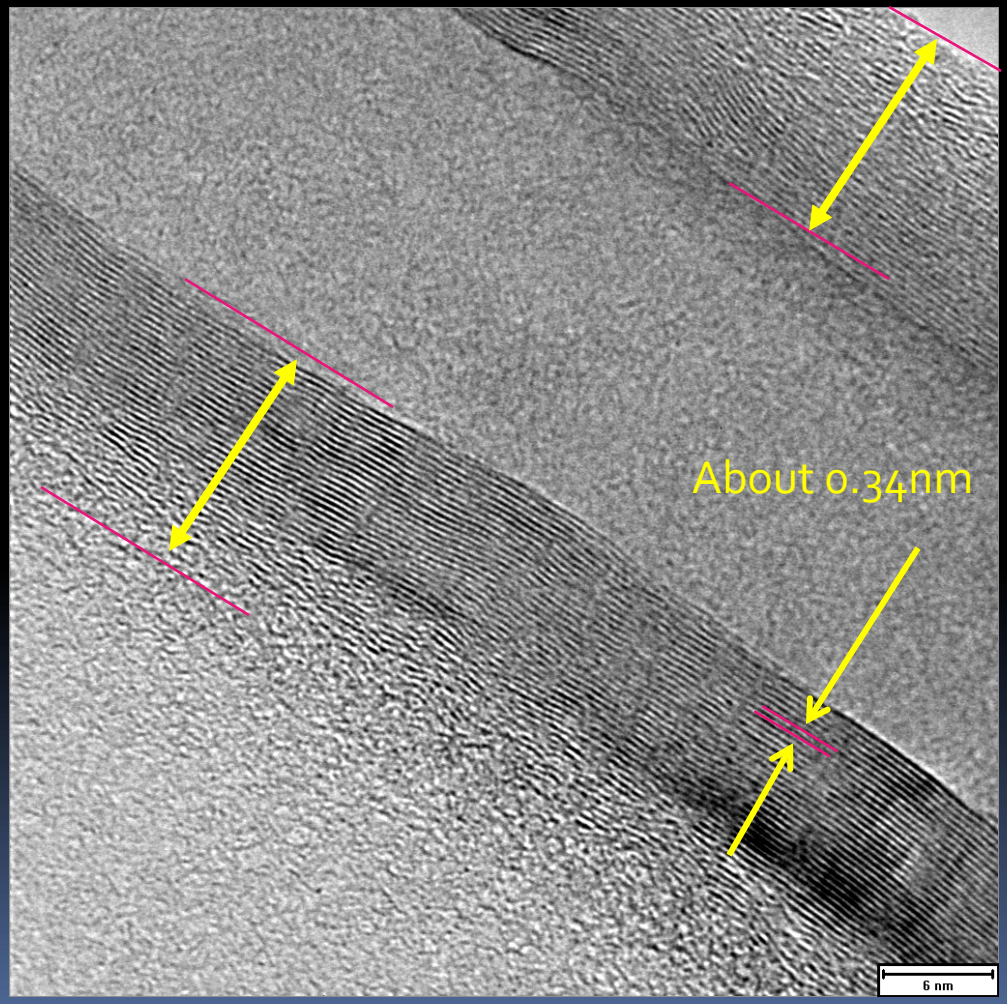


碳纳米管是由石墨片层卷曲而成的管状纳米级物体。根据片层数的多少分为单壁碳纳米管（SWCNTs）、双壁碳纳米管、多壁碳纳米管(MWCNTs)

TEM photo picture of MWCNTs

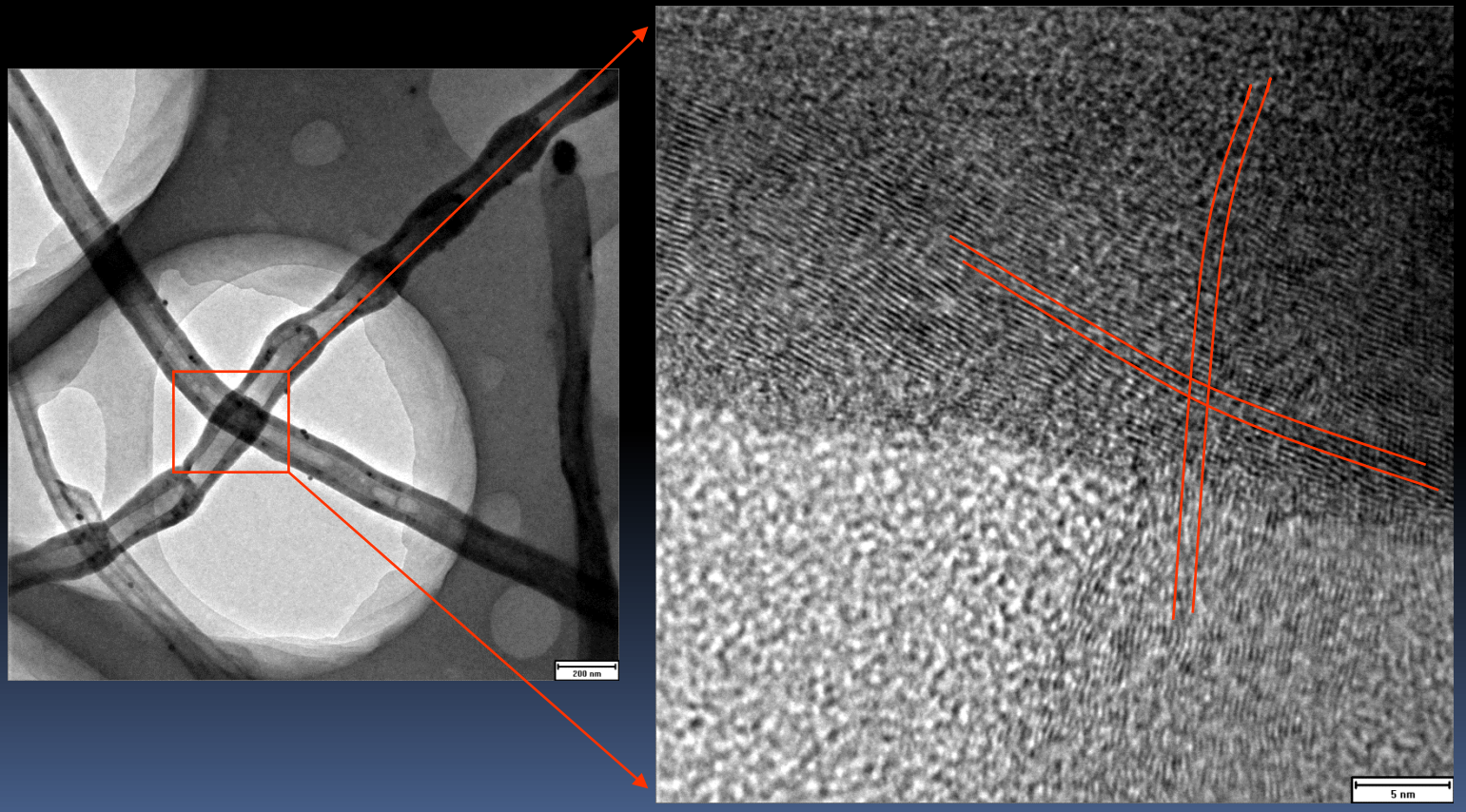
Diameter is about 30-40nm



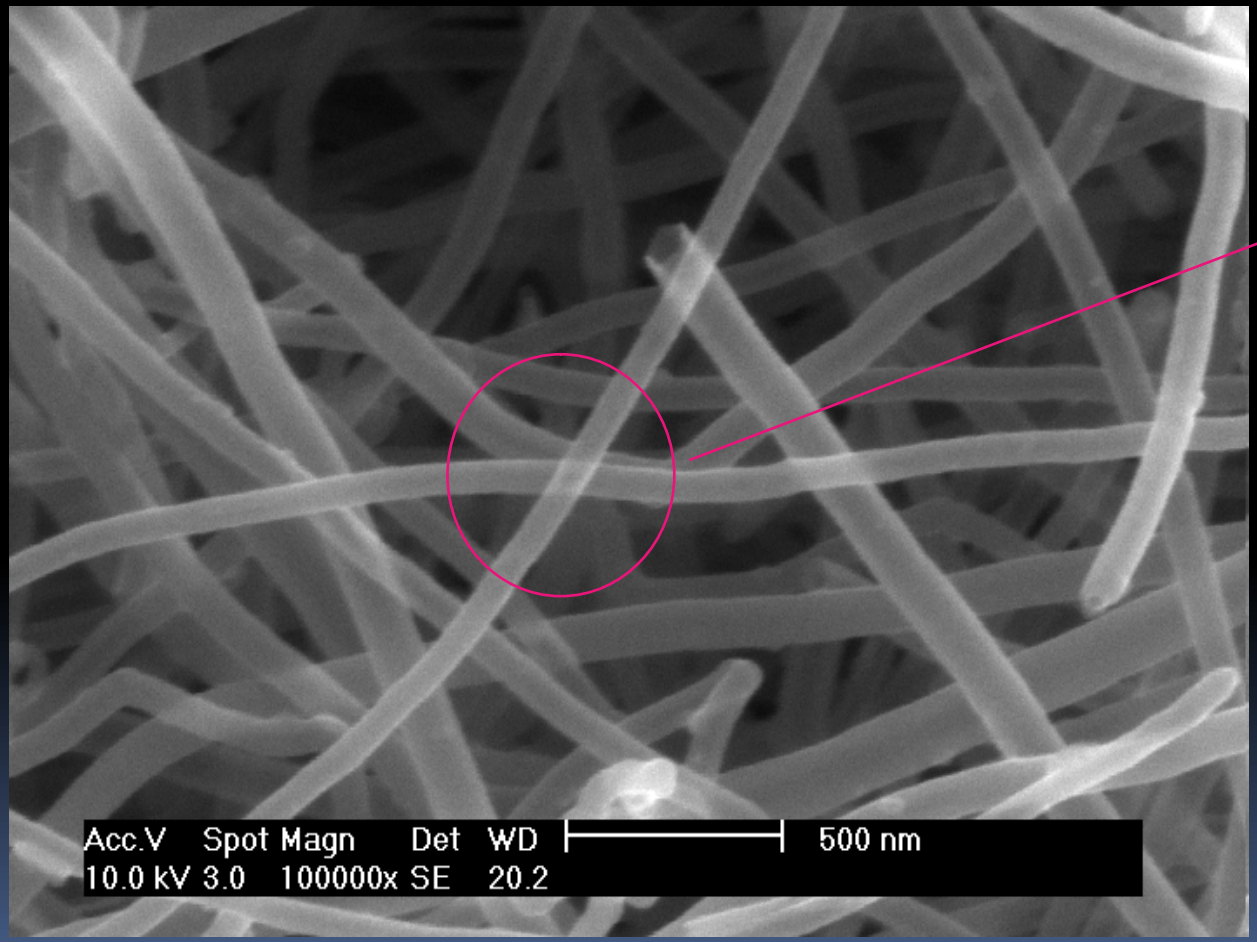


The number of wall is about 90-100.
The distance between wall is about 0.34nm

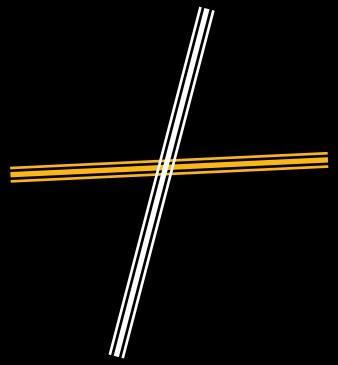
- Before joinining of MWCNTs（TEM）



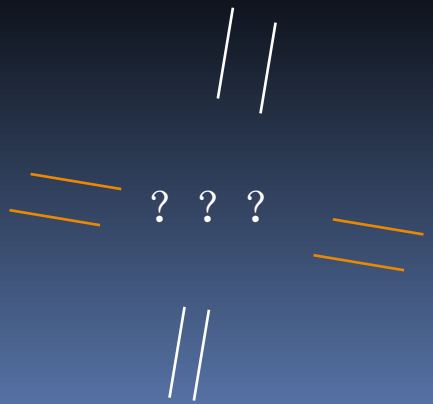
SEM Photo picture of MWCNTs



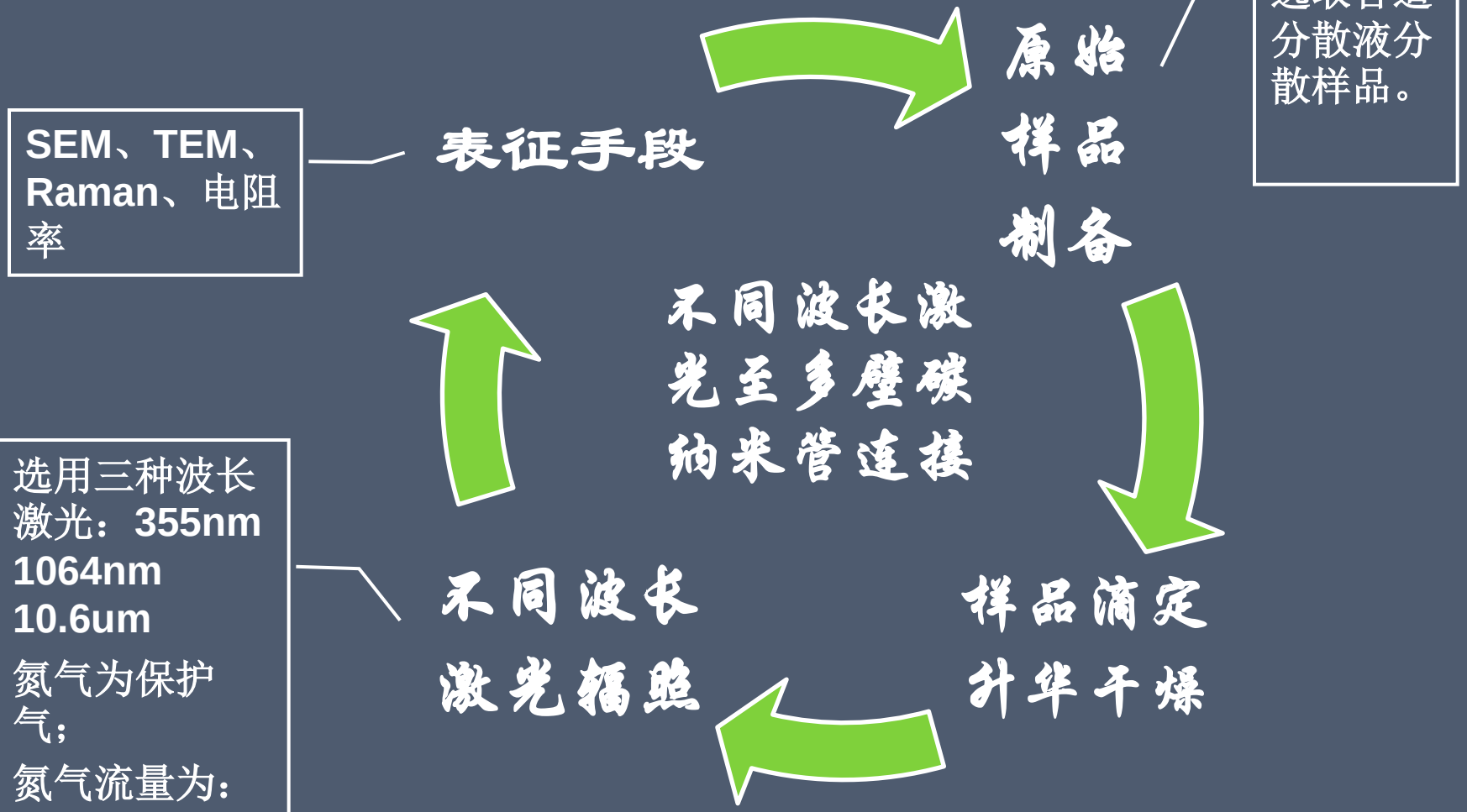
Before Joining



After Welding



研究方法



Research on the joining of MWCNTs by different wave length laser

MWCNTs under laser radiation

实验现象

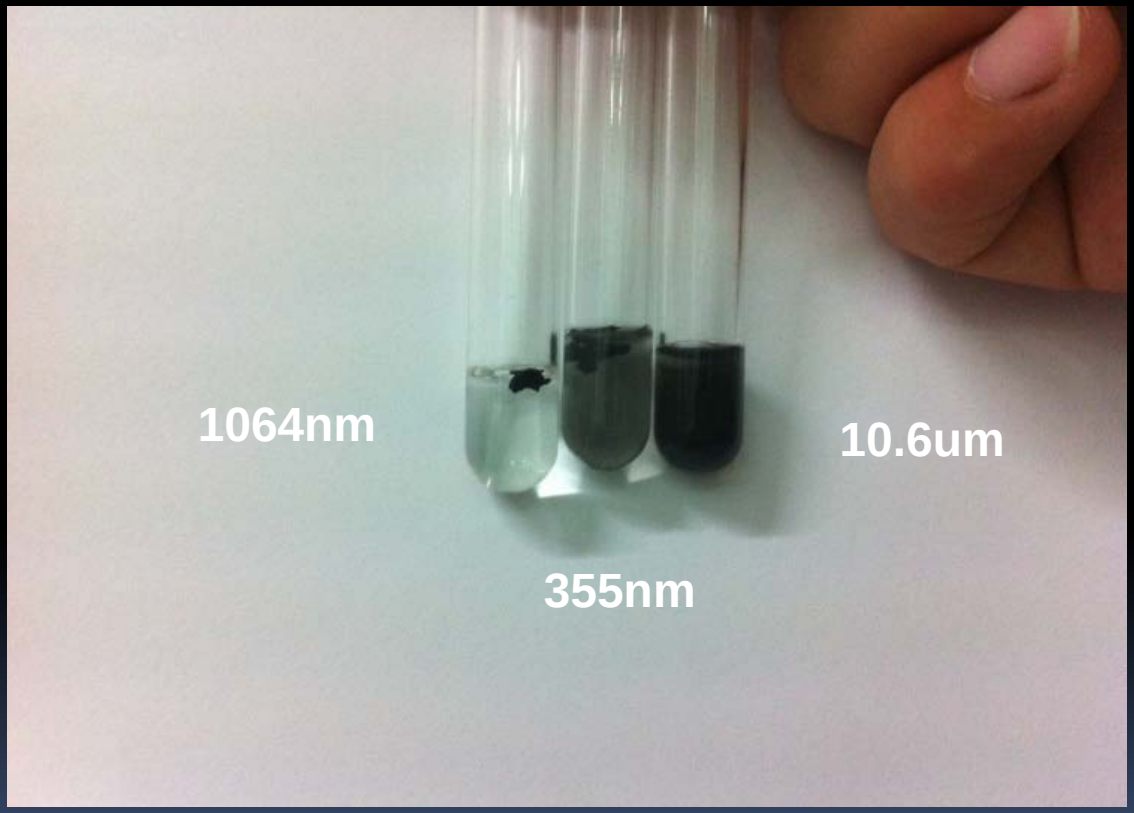
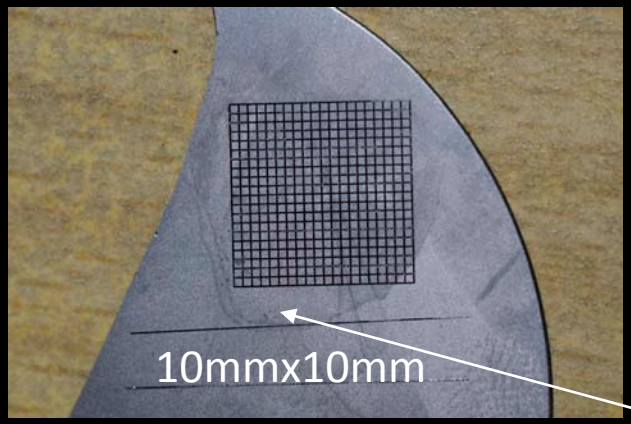
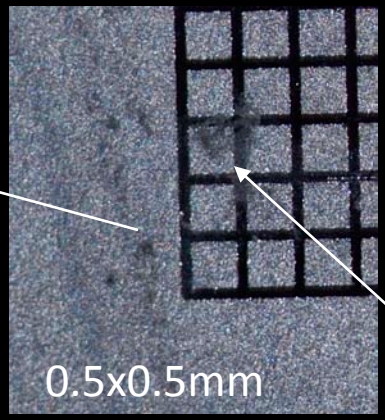
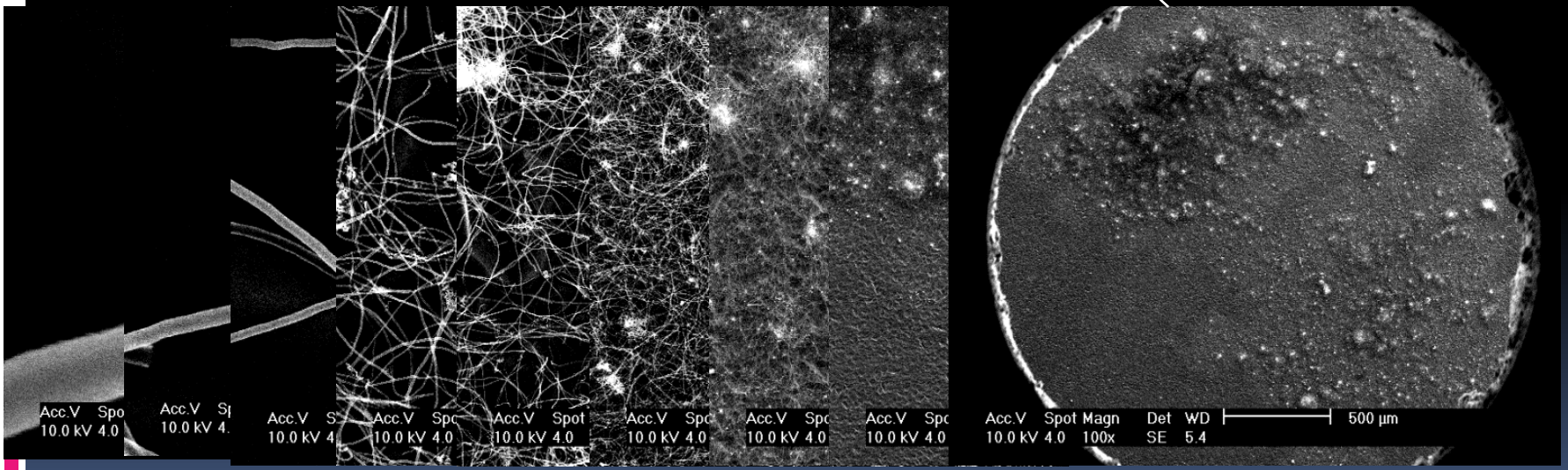


图3-3 经三种波长激光辐照后的样品被超声分散

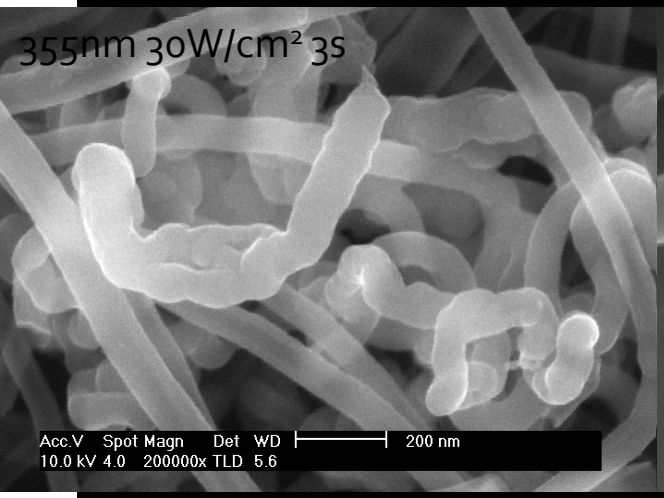


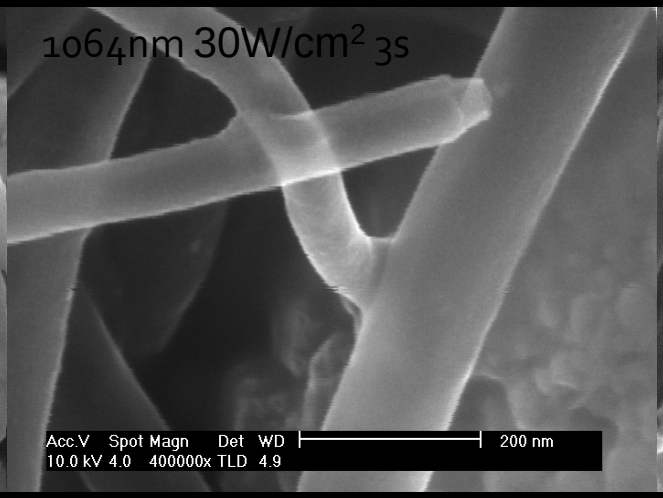


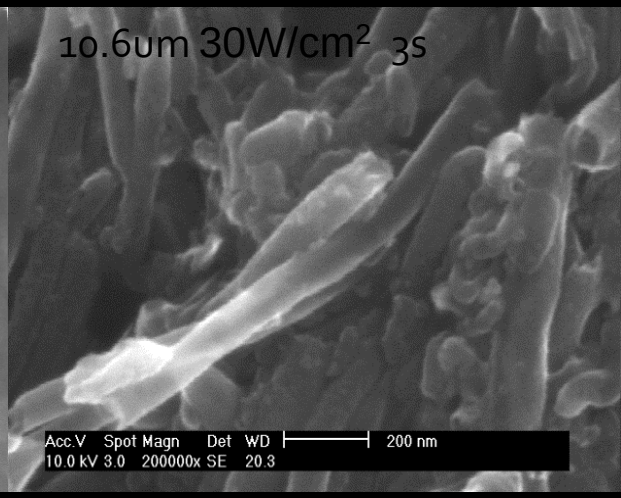


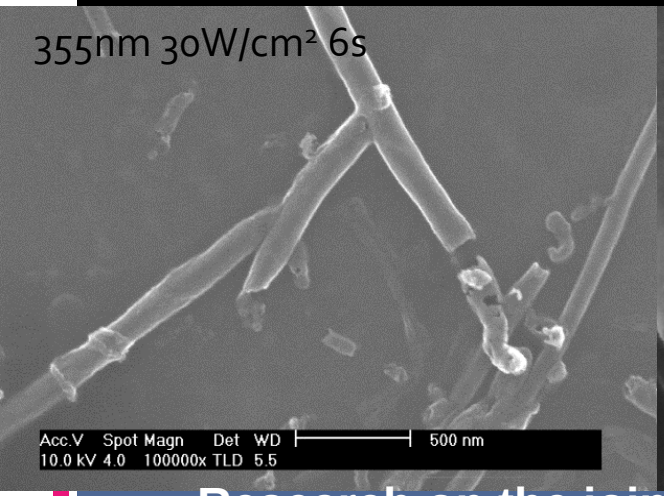
Research on the joining of MWCNTs by different wave length laser

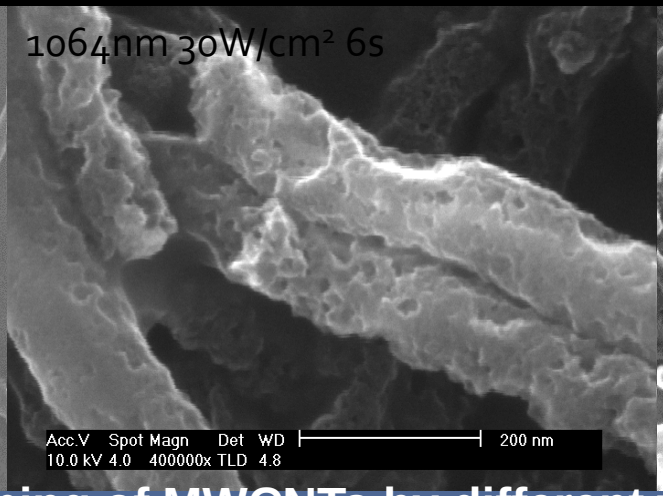
不同波长激光辐照样品的SEM图像







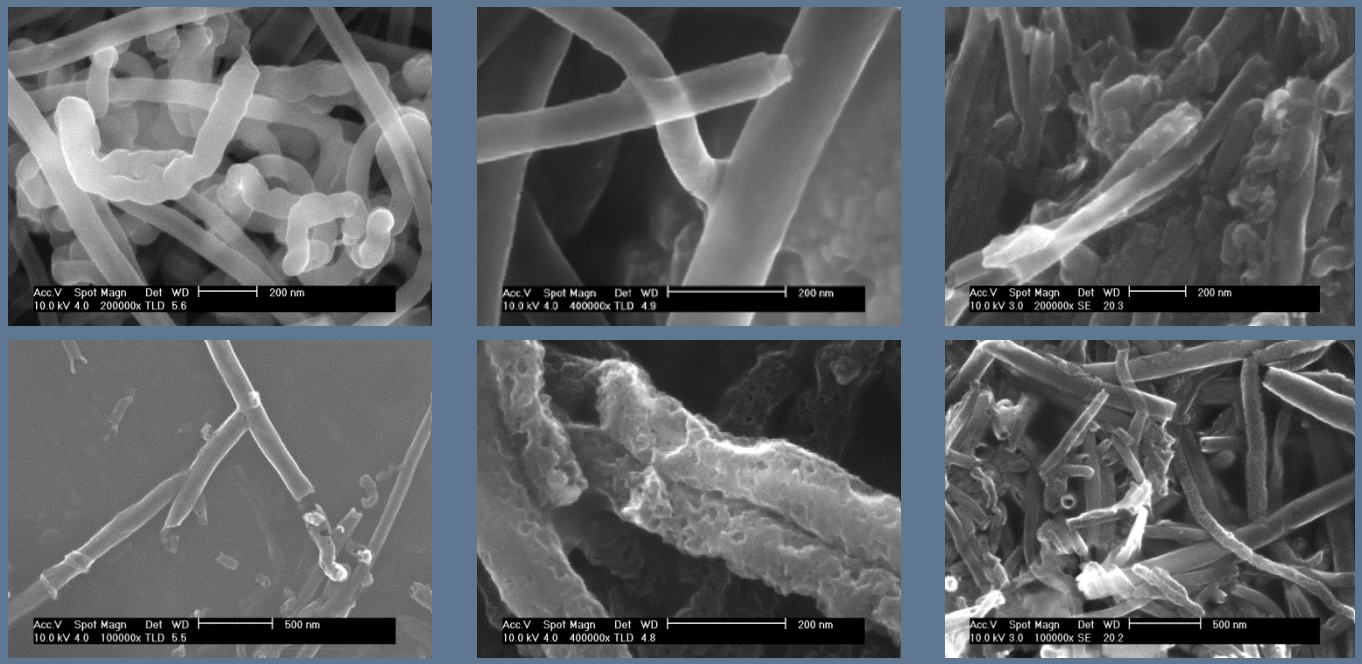




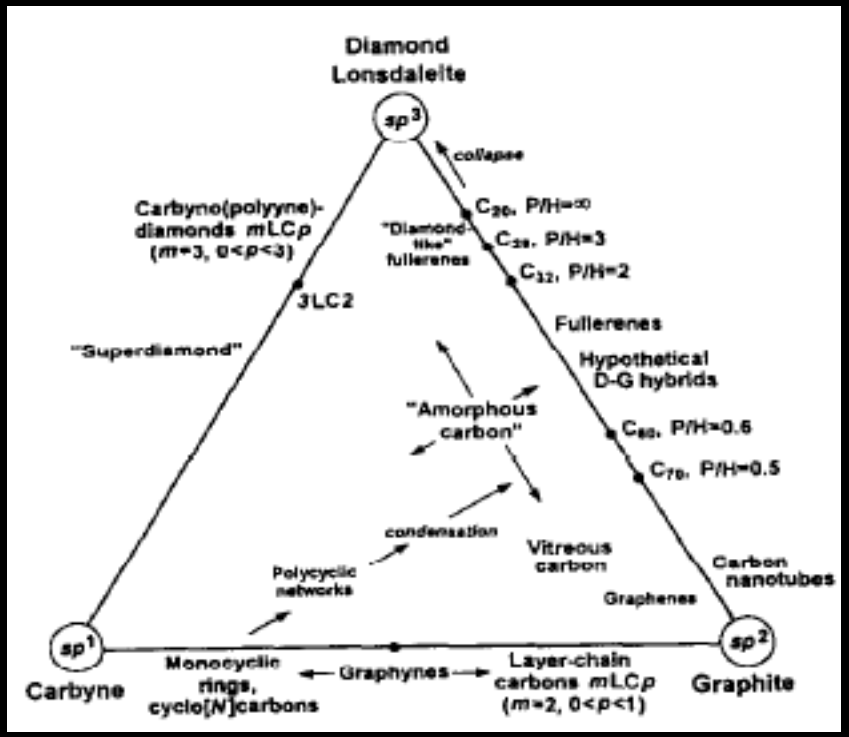
SEM分析

$$E = \frac{hc}{\lambda}$$

	355nm	1064nm	10.6um
单光子能量	3.494924eV	1.6607eV	0.116607eV

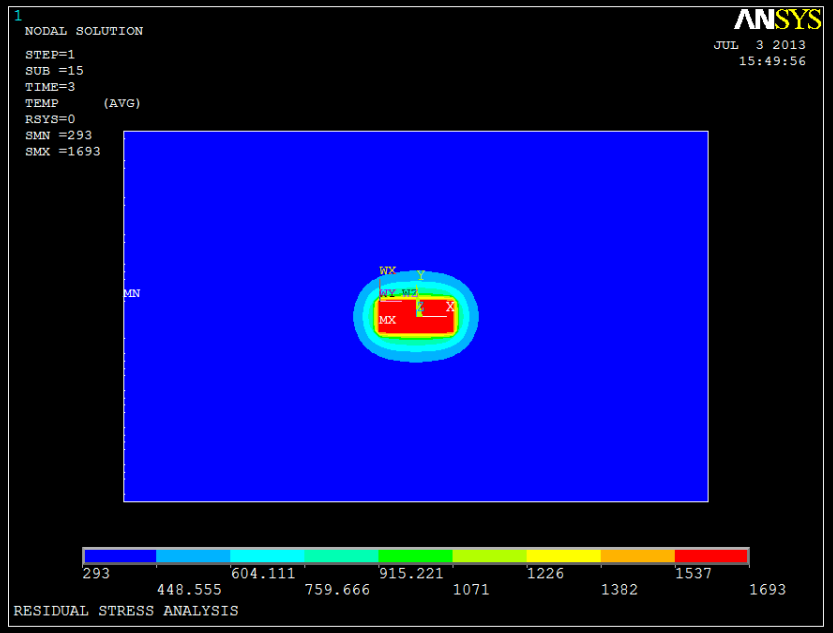


Research on the joining of MWCNTs by different wave length laser



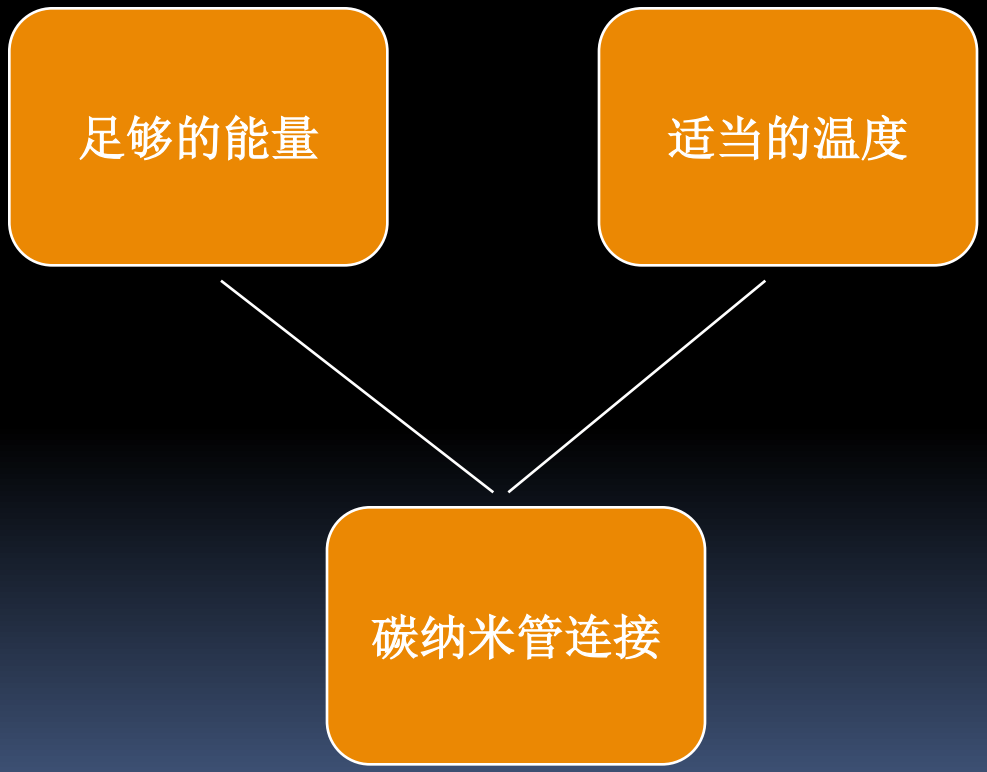
Heimann R, Evsyukov SE, Koga Y. Carbon allotropes: a suggested classification scheme based on valence orbital hybridization[J]. Carbon. 1997, 35:1654.

图3-4碳同素异形体的三元“相”图



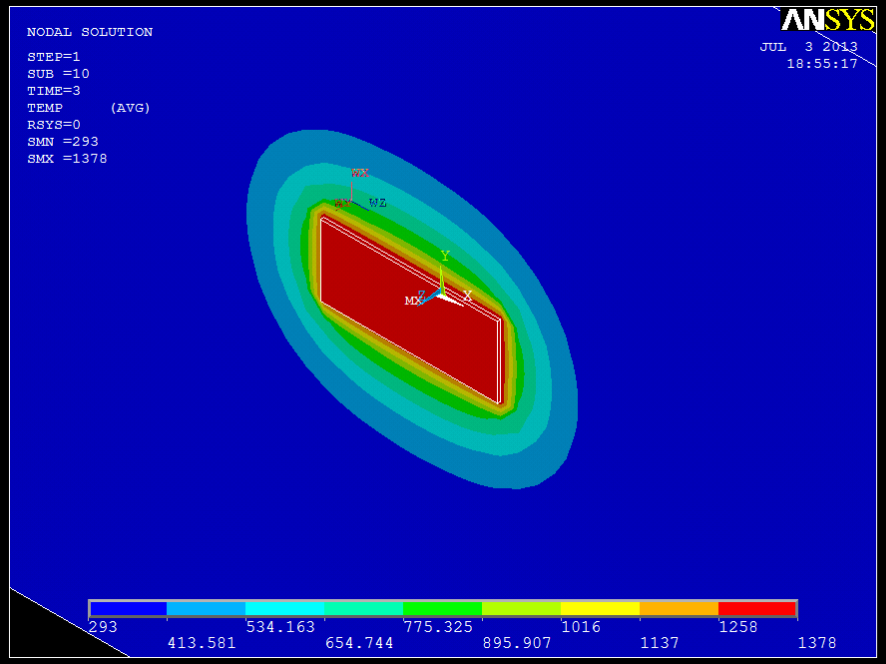
软件模拟的二氧化碳激光辐照样品3s的温度场

分析



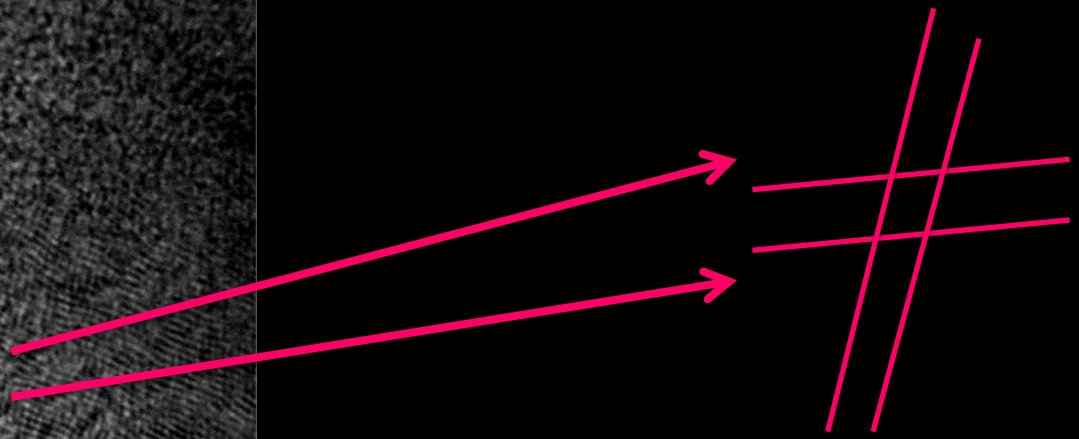
分析

	能量	温度
355nm	✓	x
1064nm	✓	✓
10.6um	x	✓

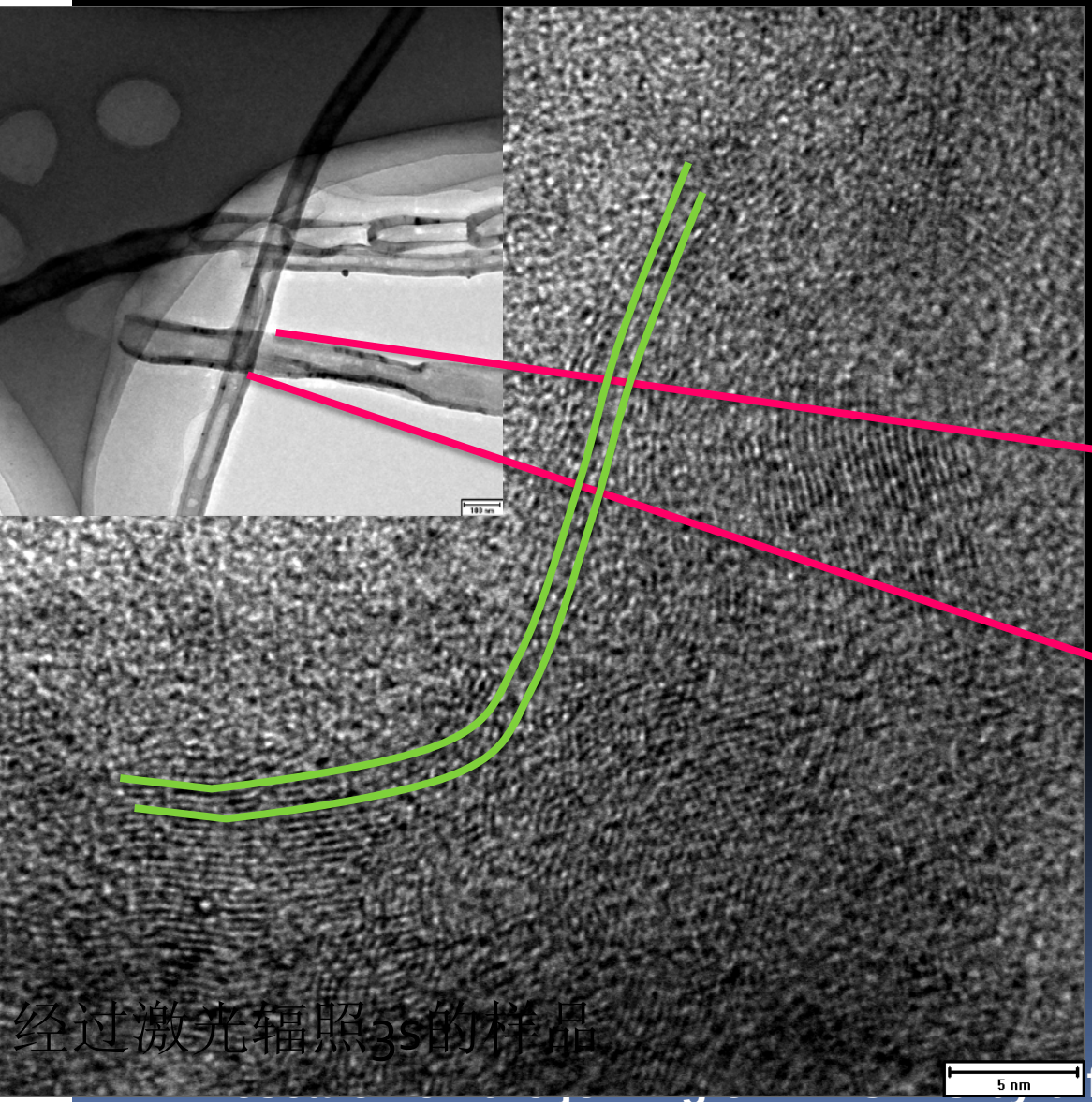


软件模拟的1064nm激光辐照样品3s的温度场

TEM分析



未经激光辐照的样品TEM图像

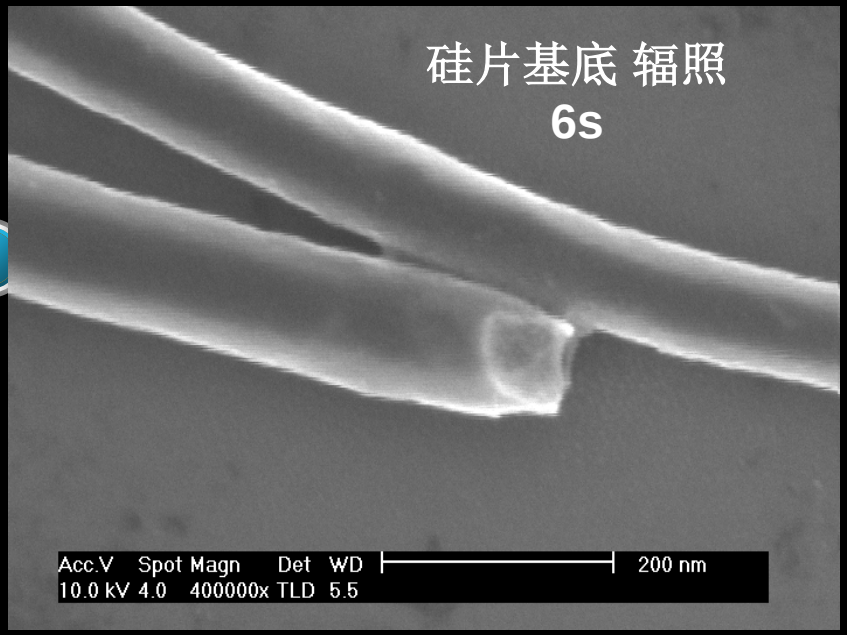


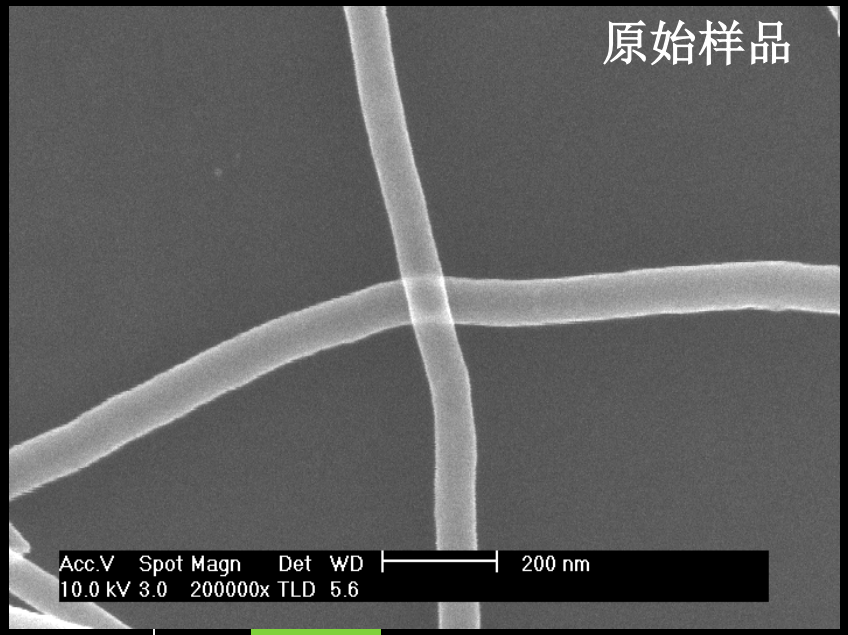
通过TEM来检测连接处的有新的石墨片层形成

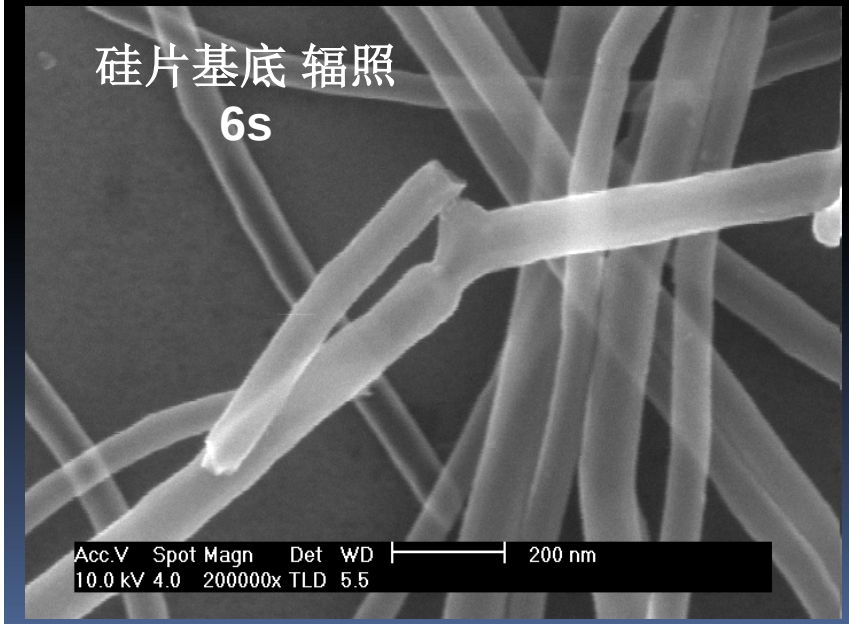
图3-9 经激光辐照的样品TEM图像

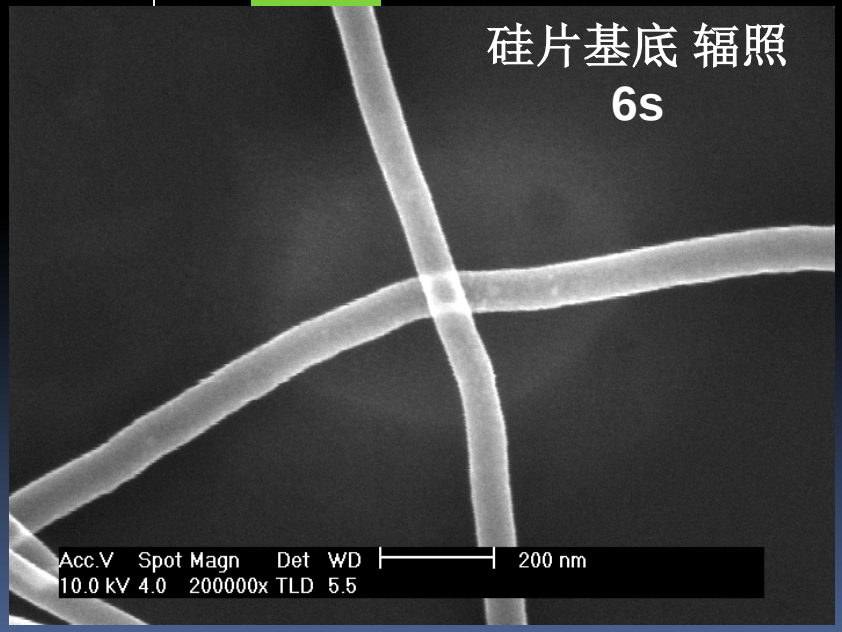
经过激光辐照3s的样品

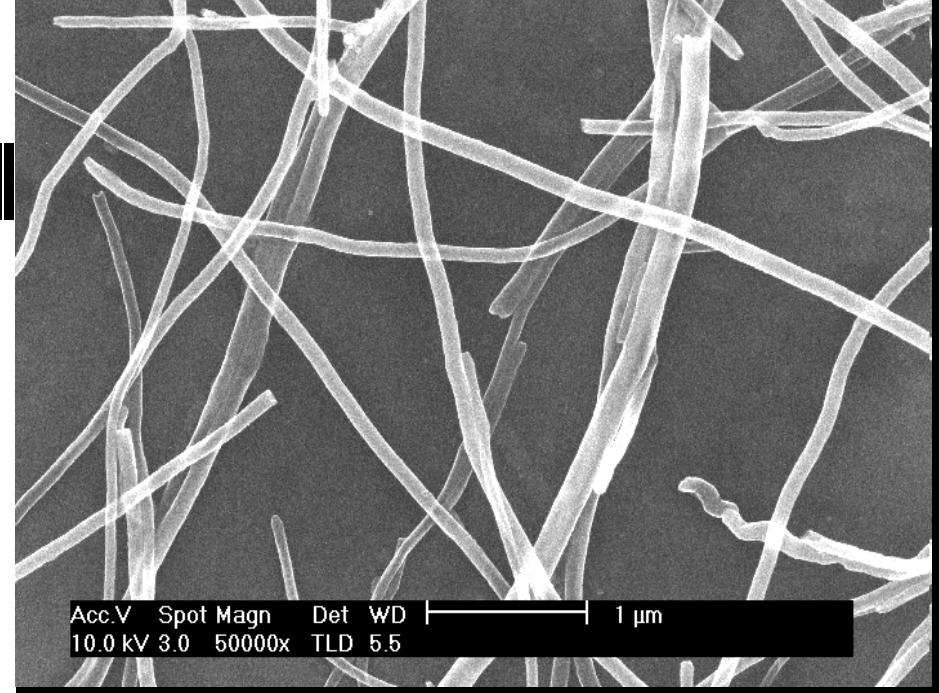
fferent wave length laser

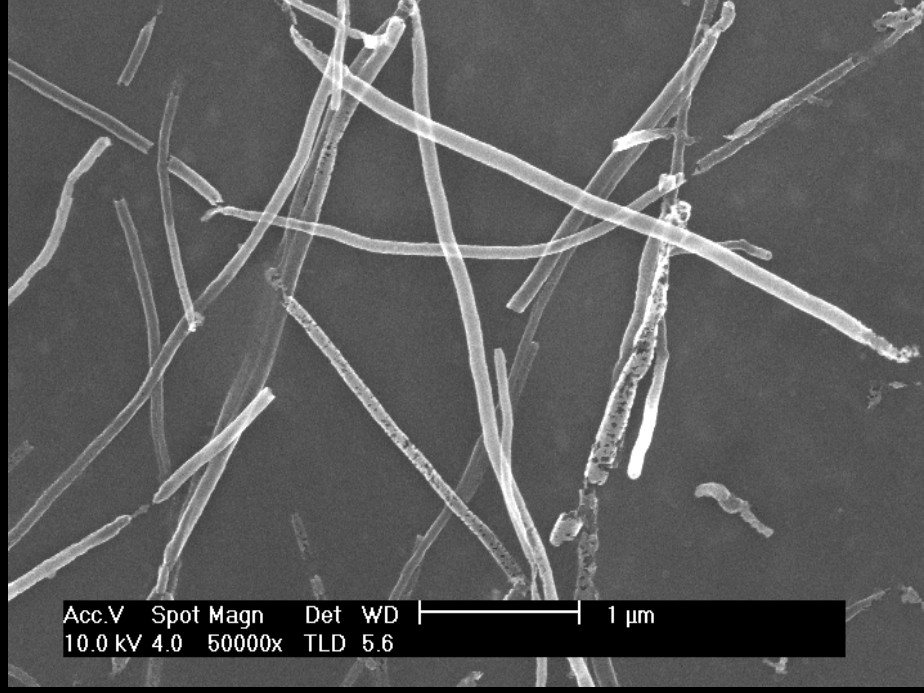

硅片基底 辐照
6s
Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 400000x TLD 5.5


原始样品
Acc.V Spot Magn Det WD 200 nm
10.0 kV 3.0 200000x TLD 5.6

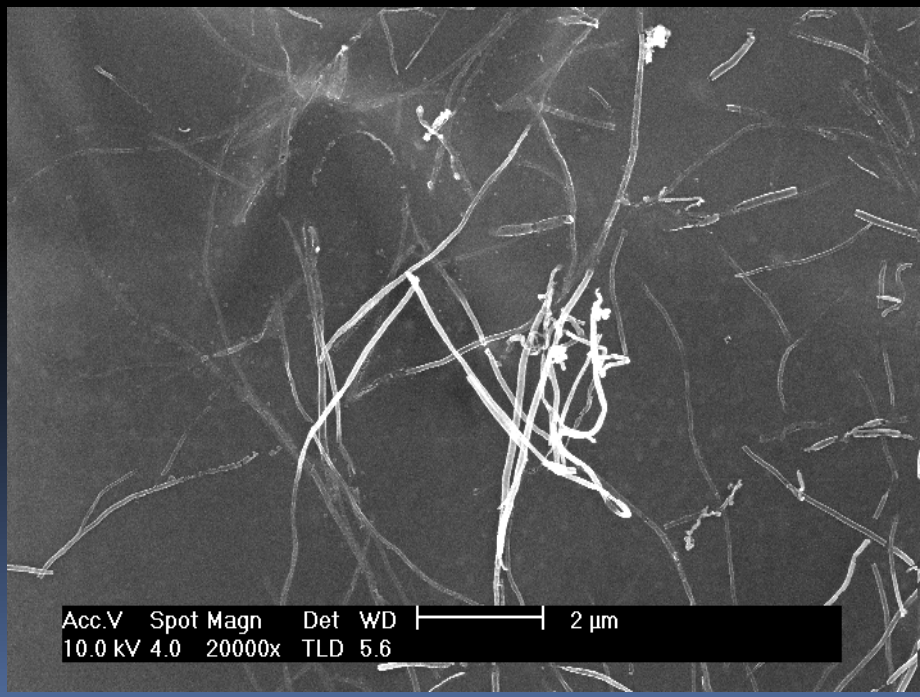

硅片基底 辐照
6s
Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 200000x TLD 5.5

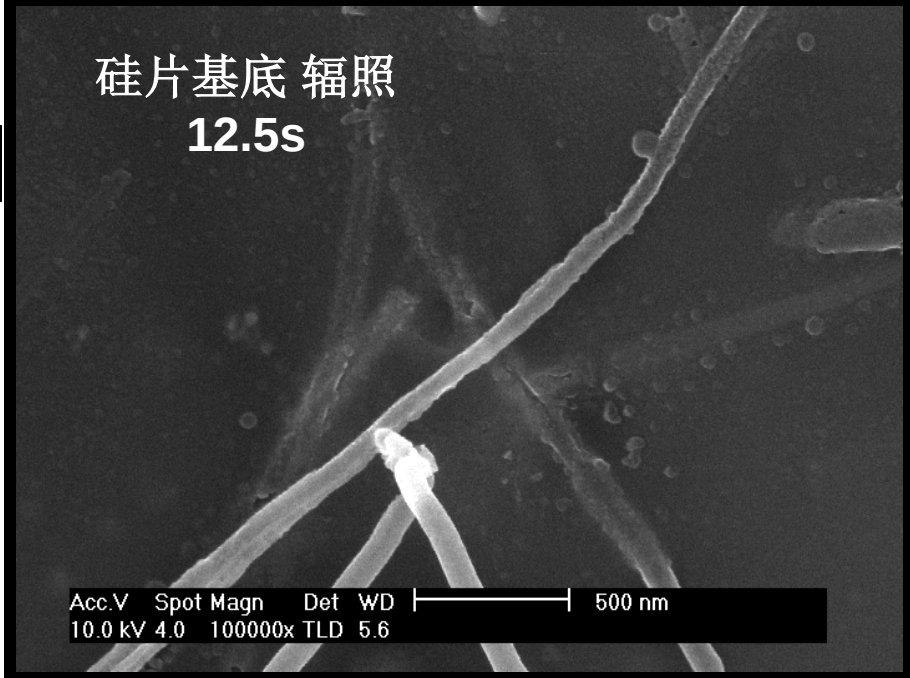

硅片基底 辐照
6s
Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 200000x TLD 5.5

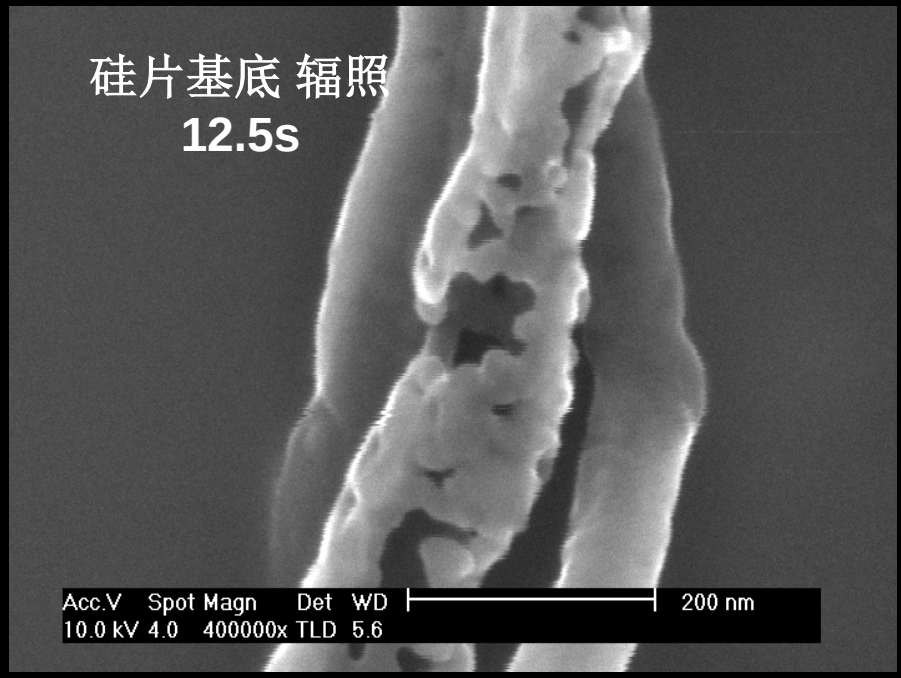

Acc.V Spot Magn Det WD 1 µm
10.0 kV 3.0 50000x TLD 5.5

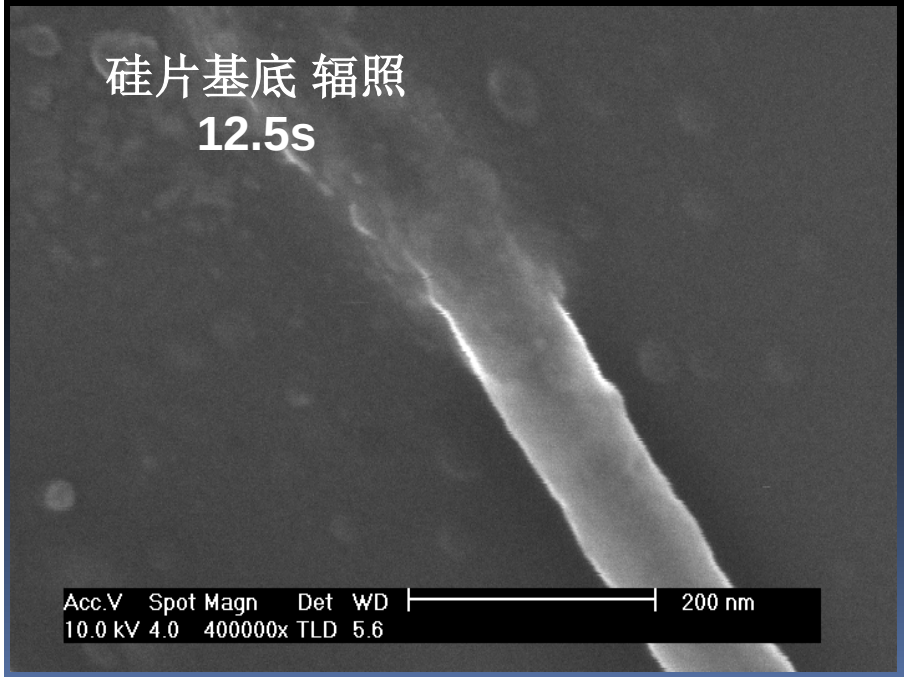

Acc.V Spot Magn Det WD 1 µm
10.0 kV 4.0 50000x TLD 5.6

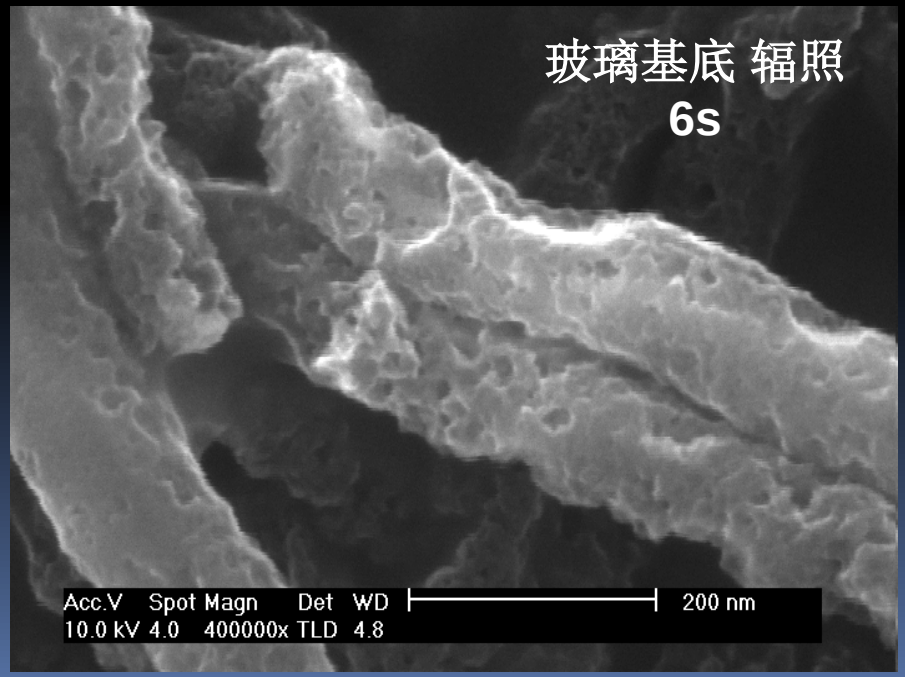

Acc.V Spot Magn Det WD 2 µm
10.0 kV 3.0 20000x TLD 5.5


Acc.V Spot Magn Det WD 2 µm
10.0 kV 4.0 20000x TLD 5.6

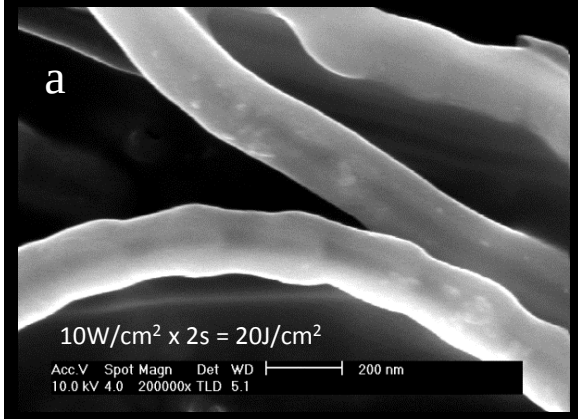

硅片基底 辐照
12.5s
Acc.V Spot Magn Det WD 500 nm
10.0 kV 4.0 100000x TLD 5.6

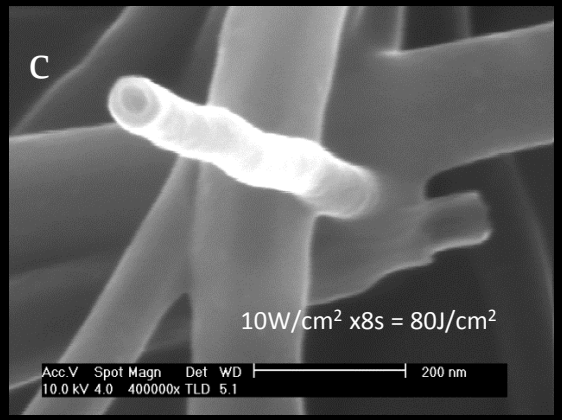

硅片基底 辐照
12.5s
Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 400000x TLD 5.6

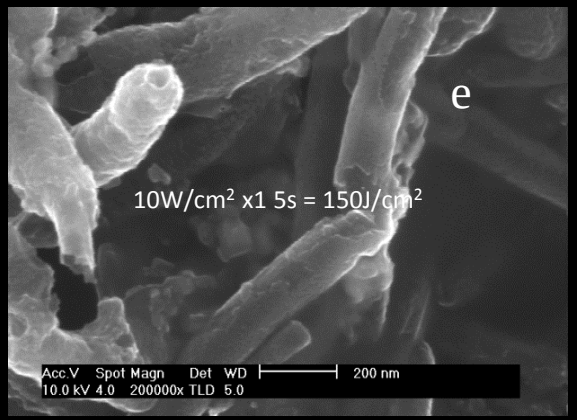

硅片基底 辐照
12.5s
Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 400000x TLD 5.6

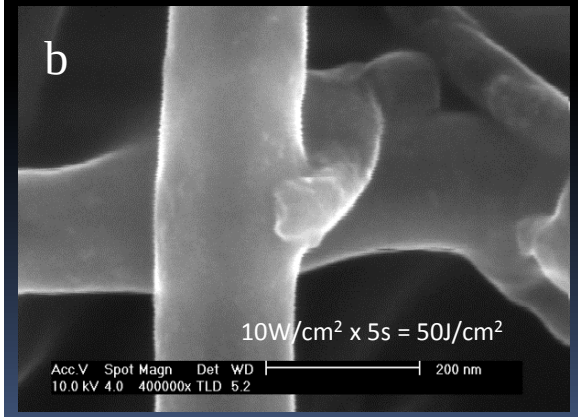

玻璃基底 辐照
6s
Acc.V Spot Magn Det WD 200 nm
10.0 kV 4.0 400000x TLD 4.8

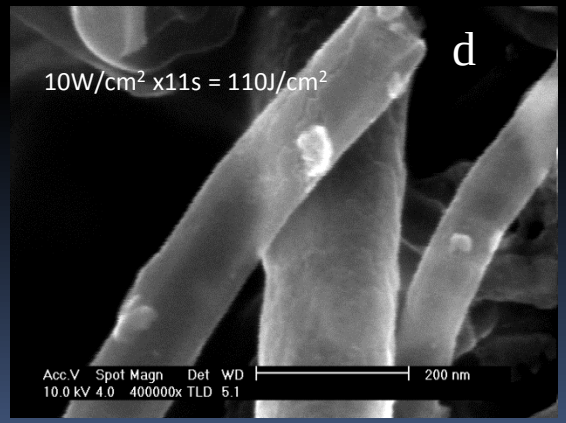
功率密度对样品的影响









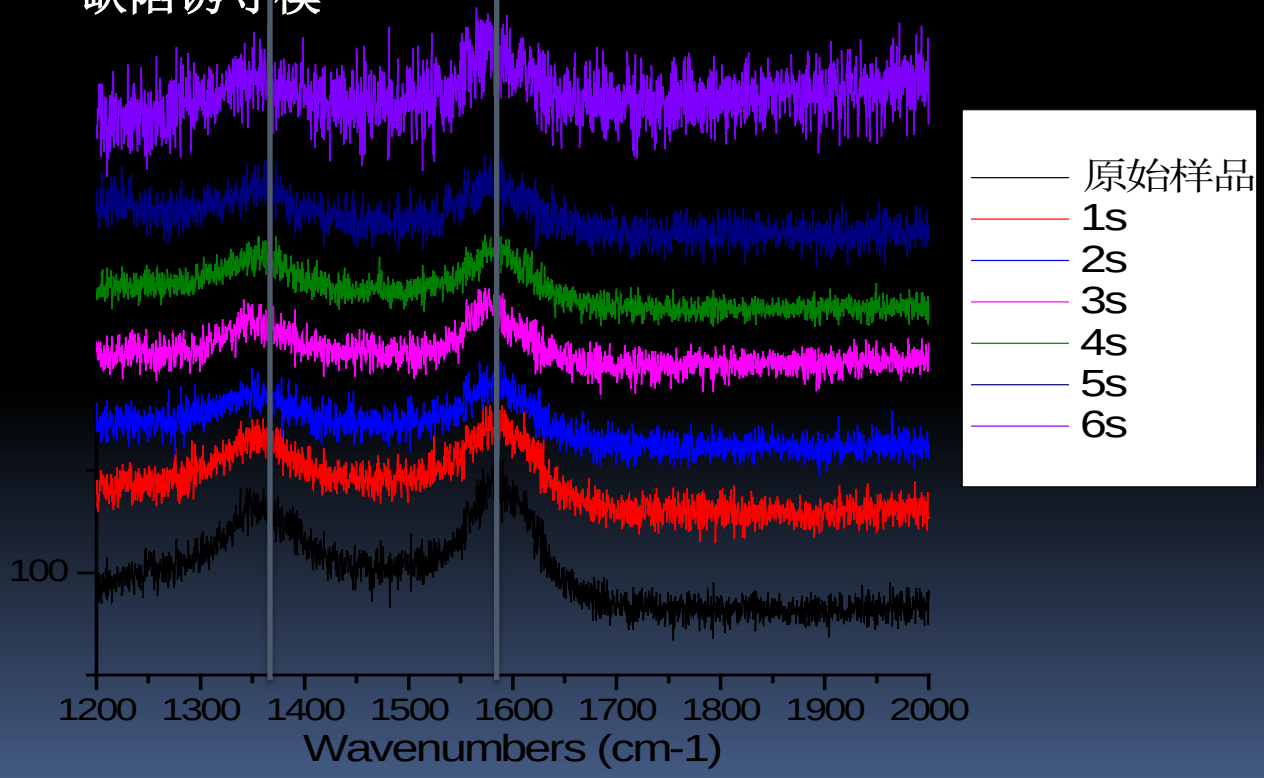


Research on the joining of MWCNTs by different wave length laser

Raman spectra分析

D峰 标准峰位
1350cm-1
缺陷诱导模

G峰 标准峰位 1580cm-1
径向震动模（sp2杂化模）



电阻变化

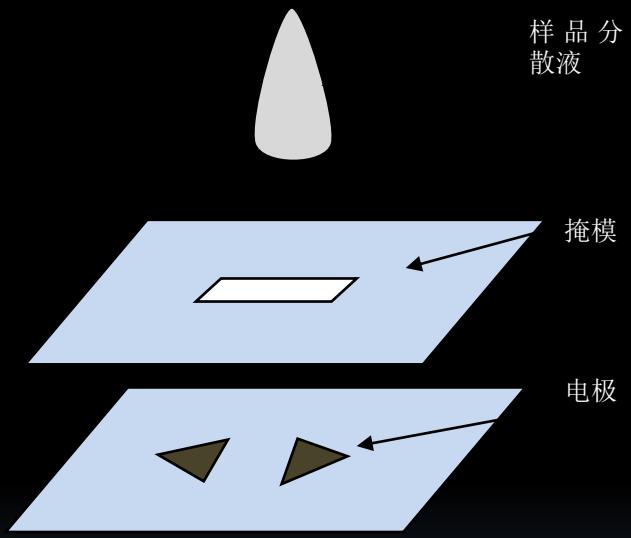


图3-10 样品制备图

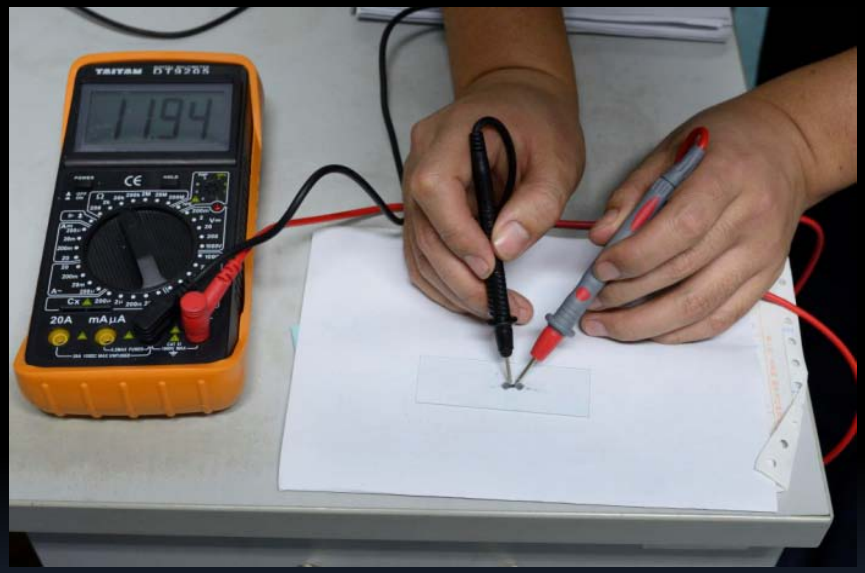


图3-11原始样品电阻值

电阻变化

辐照时间	能量密度	样品电阻值									
		样品1 电阻x 10kΩ		样品2 电阻x 10kΩ		样品3 电阻x 10kΩ		样品4 电阻x 10kΩ		样品5 电阻x 10kΩ	
		电阻	比值	电阻	比值	电阻	比值	电阻	比值	电阻	比值
原始样品		11.94	1	9.22	1	15.32	1	12.33	1	10.67	1
s	30J/cm²	1.64	0.14	1.63	0.17	2.23	0.15	1.73	0.14	1.93	0.18
s	60J/cm²	0.37	0.03	0.45	0.05	0.39	0.025	0.33	0.026	0.37	0.035
s	90J/cm²	2.94	0.25	2.74	0.3	3.92	0.26	3.44	0.28	2.36	0.22
s	120J/cm²	5.69	0.47	4.12	0.43	7.02	0.46	6.12	0.50	5.23	0.49
s	150J/cm²	8.90	0.74	6.11	0.65	13.22	0.86	9.31	0.76	8.55	0.80
s	180J/cm²	样品损坏									

表3-2 5组样品经1064nm光纤激光辐照前后的电阻值及比值

电阻变化

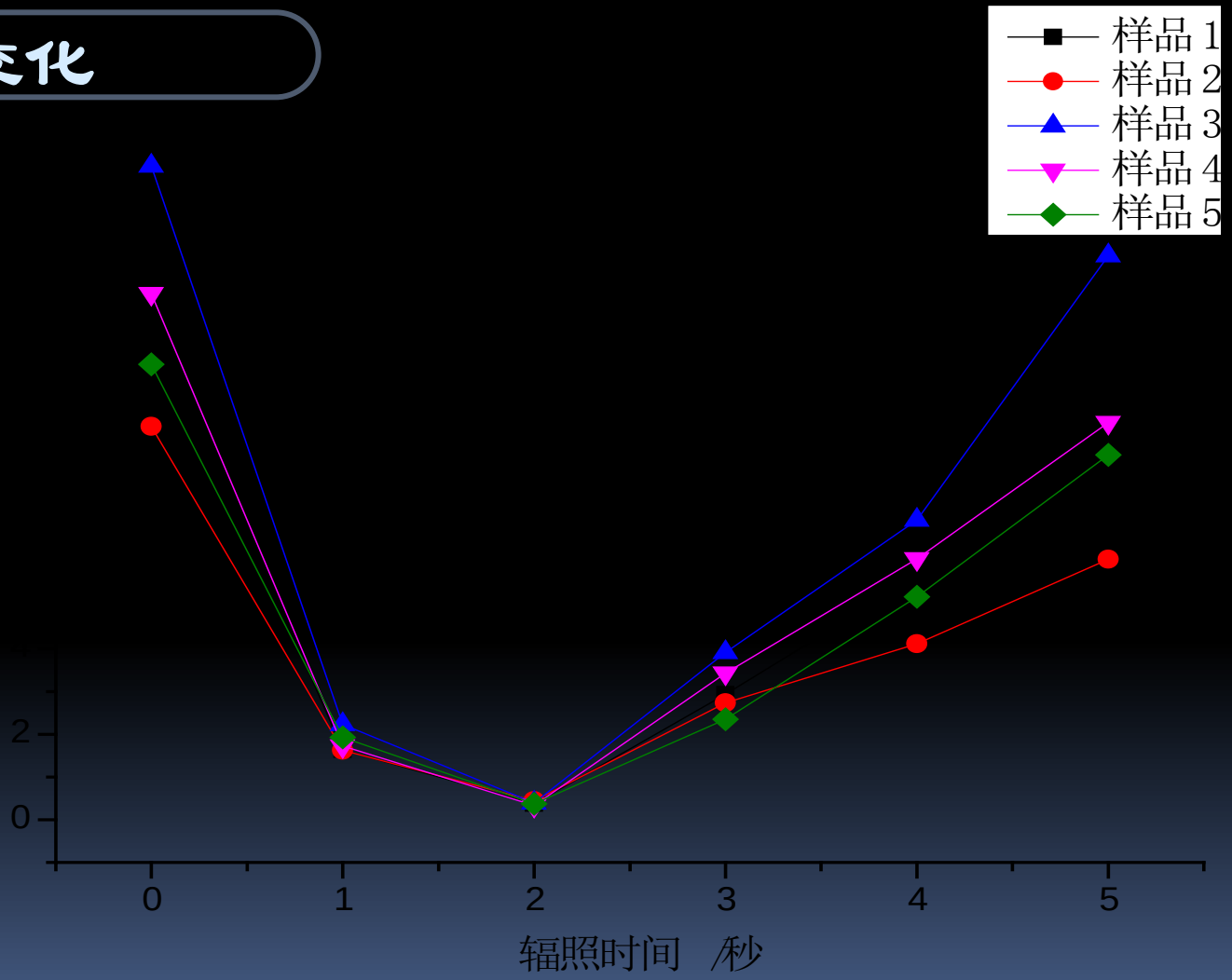
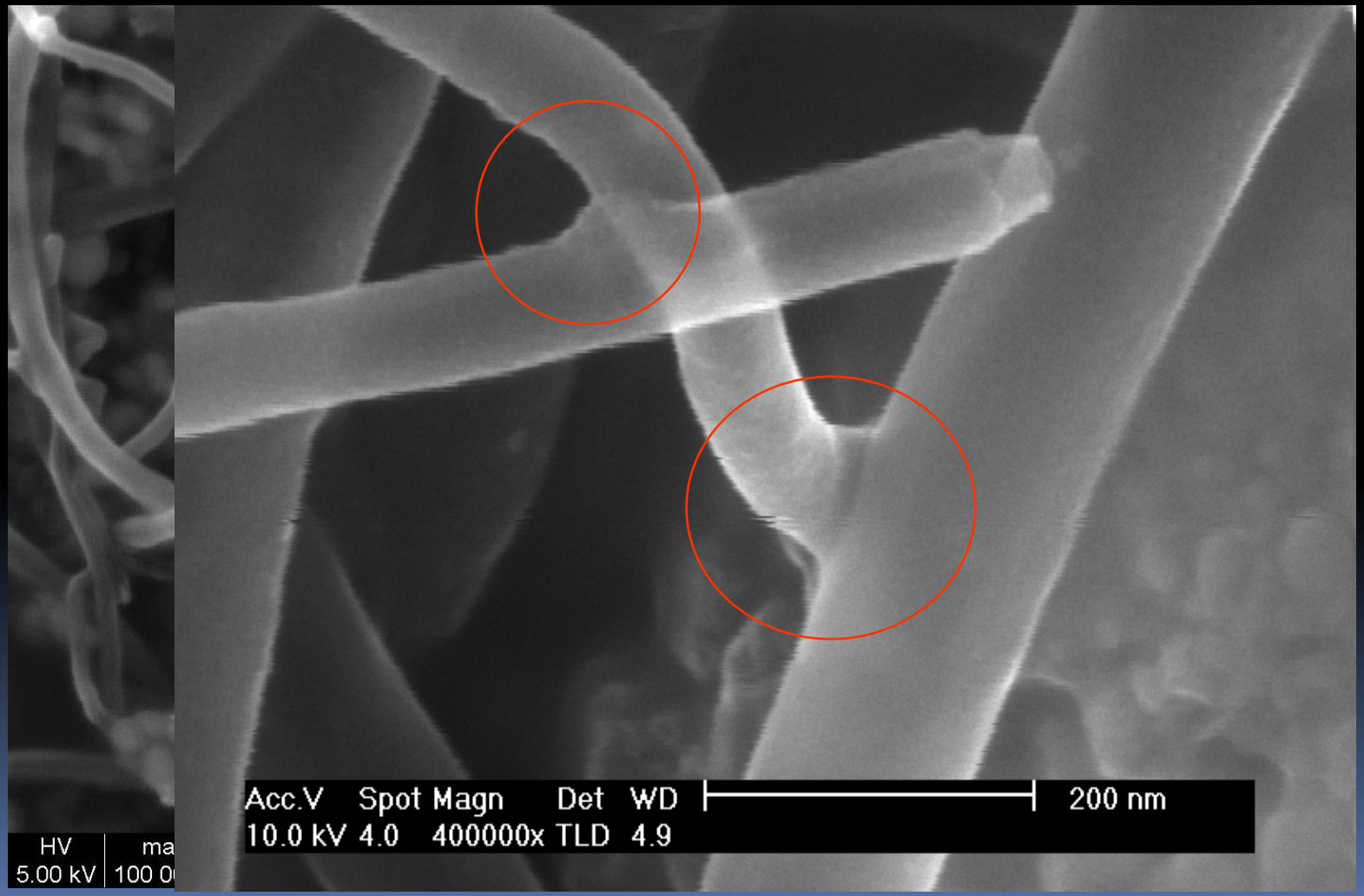


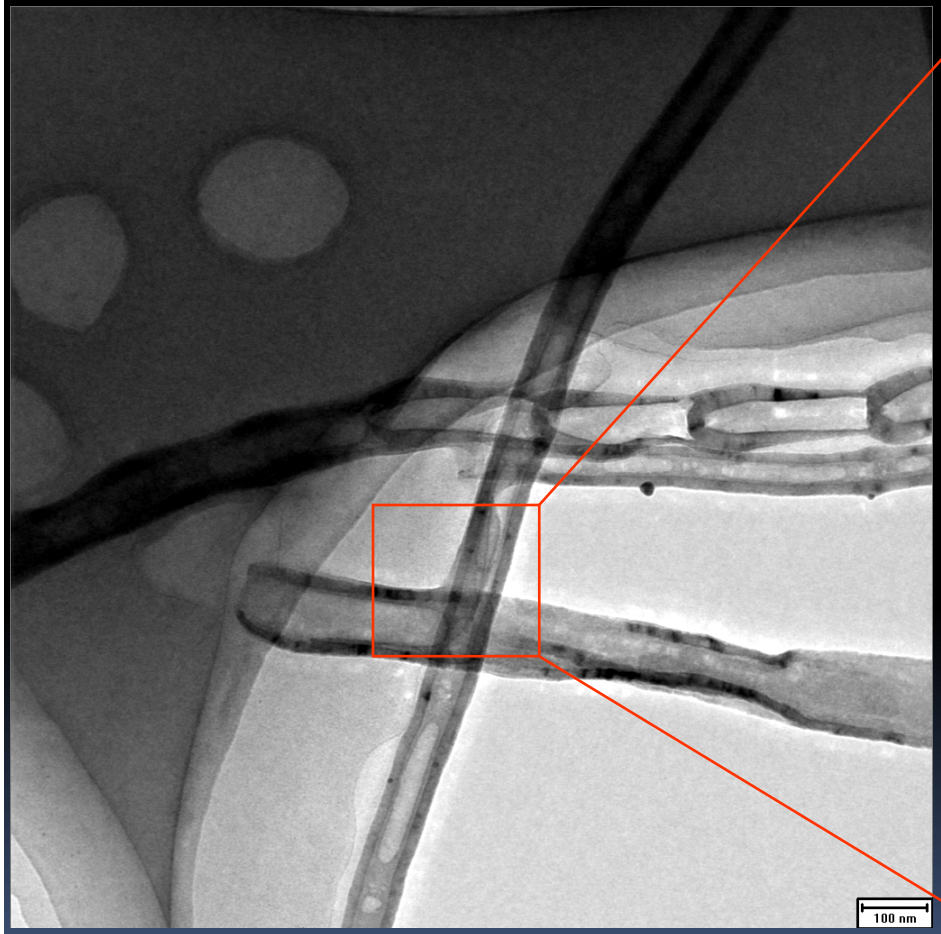
图3-12 样品电阻变化曲线图

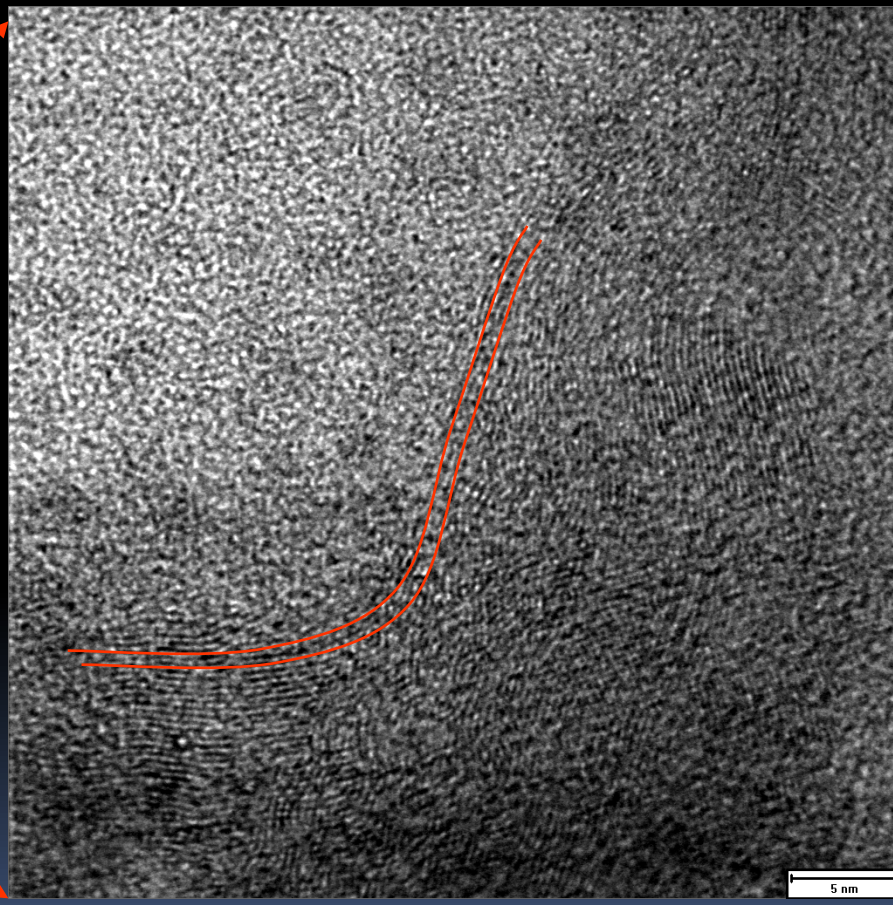
MWCNTs joining with laser

- 1064nm 30w 3s MWCNTs SEM



MWCNTs joining（TEM）



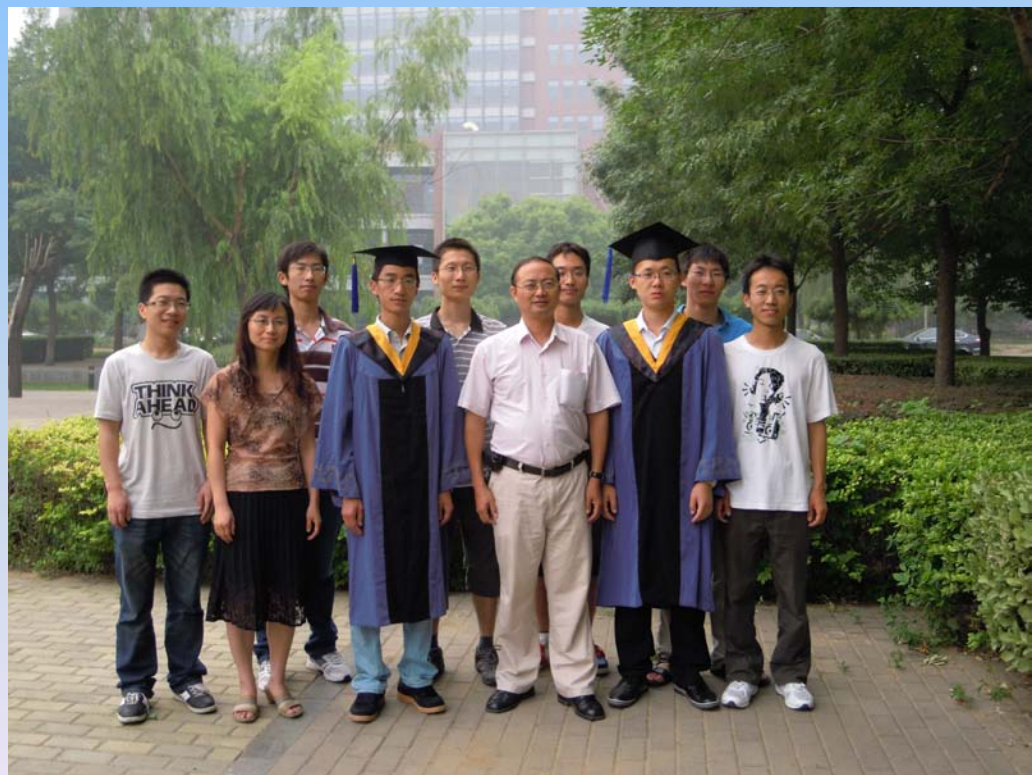


Conclusion on laser nanojoining

- MWCNTs can be joined together with laser
- The laser wave length is 1064nm and maximum time is 3 seconds with average 30W.
- A further study is under investigation

Acknowledgement

- Chinese Science and Nature Foundation
- Beijing Science and Nature Foundation
- Beijing Education Committee Foundation



Thank You!