微纳加工技术

- 现代工程与应用科学学院
- 2020-5-27

主要内容

- 背景介绍
- 微纳加工技术

1. **光学曝光技术**
2. **电子束曝光技术**
3. 聚焦离子束加工技术
4. **刻蚀法图形转移技术**
5. ……

背景介绍

There's Plenty of Room at the Bottom

I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the others in that it will not tell us much of fundamental physics (in the sense of, ''What are the strange particles?'') but it is more like solid-state physics in the sense that it might tell us much of great interest about the strange phenomena that occur in complex situations. Furthermore, a point that is most important is that it would have an enormous number of technical applications.

Why cannot we write the entire 24 volumes of the Encyclopaedia Britannica on the head of a pin?

Annual meeting of the APS （1959.12.29）

J. Microelectromechan. Syst. **1**, 60 (1992).

背景介绍

There's Plenty of Room at the Bottom

It is my intention to offer a prize of $1,000 to the first guy who can take the information on the page of a book and put it on an area 1/25,000 smaller in linear scale in such manner that it can be read by an electron microscope.

I do not expect that such prizes will have to wait very long for claimants.[1]

And I want to offer another prize—if I can figure out how to phrase it so that I don't get into a mess of arguments about definitions—of another $1,000 to the first guy who makes an operating electric motor—a rotating electric motor which can be controlled from the outside and, not counting the lead-in wires, is only 1/64 inch cube.

The second prize was indeed claimed within the year, by William McLellan.

J. Microelectromechan. Syst. **1**, 60 (1992).

背景介绍

There's Plenty of Room at the Bottom

20年后，仅被引7次

~23年（1983.2.23）后，
“Infinitesimal machinery”

1985年Thomas Newman和Fabian Pease

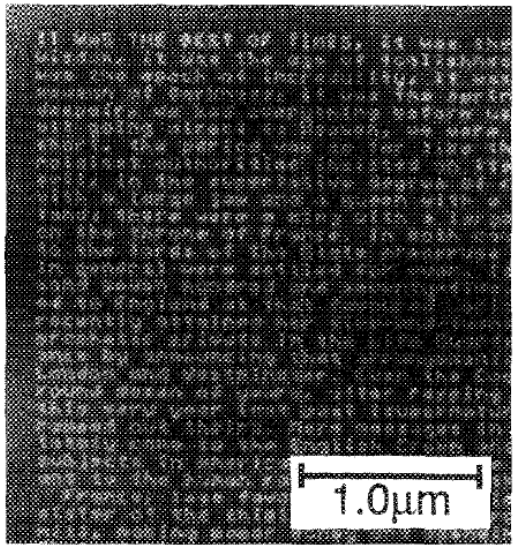


FIG. 4. Transmission electron micrograph of text patterned on thin silicon nitride membrane. Character pitch is 12 per micrometer, with an area density of 10^{10} characters/cm^2. The complete page measures 5.8 μm × 5.8 μm and contains 3500 characters.

T. H. Newman et. al., . *J. Vac. Sci. Technol. B* **5**, 88–91 (1987).

背景介绍

1990年D. M. Eigler和E. K. Schweizer

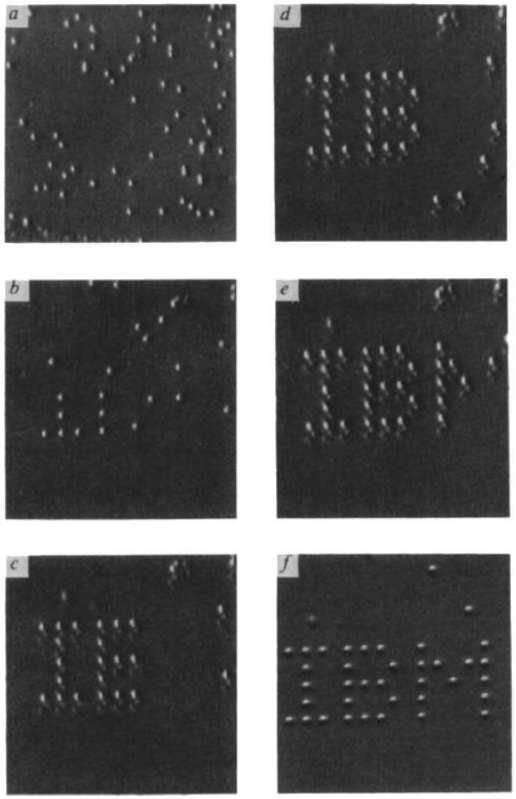
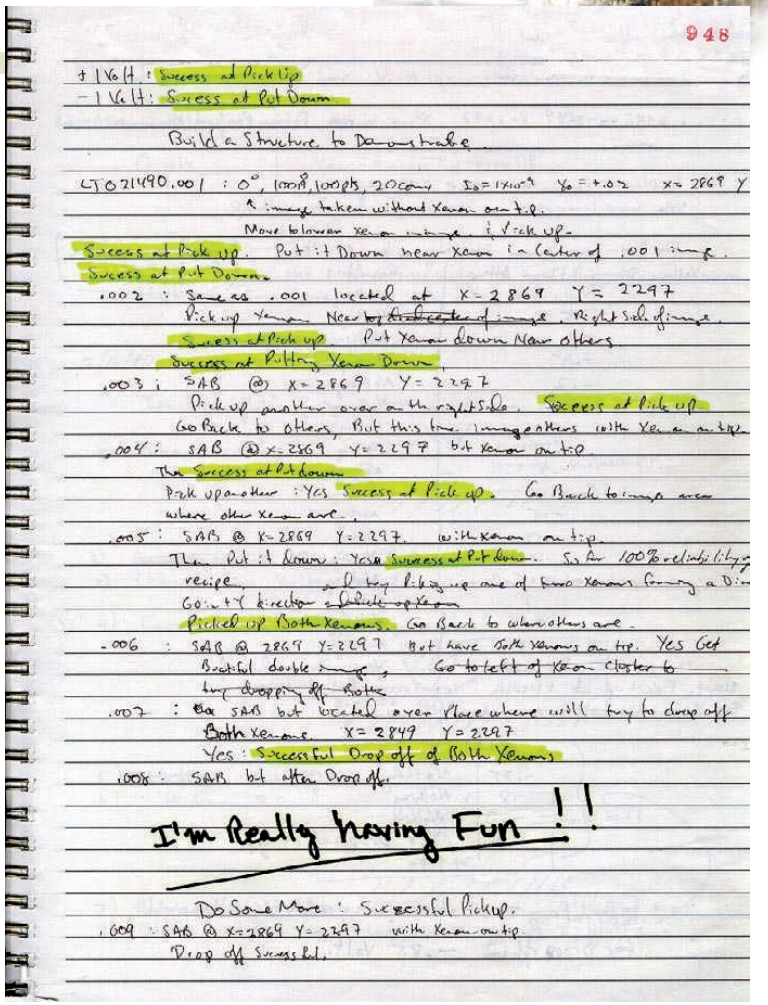


FIG. 1 A sequence of STM images taken during the construction of a patterned array of xenon atoms on a nickel (110) surface. Grey scale is assigned according to the slope of the surface. The atomic structure of the nickel surface is not resolved. The (1$\bar{1}$0) direction runs vertically. *a*, The surface after xenon dosing. *b–f*, Various stages during the construction. Each letter is 50 Å from top to bottom.

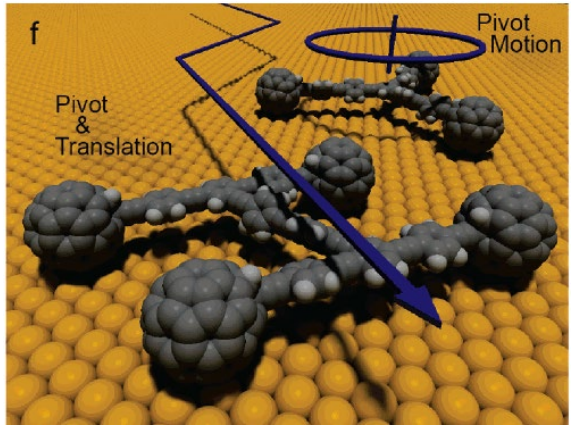
35 atoms



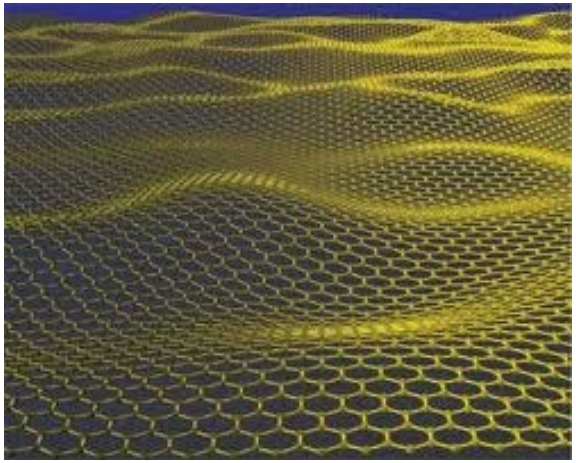
Don Eigler's lab note

D. M. Eigler and E. K. Schweizer *Nature* **344**, 524 (1990).

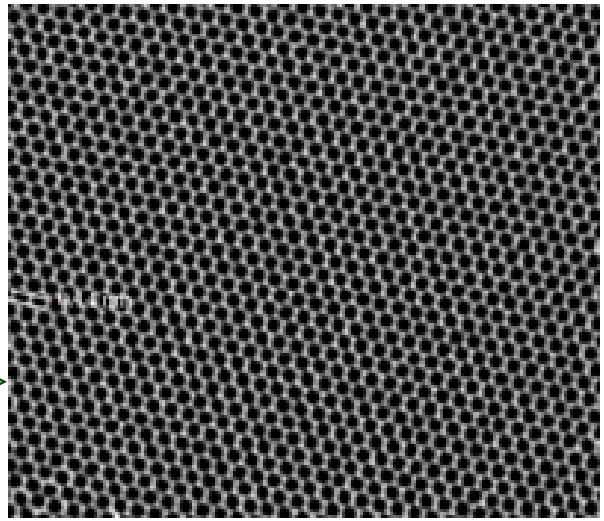
背景介绍



Nanocars



Graphene



TEAM (Lawrence Berkeley National Lab)
分辨率：**0.05 nm**

Y. Shiral, et. al., *Nano Lett* **5**, 2330 (2005).

微纳加工技术

参考文献：

1. 崔铮,《微纳米加工技术及其应用》（高等教育出版社）
2. 韩郑生等（译），半导体制作工艺，（电子工业出版社）
3. J. Jahns, S. Helfert, Introduction to micro-and Nanooptics, (Wiley-VCH, 2011)

光刻

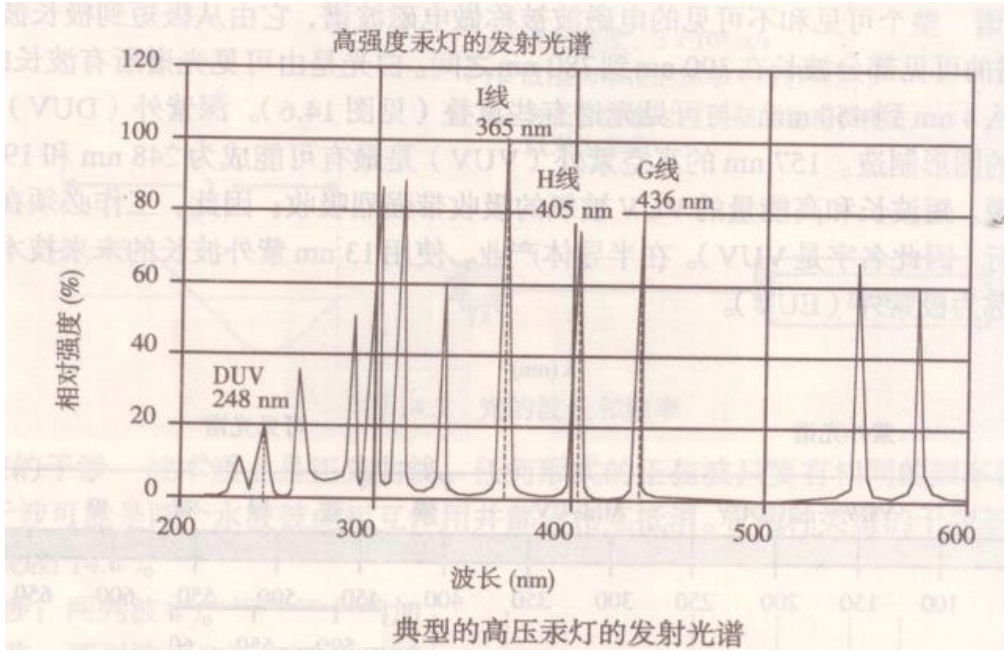
光刻（Photolithography)

Photolithography=photo (light)+litho (stone)+graphy (write)

Photolithography is an optical means for transferring patterns onto a substrate.

光刻

曝光光源：汞灯、准分子激光



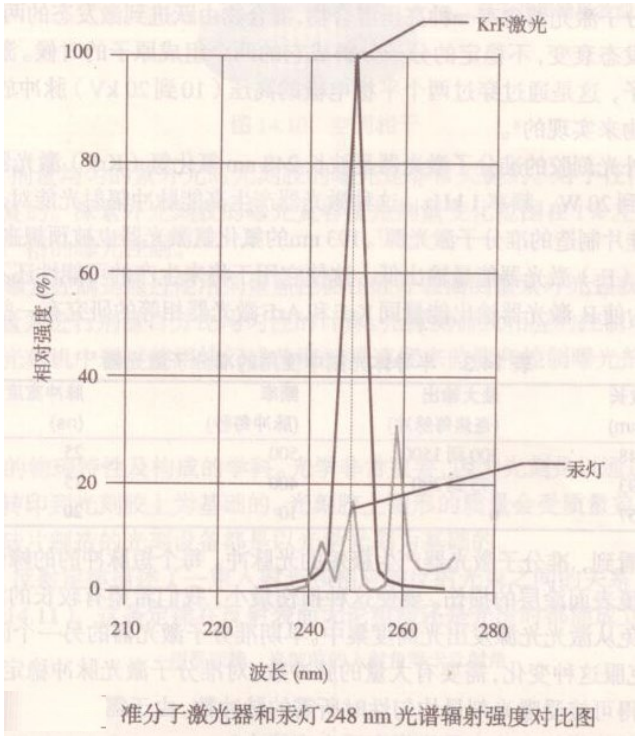
典型的高压汞灯的发射光谱

表 14.2　汞灯强度峰

UV 光波长（nm）	描述符	CD 分辨率（μm）
436	G线	0.5
405	H线	0.4
365	I线	0.35
248	深紫外（DUV）	0.25

光刻

曝光光源：汞灯、准分子激光



准分子激光器和汞灯 248 nm 光谱辐射强度对比图

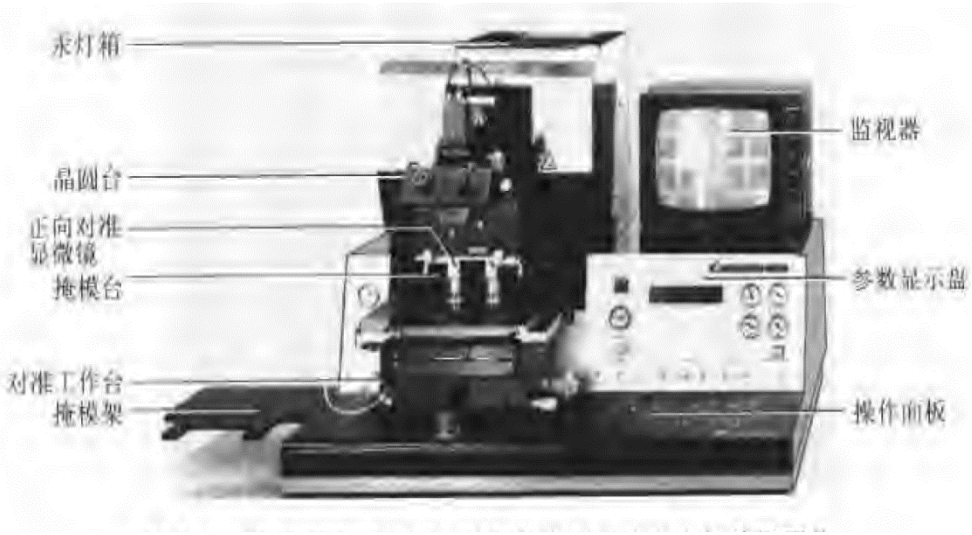
半导体光刻中使用的准分子激光器

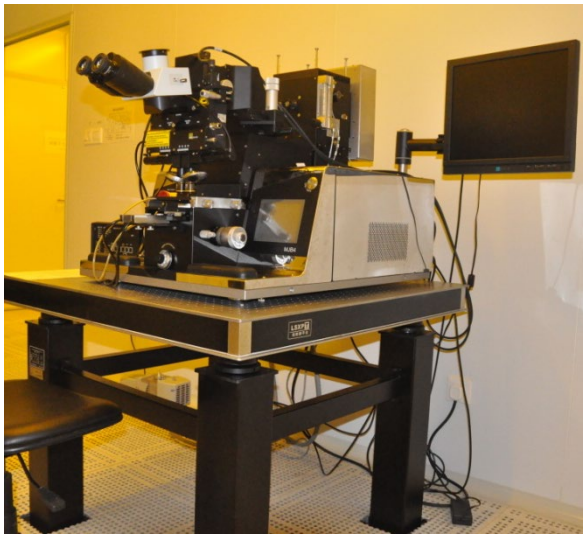
材料	波长 (nm)	最大输出 (毫焦每脉冲)	频率 (脉冲每秒)	脉冲宽度 (ns)	CD 分辨率 (μm)
KrF	248	300 到 1500	500	25	≤ 0.25
ArF	193	175 到 300	400	15	≤ 0.18
F_2	157	6	10	20	≤ 0.15

光刻

曝光方式

接触式曝光、接近式曝光、投影式曝光





掩模对准式曝光机（maskaligner）

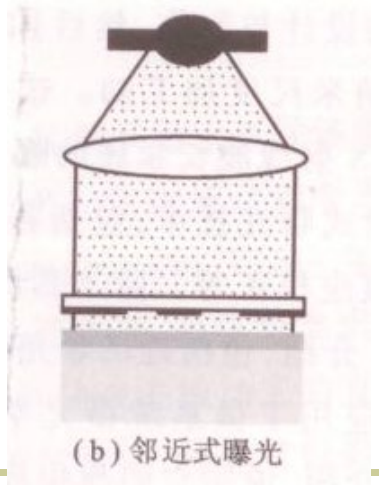
光刻

接触式曝光：掩模与光刻胶接触。

特点：简单、成本廉价、分辨率较高、易产生污染和缺陷（掩模寿命短)

接近式曝光：掩模与光刻胶保持一定的距离。

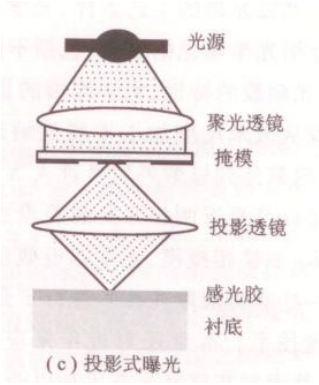
特点：简单、成本廉价、分辨率低、 污染 和缺陷少（掩模寿命长)



光刻

投影式曝光：

特点：分辨率高、掩模制备容易、便于大规模集成….



投影式光刻系统

投影光学系统通常是由缩倍的透镜、反射镜、或者复合组成的聚焦成像光学系统，其缩倍率可以是1：1，4：1，5：1，10：1等

光刻

投影式曝光

NSR-S310F ArF scanner

Performance	
Resolution	≦ 38 nm
NA	1.35
Exposure light source	ArF excimer laser (193 nm wavelength)
Reduction ratio	1:4
Maximum exposure field	26 mm × 33 mm
Overlay	≦ 2 nm
Throughput	≧ 200 wafers/hour (300 mm wafer, 125 shots)

光刻

光学曝光的工艺流程

表面处理
涂胶
前烘
曝光
显影
后烘
刻蚀
去胶

光刻

光学曝光的工艺流程

表面处理：

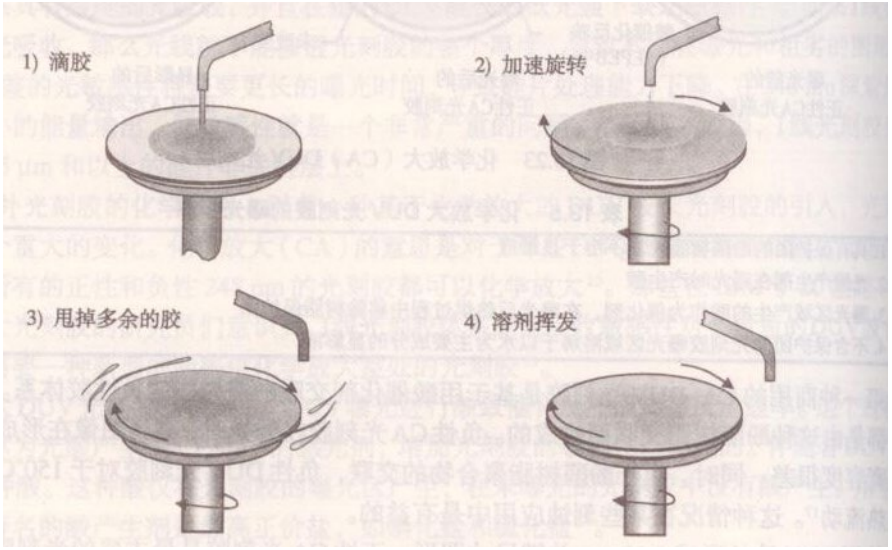
清洗：丙酮、异丙醇、去离子水
烘烤：热板、烘箱

HMDS：（Hexamethyl Disilazane）六甲基二硅胺烷
HMDS分子的一端与基片表面成键结合，另一端与光刻胶分子成键，从而提高光刻胶与衬底之间的黏附力。
可使用旋涂或者蒸气熏烘的办法使其涂覆成膜。

光刻

涂胶（spin coating)

分滴
旋转铺开
旋转甩胶
溶剂挥发

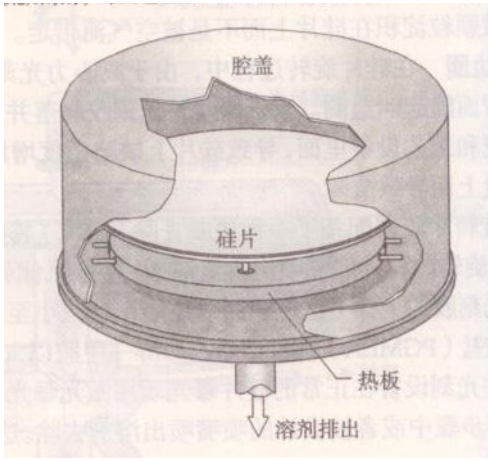


旋涂步骤

光刻

前哄（pre-bake或soft bake)

蒸发掉胶中的有机溶剂成分，使硅片表面的胶固化

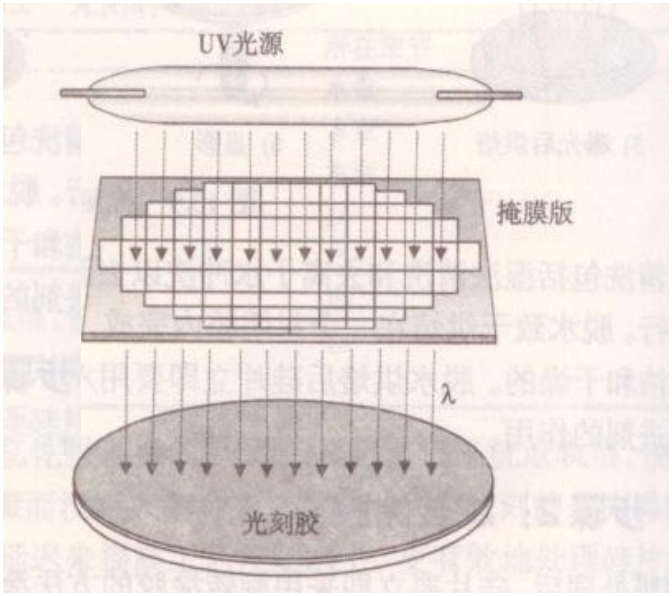


热板

参数：温度85°C～120°C，时间30～60秒

光刻

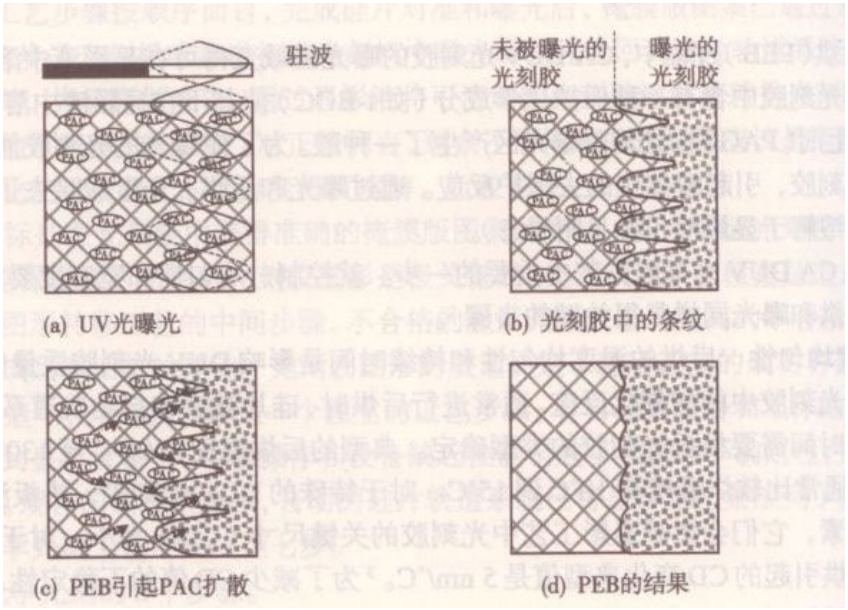
曝光



光刻

后烘

消除驻波的影响

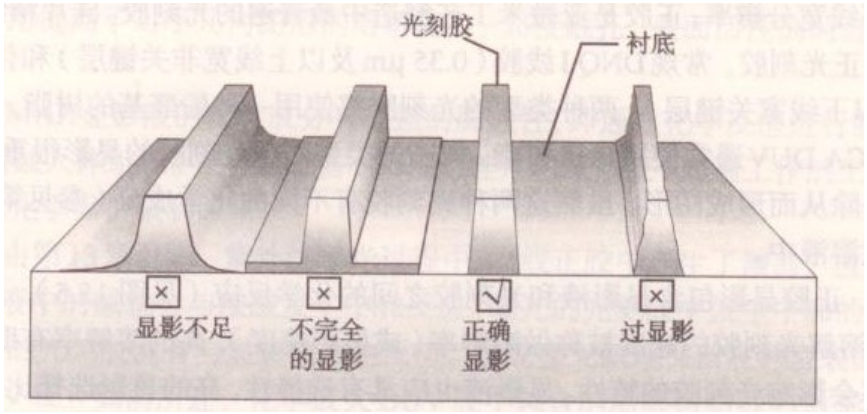


光刻

显影

用化学显影液溶解由曝光造成的光刻胶的可溶解区域

显影



易出现的问题

光刻

坚模（硬烘烤）

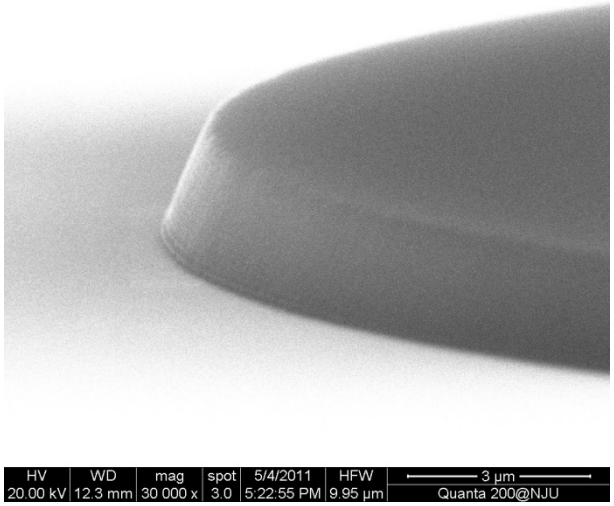
通过加温烘烤使胶膜更牢固地黏附在基片表面，并增加胶层的抗刻蚀能力

非必要步骤

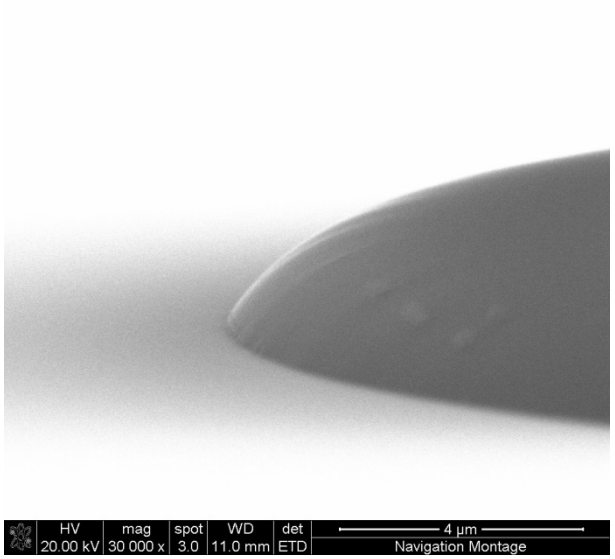
缺点：会改变光刻胶的形状
增加去胶的难度

光刻

坚模（硬烘烤）



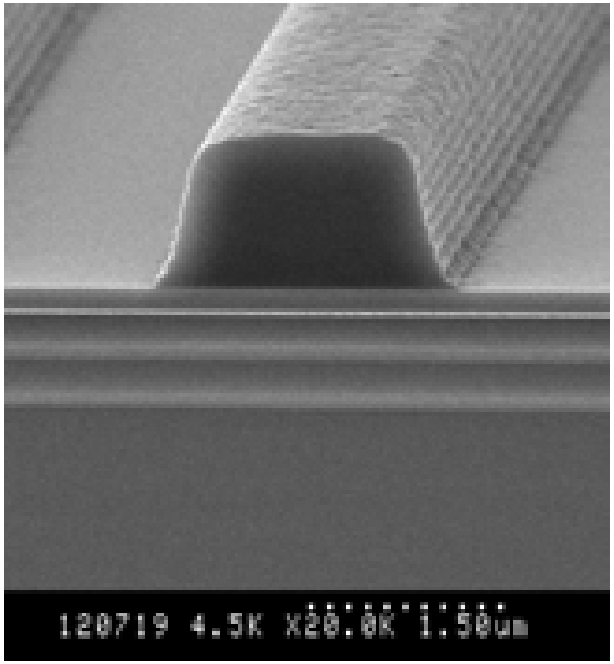
无硬烘

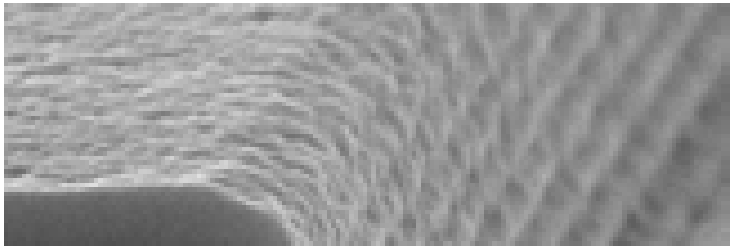


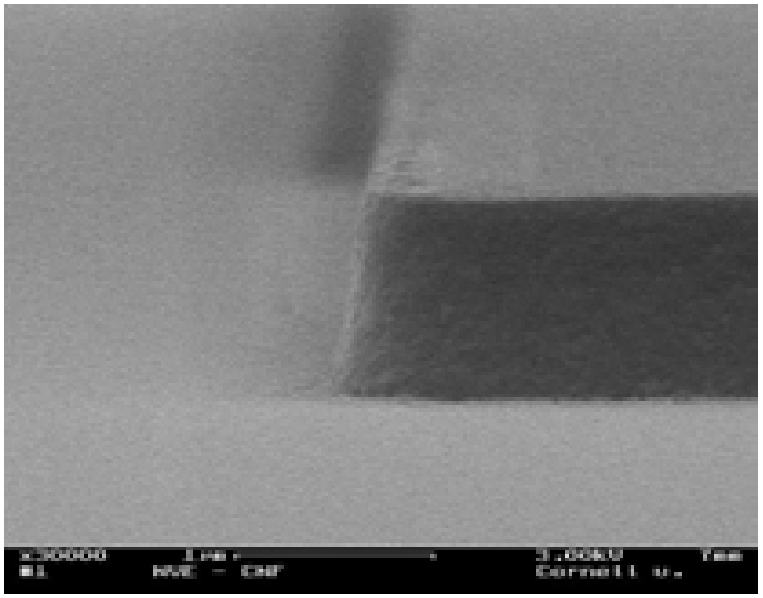
有硬烘

光刻

光刻胶







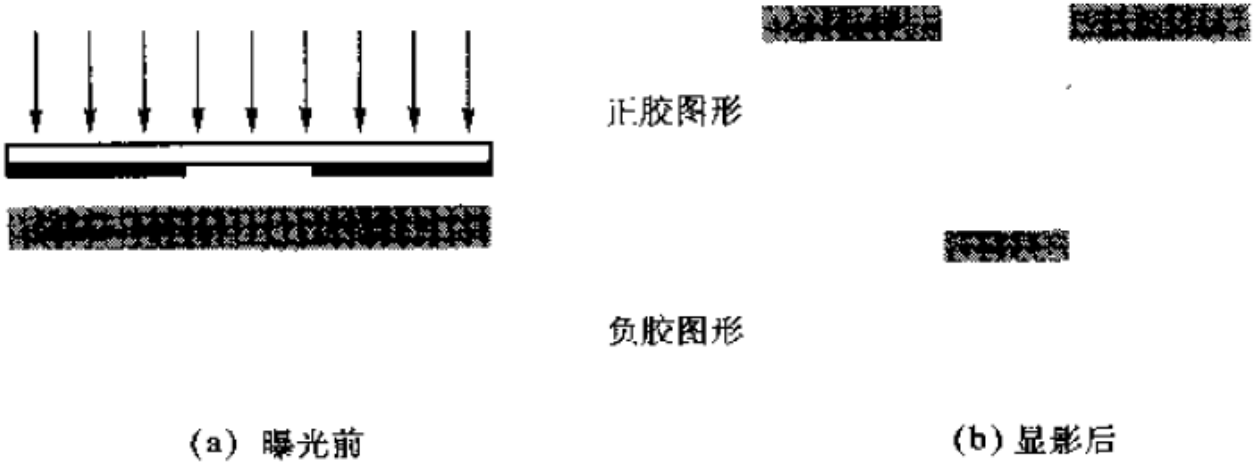
Resist Profile AfterPostbake

驻波

光刻

光刻胶：指一大类具有光敏化学作用的高分子聚合物材料

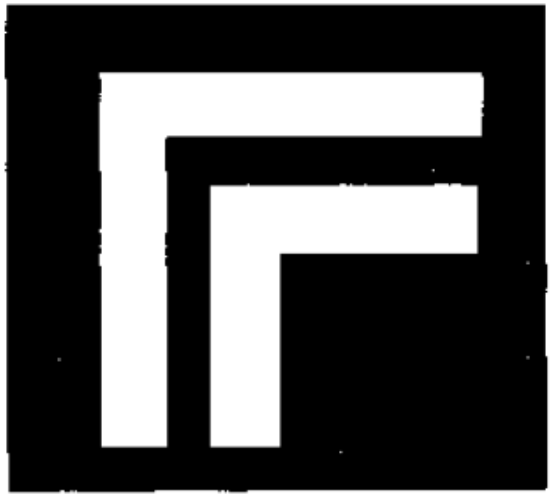
分为：正型胶、负型胶



正型光刻胶与负型光刻胶的区别

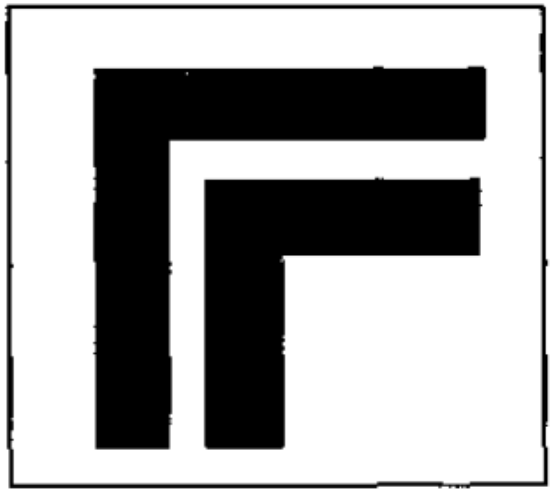
光刻

正型胶与负型胶的比较



(a) 暗场掩模

用于正型胶



(b) 亮场掩模

用于负型胶

光刻

正型胶与负型胶的比较

表 2.1　正、负型光刻胶的比较

光刻胶特性	光刻胶类型	
	正型胶	负型胶
与晶圆的附着力	一般	好
灵敏度	较低	高
对比度	高	低
成本	较贵	较便宜
显影液	水溶性	有机溶剂
受环境中氧气的影响	无	有
最小可分辨图形尺寸	0.5 μm 以下	2 μm 左右
抗刻蚀比	高	低
遗留残胶现象	仅可能发生在小于 1 μm 的图形	较普遍
覆盖晶圆表面台阶能力	好	差
显影后膨胀	无	有
热稳定性	好	一般

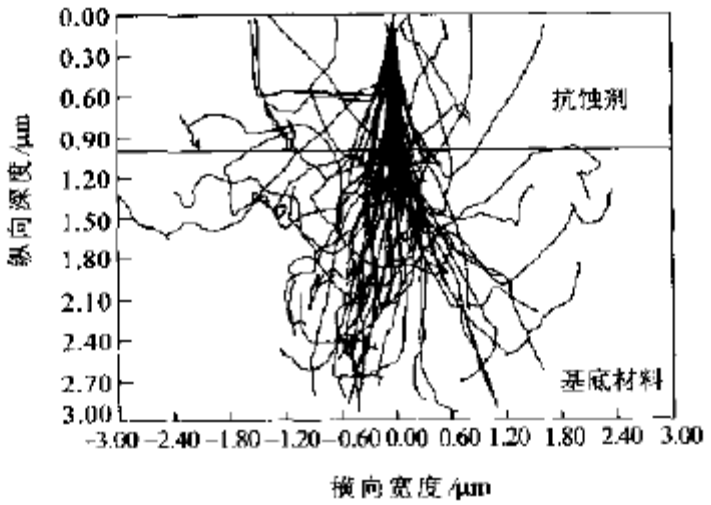
电子束曝光技术

电子束曝光原理：利用某些高分子聚合物对电子敏感而形成曝光图形

电子德布罗意波长：

$$\lambda = \frac{1.226}{\sqrt{V}}\,(\mathrm{nm})$$

100 eV的电子其波长为0.12 nm



电子散射轨迹（入射电子能量：20 kV；基底材料：硅）

分辨率取决于各种电子相差和电子在抗蚀剂中的散射，而非电子波长。

电子束曝光技术

Optical Lithography	e-Beam Lithography
High speed for large shapes	High speed for complex Patterns
High Speed, Parallel Exposure	Point by Point Exposure Limits Speed
Light Diffraction Limits	Not Diffraction-limited;

电子束曝光技术

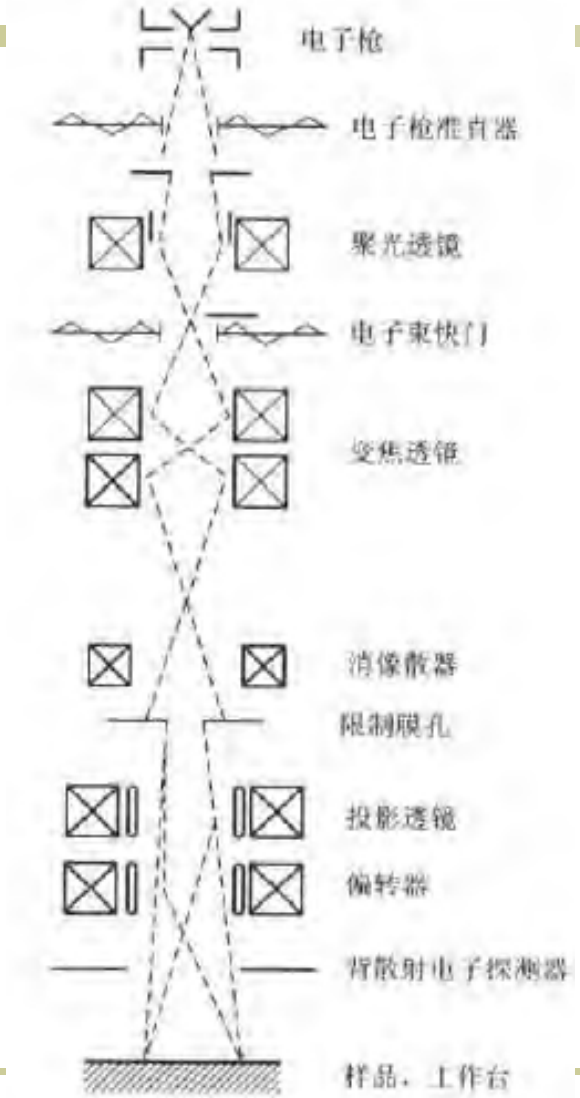


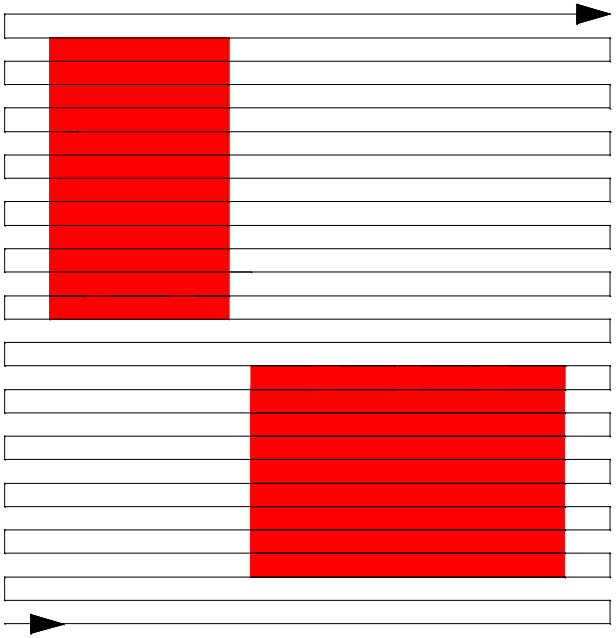
图 3.8 电子束曝光机的电子光学系统示意图

VISTEC EBPG5000PLUS

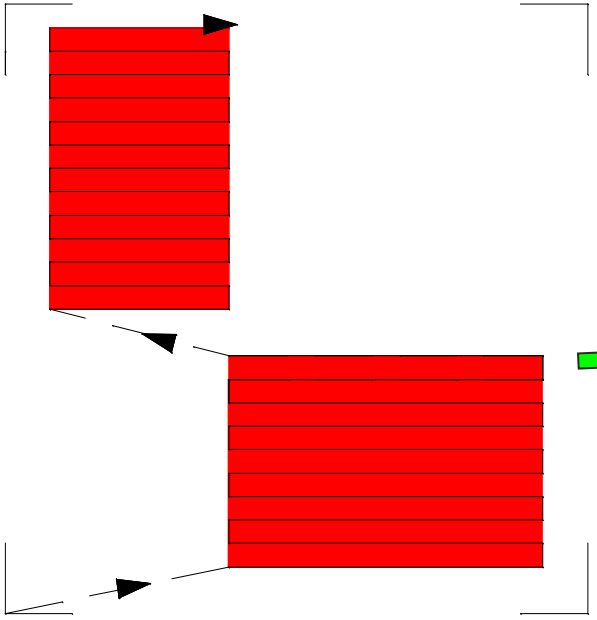
- high current density Thermal Field Emission gun for operation at 20, 50 and 100 kV
- availability of 150 mm platform
- minimum feature size of less than 8 nm

电子束曝光技术

电子束曝光机扫描方式



光栅扫描



矢量扫描

矢量扫描与光栅扫描区别在于，矢量扫描曝光的电子束只在曝光图形部分扫描，而光栅扫描则是对整个曝光场扫描，但电子束曝光快门只在曝光图形部分打开。

电子束曝光技术

电子束抗蚀剂

表 3.8　传统电子抗蚀剂的特性比较

	类型	分辨率/nm	灵敏度①	显影液
PMMA	+	10	100	MIBK:IPA
ZEP－520	+	10	30	xylene:p－dioxane
ma－N 2400	－	80	60	MIF726
EBR－9	+	200	10	MIBK:IPA
PBS	+	250	1	MIAK:2－Pentanone 3:1
COP	－	1 000	0.3	MEK:ethanol 7:3

① 加速电压为 20 kV 时的灵敏度，单位：$\mu C/cm^2$（微库仑每平方厘米）

电子束曝光技术

配方举例：

PMMA

Surface Preparation	In general, no surface preparation (aside from normal cleaning) is necessary. Excellent adhesion to most surfaces.
Spin	Speed 1000-5000 rpm, 60 sec. (100-1000 nm)
Pre-bake	170°C hotplate, 15 min., non-critical. Must be 150 < T < 200 degrees, for at least 10 minutes. May also be oven baked at 170°C for 1 hour.
Expose	Dose around 800 uC/cm^2 at 100 kV.
Develop	For low resolution features: MIBK:IPA 1:1, 1-2 minutes. For Higher resolution features: MIBK:IPA 1:3, 1-2 minutes
Rinse	With IPA
Dry	By spinning or dry N_2
Post-Bake	Not normally necessary. Flow can begin as low as 120°C. Does not seem to noticeably improve adhesion or etch resistance.

Cornell NanoScale Science & Technology Facility

电子束曝光技术

配方举例：

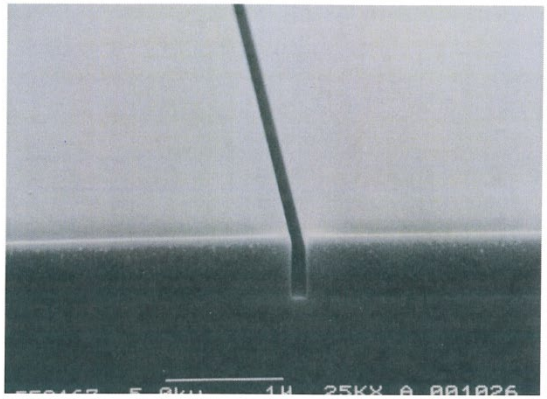
ZEP 520A

Surface Preparation	In general, no surface preparation (aside from normal cleaning) is necessary. Excellent adhesion to most surfaces.
Spin	Speed 1000-5000 rpm, 60 sec. (100-1000 nm)
Pre-bake	170°C hotplate, 2 minutes
Expose	10 - 20% the dose requirement of PMMA
Develop	Solvent develop depending on resist
Rinse	With IPA
Dry	By spinning or dry N_2
Post-Bake	Not normally necessary.

Cornell NanoScale Science & Technology Facility

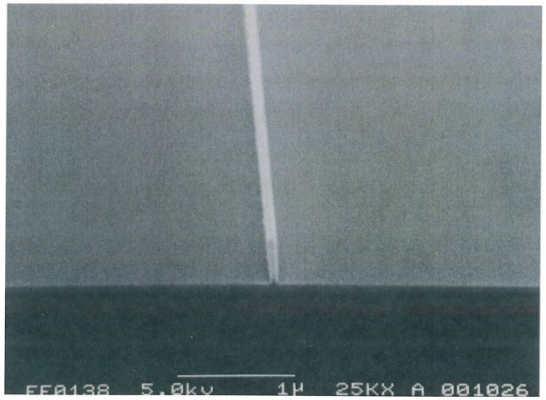
电子束曝光技术

配方举例：



0.15μm Isolated space

Process Conditions
Resist : ZEP520
Film thickness : 5000Å
PB temp. : 180°C
PB time : 2 min.
Exposure : 30kV, 5×10^{-11}A, 1 line exp.
50×10^{-5}μC/cm
Dev. temp. : ZED-WN, 23°C, 30 sec.
Rinse : IPA, 23°C, 20 sec.



0.1μm Isolated line

Process Conditions
Resist : ZEP520
Film thickness : 5000Å
PB temp. : 180°C
PB time : 2 min.
Exposure area : 100μm (20000×20000dc
Exposure : 30kV, 5×10^{-11}A, 1 line exp.
0.7μsec./dot
Dev. temp. : ZED-WN, 23°C, 60 sec.
Rinse : IPA, 23°C, 20 sec.

谢谢