Nano Materials

Contents

Fabrication of Nano Structure

- ☐ Lithographic techniques
- ☐ Nanomanipulation and nanolithography
- ☐ Soft lithography
- ☐ Self-assembly of nanoparticles or nanowires
- ☐ Other methods
- ☐ Quantum dots

Fabrication of Nano Structure-lithography

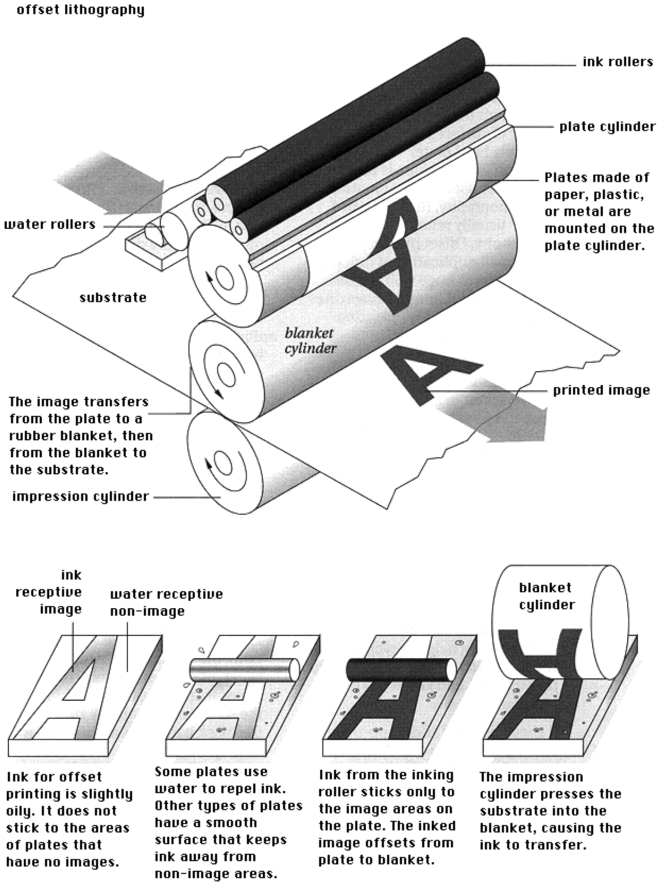
- Lithography
- Photolithography
- Phase shift optical lithography
- Electron beam lithography
- X-ray lithography
- Focused ion beam lithography
- Neutral atomic beam lithography

Fabrication of Nano Structure-lithography

❑ Lithography

- photoengraving
- process of transferring a pattern into a reactive polymer film, termed at resist, which will subsequently be used to replicate that pattern into underlying thin film or substrate

Lithography stone and mirror-image print of a map of Munich.



Plates made of paper, plastic, or metal are mounted on the plate cylinder.

The image transfers from the plate to a rubber blanket, then from the blanket to the substrate.

Ink for offset printing is slightly oily. It does not stick to the areas of plates that have no images.

Some plates use water to repel ink. Other types of plates have a smooth surface that keeps ink away from non-image areas.

Ink from the inking roller sticks only to the image areas on the plate. The inked image offsets from plate to blanket.

The impression cylinder presses the substrate into the blanket, causing the ink to transfer.

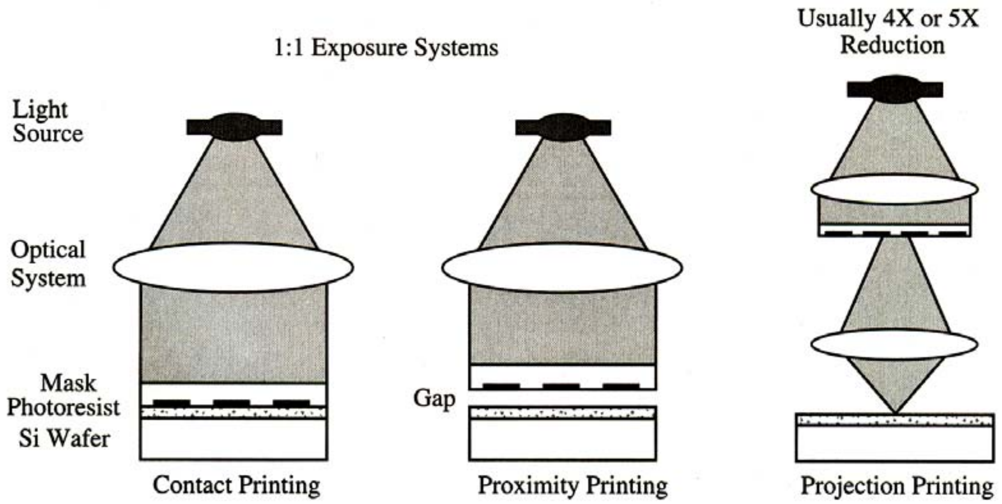
http://en.wikipedia.org/wiki/Lithography http://www.chromaticity.com.au/Glossary/Lithography.GIF

Fabrication of Nano Structure-lithography

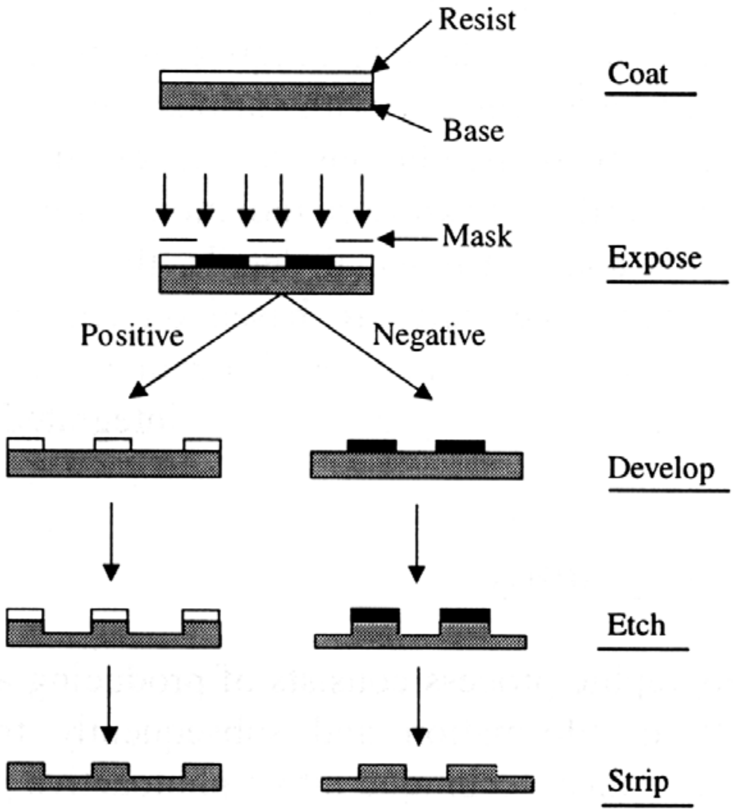
❑ Photo-lithography

- basic steps

- shadow printing- contact printing
proximity printing
projection printing



J.D. Plummer, Silicon VLSI Technology, 2000.

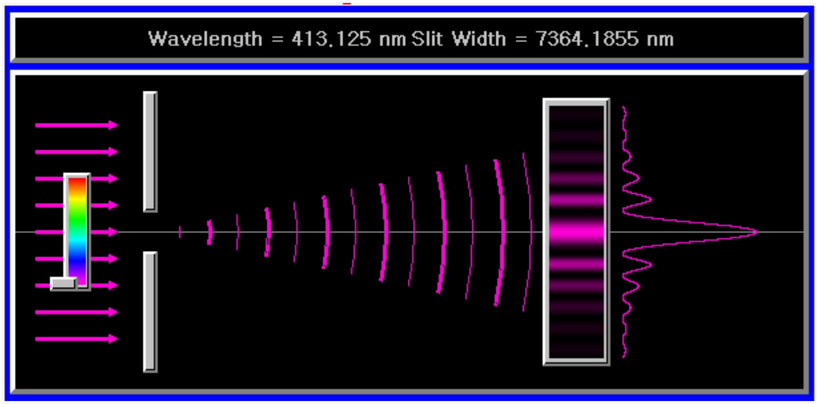


G. Cao, Nanostructures and Nanomaterials, 2004.

Fabrication of Nano Structure-lithography

❑ Photo-lithography

- diffraction limits maximum resolution and minimum size



Wavelength = 413.125 nm Slit Width = 7364.1855 nm

$$2b_{\min} = 3\sqrt{\lambda\left(s+\frac{d}{2}\right)}$$

2b: grating period
s: gap width
λ: wavelength
d: photoresist thickness

- for hard contact printing, s=0, λ=400 nm, d=1 μm, $2b_{\min}$ ~ 1μm
  maximum resolution- seldom achieved because of dust on the substrate and non-uniformity of resist thickness

→ Proximity printing- resolution decreases with increasing gap
difficulty in the control of constant gap space

http://www.phys.hawaii.edu/~teb/optics/java/slitdiffr/

Fabrication of Nano Structure-lithography

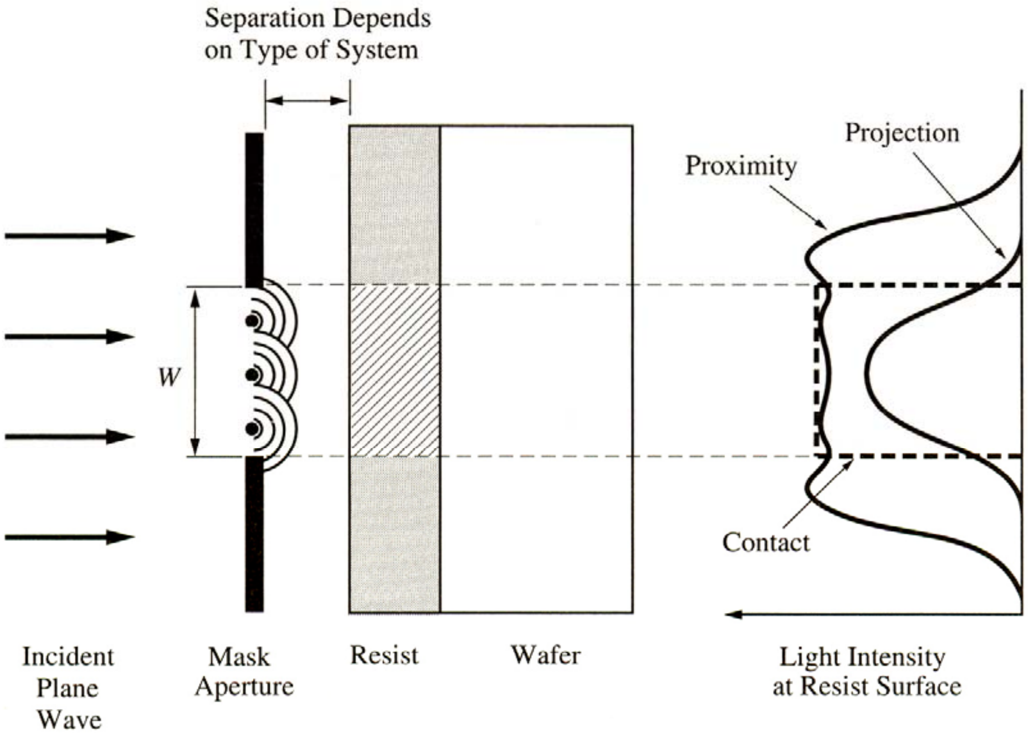


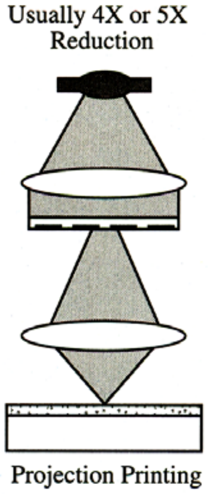
Figure 5–15 Aerial images produced by the three types of optical lithography tools. The mask and wafer would be in hard contact in a contact aligner, separated by a gap *g* in a proximity aligner, and far apart with an intervening focusing lens in a projection system.

J.D. Plummer, Silicon VLSI Technology, 2000.

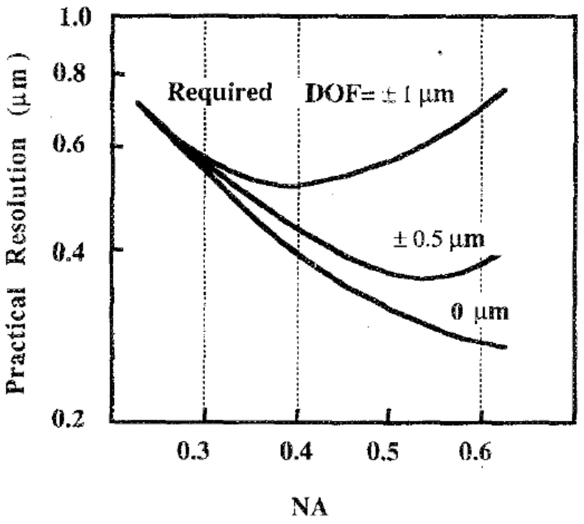
Fabrication of Nano Structure-lithography

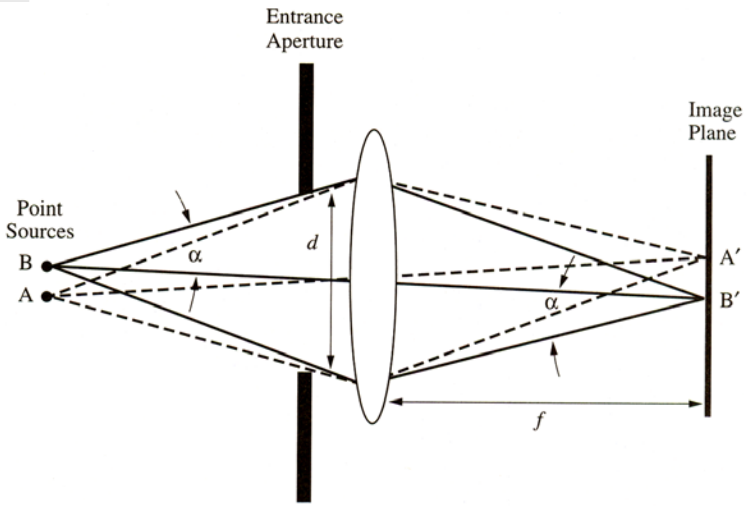
Photo-lithography

- projection printing- lens- lens imperfection and diffraction
  - resolution- Rayleigh criterion~ λ/2 (200 nm)
  - for higher resolution, short wavelength and larger NA
  - for high NA, small depth of focus- sensitive to slight variations in the thickness and absolute position of the resist layer



$$R = \frac{k_1\lambda}{NA}, \quad DOF = \frac{k_2\lambda}{NA^2}, \quad NA = n\sin\theta$$





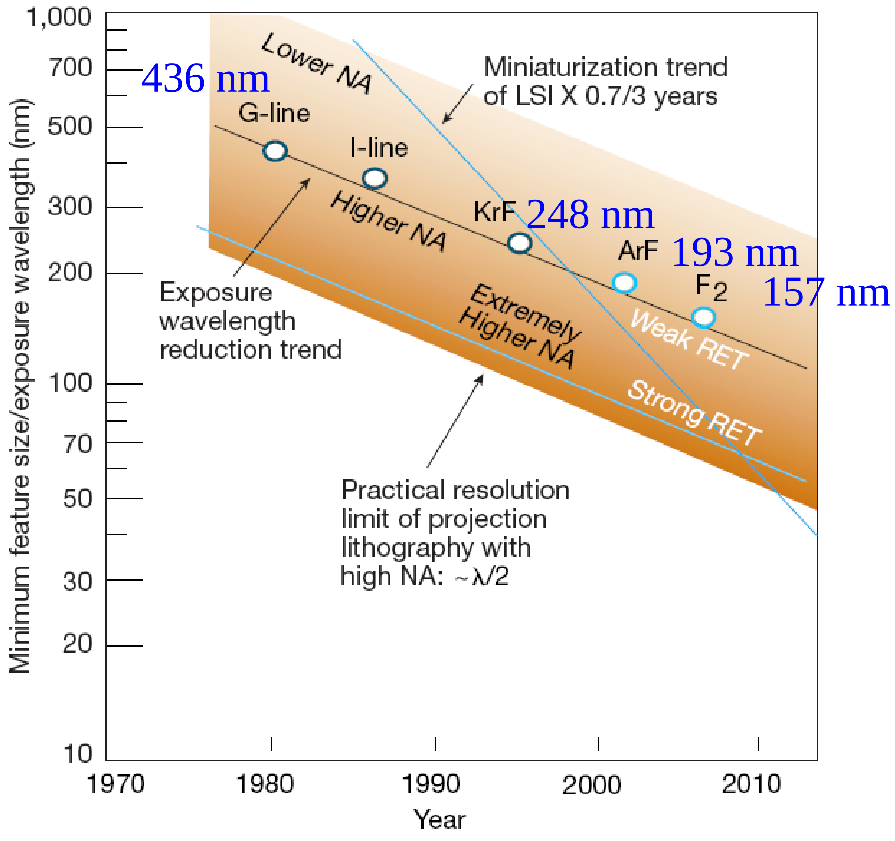
k_1: 0.61 (0.6~0.8)
k_2: 0.5
λ: wavelength
NA: numerical aperture (~0.5)
n: refractive index(=1)

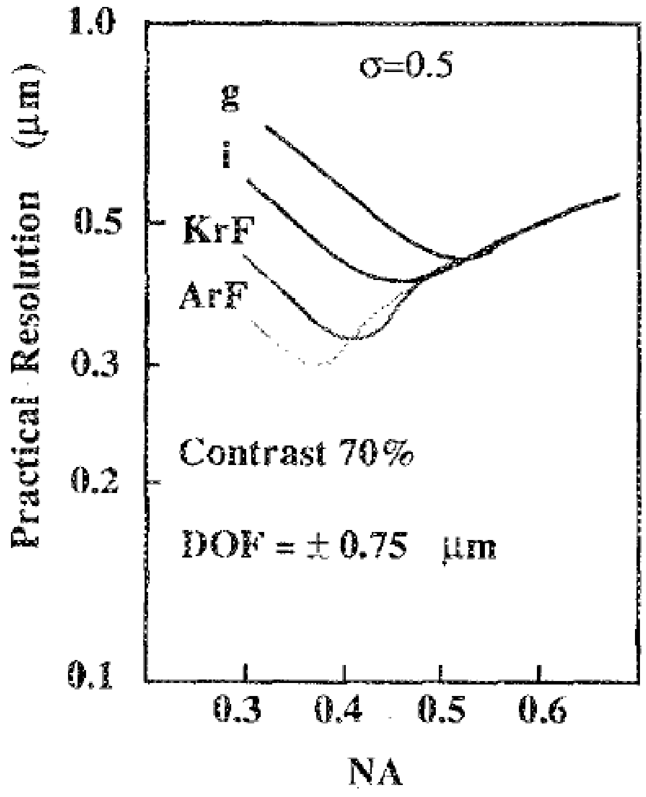
S. Okazaki, J. Vac. Sci. Tech. B9 (1991) 2829.

Fabrication of Nano Structure-lithography

☐ Photo-lithography

- deep ultra-violet lithography (DUV)





T. Ito, Nature, 406 (2000) 1027.

S. Okazaki, J. Vac. Sci. Tech. B9 (1991) 2829.

Fabrication of Nano Structure-lithography

❑ Photo-lithography

- extreme ultra-violet lithography (EUV)

problems) strong absorption (all reflective optic system instead refractive lens)
mirror- multilayer structure
extremely high precision metrology
EUV source

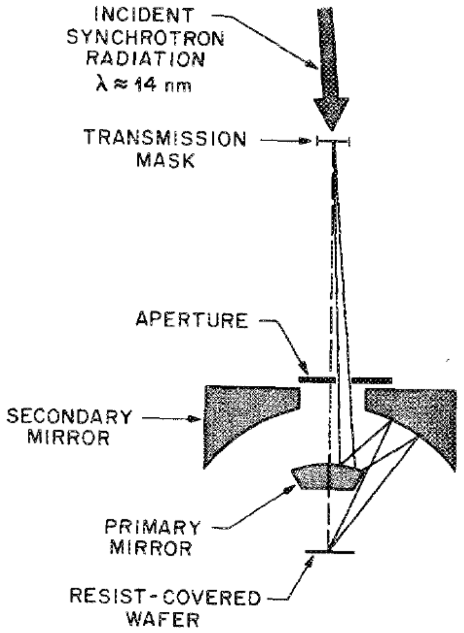


FIG. 1. Schematic diagram of the basic experimental setup. The two mirrors comprising the Schwarzschild objective were coated with Mo/Si multilayers to provide a reflectance of ~40% at 14 nm.

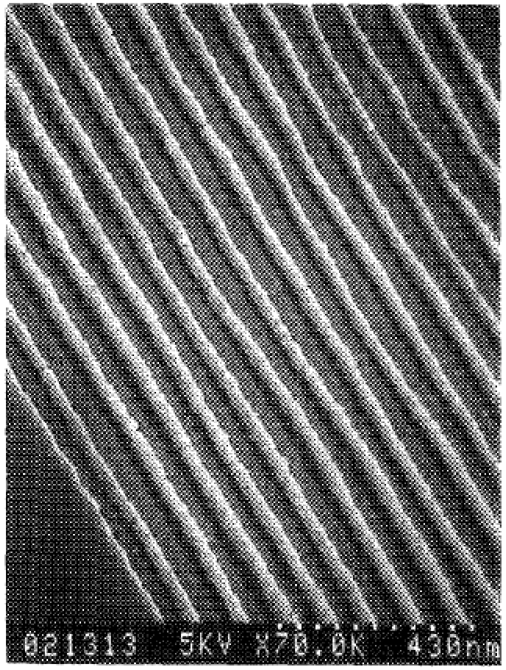


FIG. 9. SEM micrograph showing a closeup of the 0.05 μm lines and spaces shown in Fig. 8.

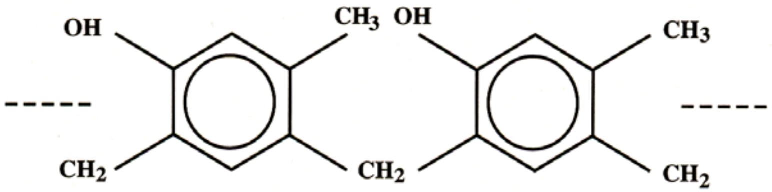
J.E. Bjorkhoim, J. Vac. Sci. Tech. B8 (1990) 1509.

Fabrication of Nano Structure-lithography

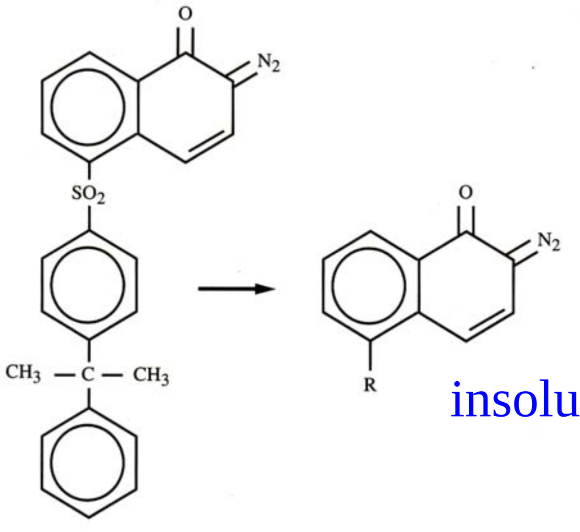
❑ Photo-lithography

- resist- three components- inactive resin (base)
  photoactive compound (PAC)
  solvent
- ex) positive- diazonaphthoquinone (DNQ)

base: novolac

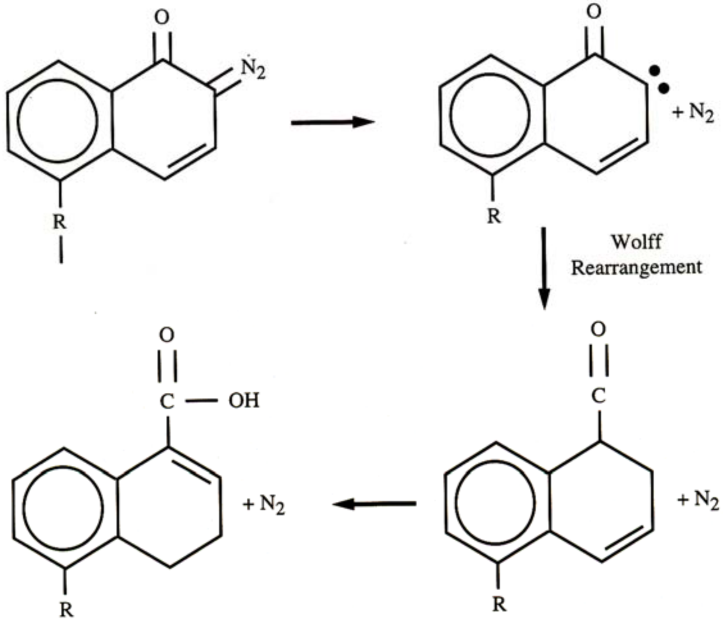


PAC: diazoquinone



insoluble

decomposition upon exposure
→ soluble in developer



J.D. Plummer, Silicon VLSI Technology, 2000.

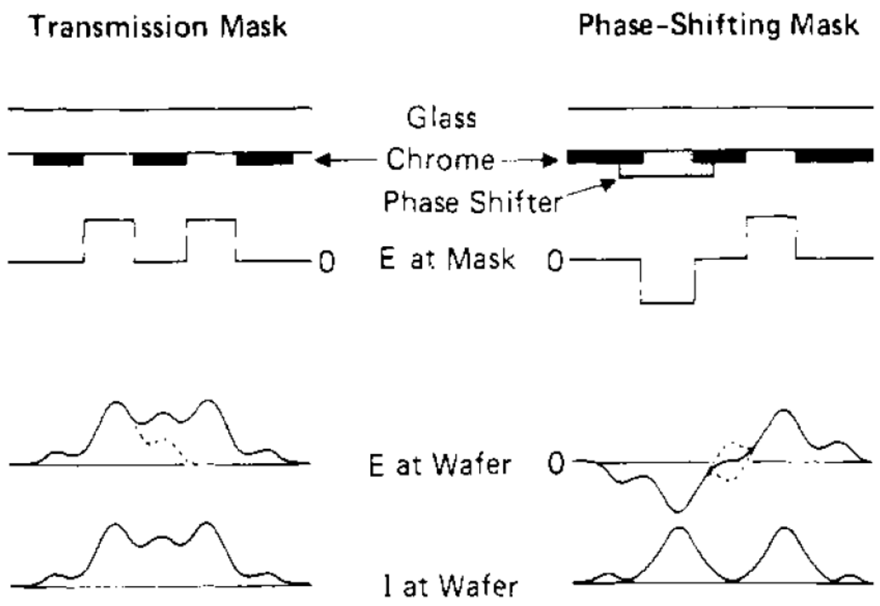
Fabrication of Nano Structure-lithography

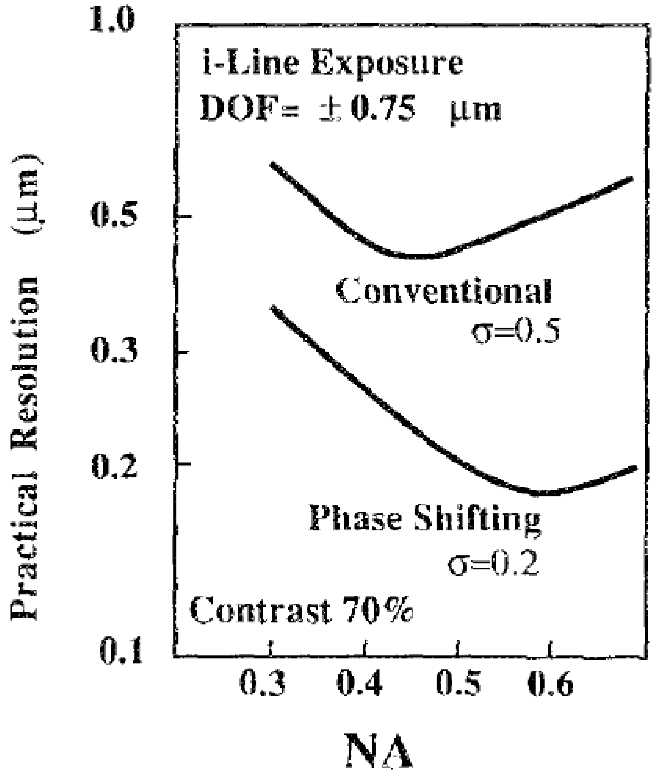
Phase-shifting photo-lithography

- phase shifter or phase mask with thickness $t = \frac{\lambda}{2(n-1)}$

phase shift by 180^{o}- destructive interference between wave diffracted from adjacent apertures- higher resolution

difficult to apply to random pattern



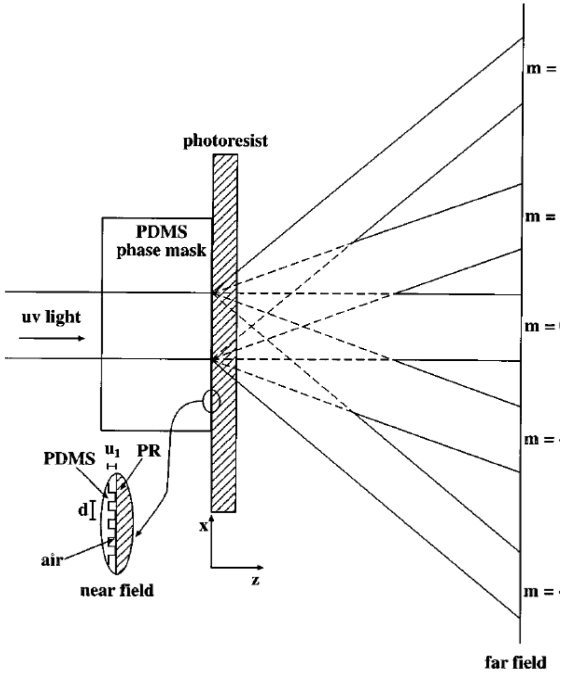


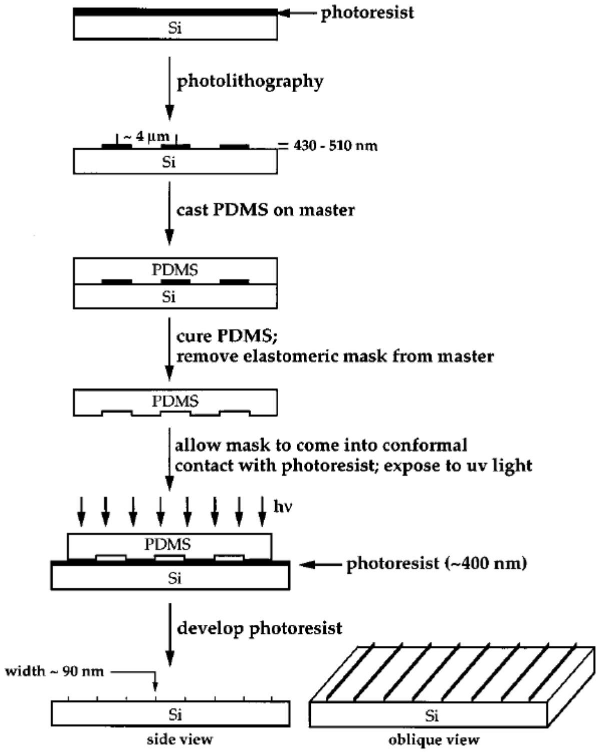
M.D.Levenson, IEEE Trans. Electron Dev. ED-29(1982)1828. S. Okazaki, J. Vac. Sci. Tech. B9 (1991) 2829.

Fabrication of Nano Structure-lithography

❑ Phase-shifting photo-lithography

- elastomeric phase mask PDMS





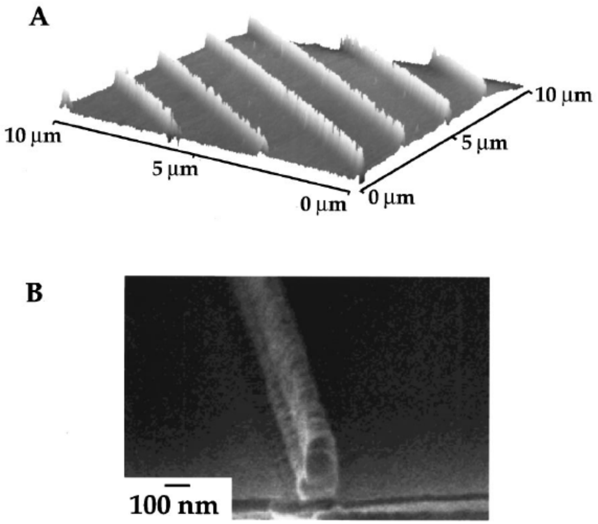
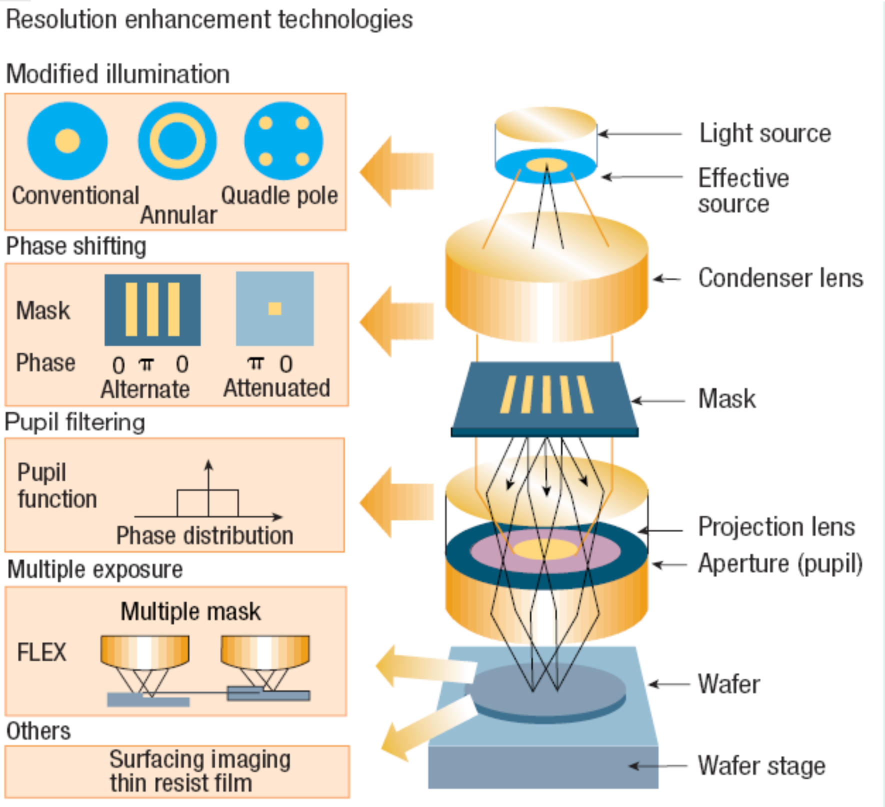


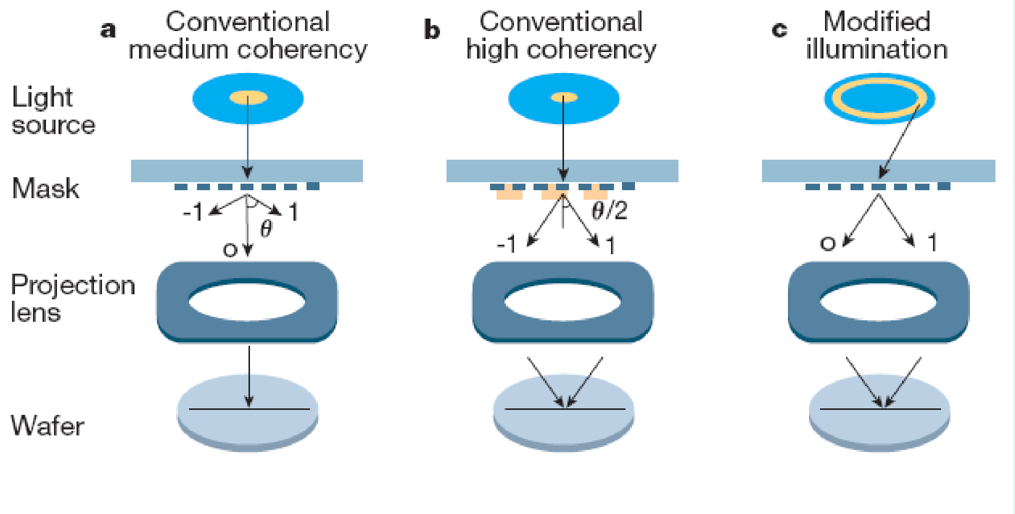
FIG. 15. Parallel lines formed in photoresist using nearfield contact-mode photolithography have widths on the order of 100 nm and are ~300 nm in height as imaged by (A) AFM and by (B) SEM.

J.A. Roger, J. Vac. Sci. Tech. B16 (1998) 59.

Fabrication of Nano Structure-lithography

❑ Resolution enhancement technique





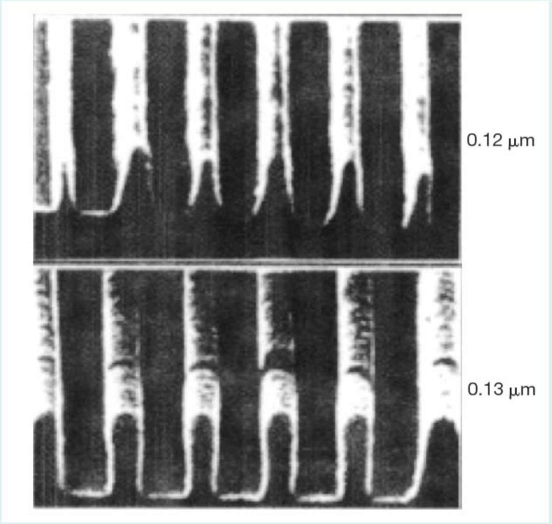


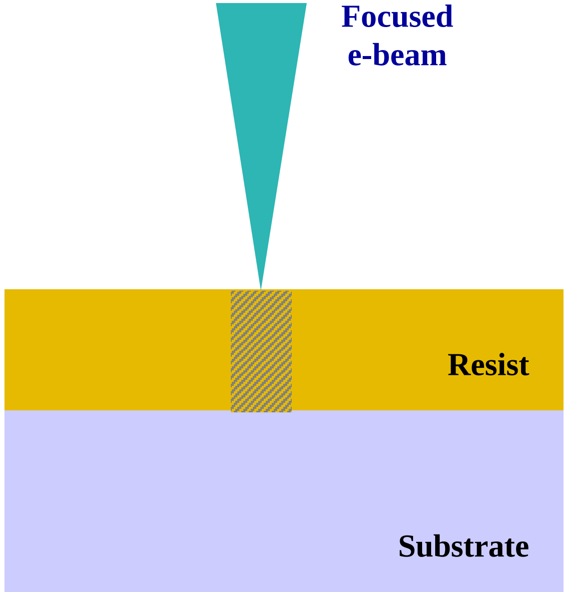
Figure 5 An example of resolution enhancement using phase-shifting technology. The exposure system uses a KrF excimer laser ($\lambda = 0.248$ µm; NA = 0.55; $\sigma = 0.3$). Structures having half the wavelength of the exposure light are clearly visible.

T. Ito, Nature 406 (2000) 1027.

Fabrication of Nano Structure-lithography

❑ Electron beam lithography

- focused beam of electrons
- fabrication of features as small as 3-5 nm
- limited by forward scattering of the electrons in the resist and back scattering from the underlying substrate
- scanning or projecting
- very small throughput



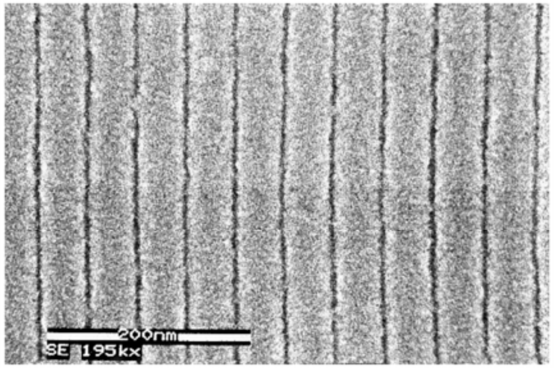


Fig. 1. Scanning electron micrographs of an array of 3–5 nm wide lines obtained by EBL in a 140-nm thick PMMA resist layer after development using US agitation.

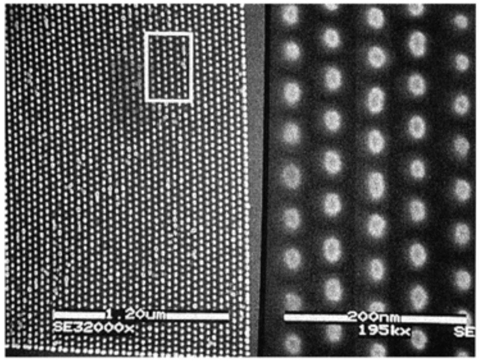


Fig. 7. SEM image of a 40-nm pitch pillar grating after nickel lift-off when developing with US assistance. Exposure dose was 17 fC/pt.

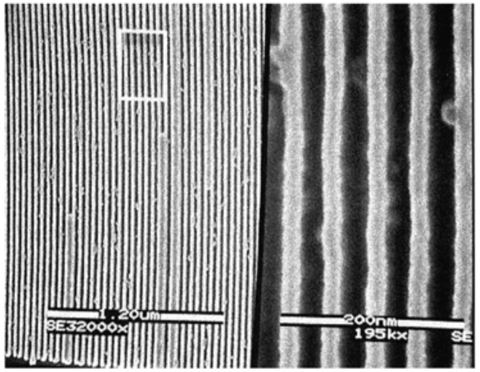


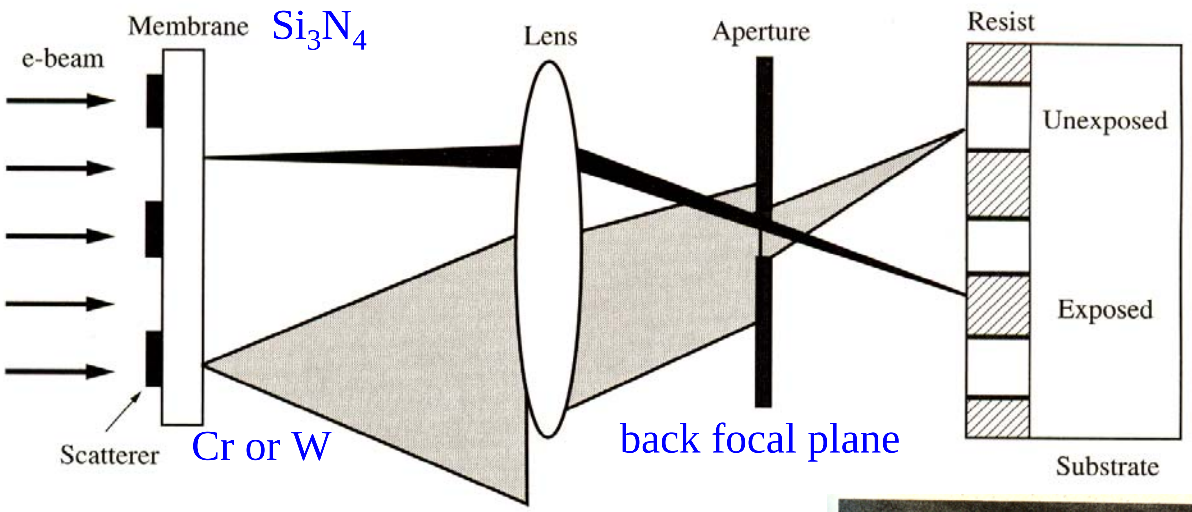
Fig. 8. SEM image of a 20-nm line and space grating after nickel lift-off when developing without US assistance. The exposure dose was 5 nC/cm.

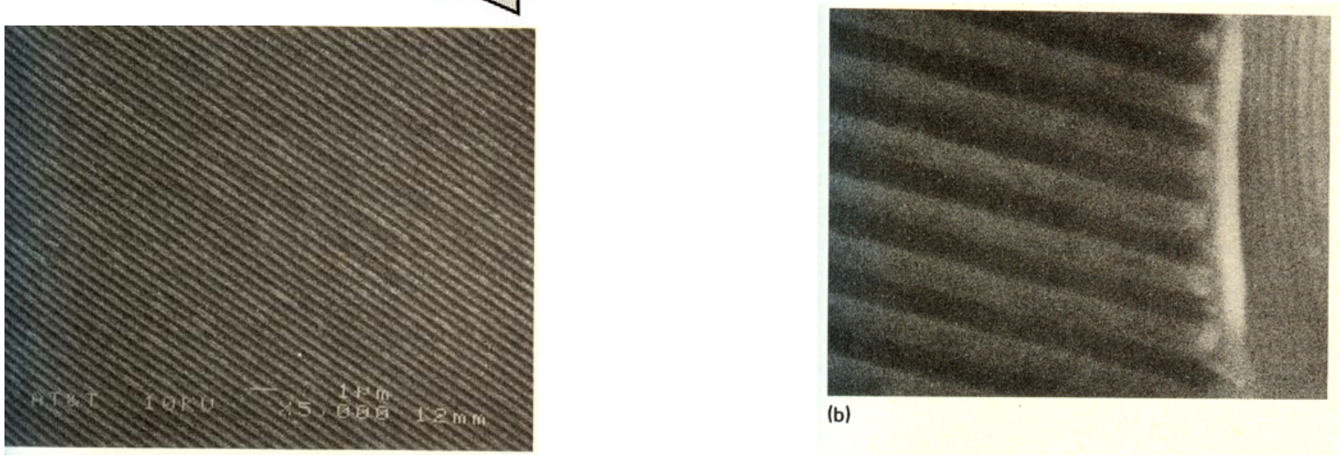
C. Vieu, Appl. Surf. Sci. 164 (2000) 111.

Fabrication of Nano Structure-lithography

❑ Electron beam lithography

- SCALPEL (scattering angular-limited projection electron-beam lithography)





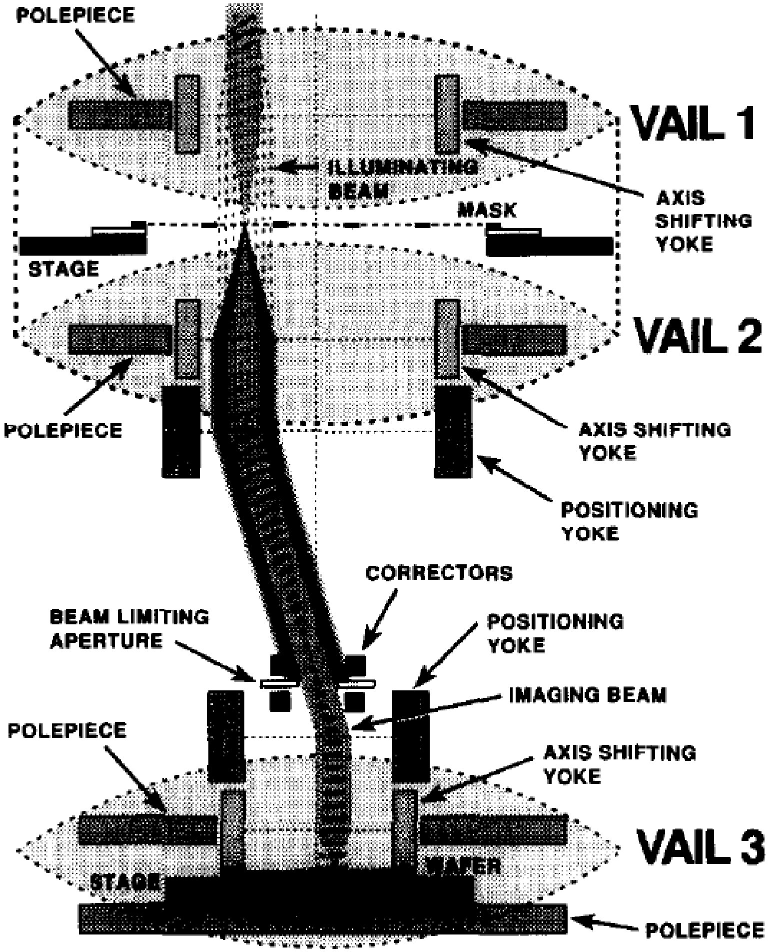
. (a) Plan view of 0.2-µm lines and spaces printed in PMMA. (b) sectional view of pattern in (a).

S.D. Berger, J. Vac. Sci. Tech. B9 (1991)2996.

Fabrication of Nano Structure-lithography

☐ Electron beam lithography

- PRIVAIL (projection reduction exposure with variable-axis immersion lenses)



H.C. Pfeiffer, Microelectrom. Eng. 27 (1995) 143.

Fabrication of Nano Structure-lithography

❑ X-ray lithography

- X-ray: λ= 0.04~0.5 nm
- difficult to focus X-ray → proximity printing
- mask: Si, Si_3N_4, SiC (transmitting)+ Au, W, Ta (absorbing)
- source: electron impact, synchrotron
- mirror: multilayer

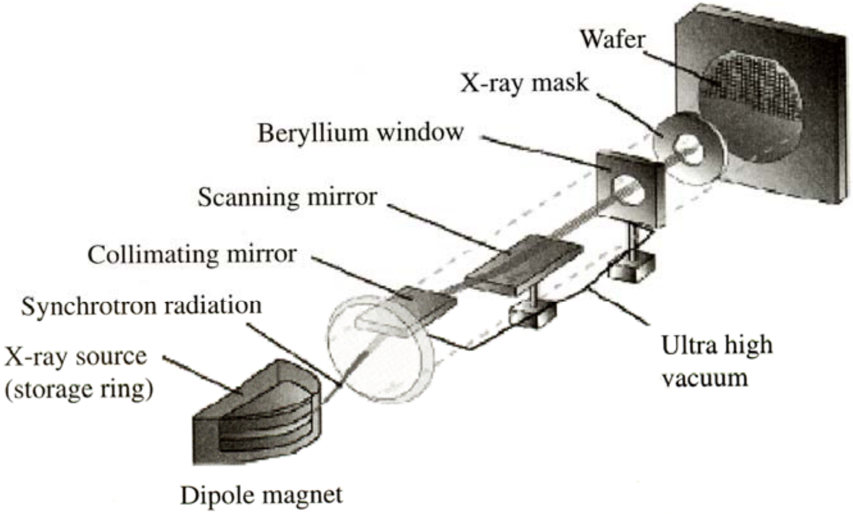


Figure 5-54 Proximity X-ray exposure system. This figure was taken from the Sematech Web site at http://www.sematech.org/public/.

Synchrotron radiation (0.65~1.2 nm, 0.7 nm)
2-μm thick SiN membrane, 0.65 μm thick Ta absorber

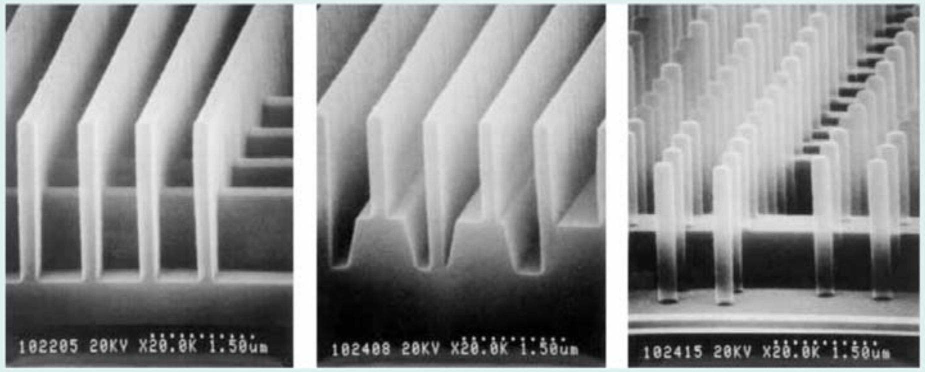


Figure 7 Resist patterns produced on different substrates using proximity X-ray lithography (PXL). (Courtesy of NTT-AT.)

K. Deguchi, Jpn. J. Appl. Phys. 31 (1992) 2954.

Fabrication of Nano Structure-lithography

❑ X-ray lithography

- ex) synchrotron radiation 1.1 nm

electroplated Au/SiC absorber and sputtered W/SiC absorber

PMAA, PMAA/MAA resist on Si or Cr/Au coated Si

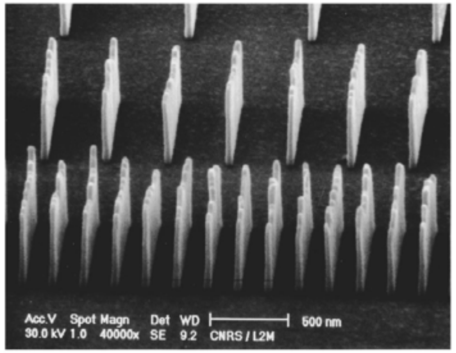


FIG. 1. 35-nm-wide Au lines grown by electroplating. The mean thickness is about 450 nm which corresponds to an aspect ratio close to 13. Note the relatively high thickness inhomogeneity at the surface of the structures.

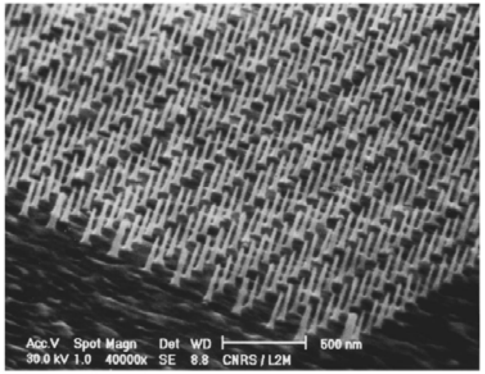


FIG. 2. 20-nm-wide W dots obtained after reactive ion etching of a 250-nm-thick W layer. The aspect ratio can hardly be larger than 10 but the thickness oscillations are very weak.

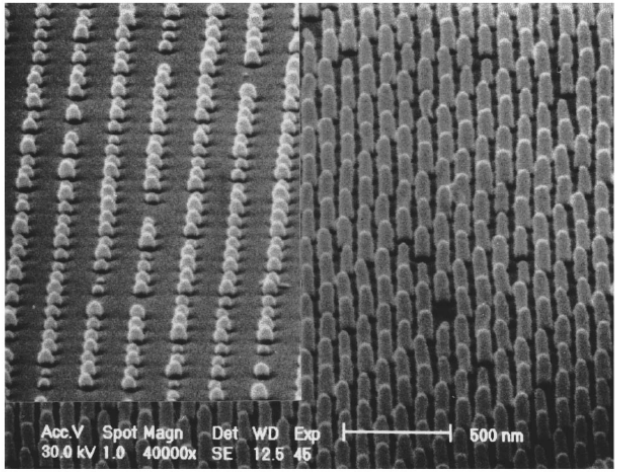


FIG. 5. Replication of dots in PMMA from 380-nm-thick Au absorber features. The nominal diameter was 50 nm. The resist patterns are 50 nm wide but the residual resist thickness is 160 nm in the case of monochromatic radiation (right part) and 80 nm for polychromatic radiation (left part).

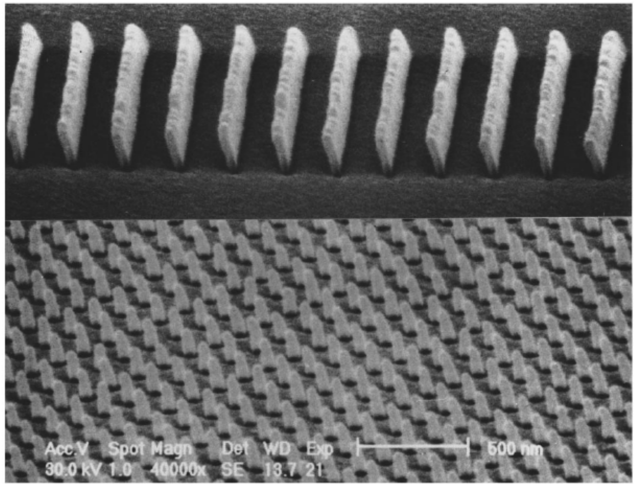


FIG. 7. 20-nm-wide PMMA lines replicated from 50-nm-wide W patterns and 30-nm-wide dots replicated from 30-nm-wide W structures. The thickness of the absorber was 250 nm.

G. Simon, J. Vac. Sci. Tech. B15 (1997) 2489.

Fabrication of Nano Structure-lithography

❑ Focused ion beam (FIB) lithography

- scattering of ions in MeV range- several order of magnitude less than electrons
- Ga, Au-Si-Be alloys- long lifetime and high stability
- high resist exposure sensitivity, negligible ion scattering in the resist, low back scattering from the substrate
- magnetic nanostructure- less influenced by magnetic properties of material
- direct etching and deposition capability

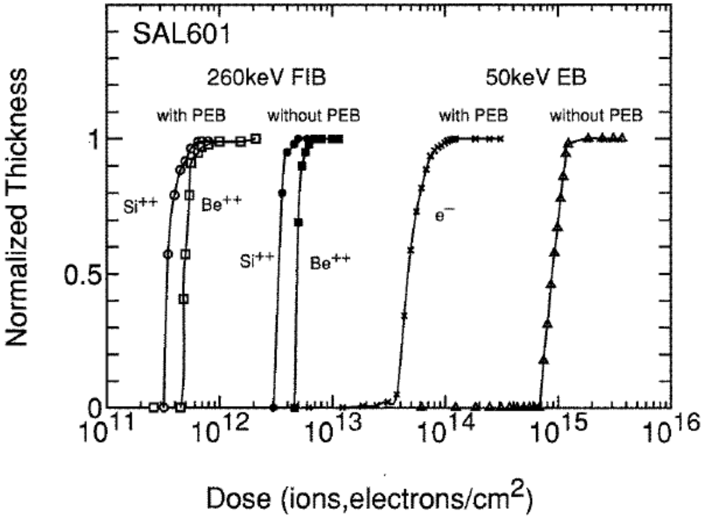


Figure 1. Resist sensitivities of SAL601-ER7 [31].

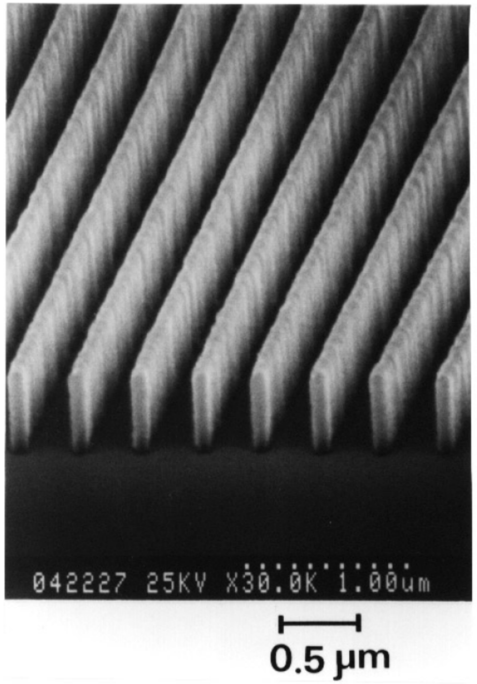


Figure 2. 0.1 µm linewidth, 0.6 µm thick SAL601-ER7 resist patterns fabricated by 260 keV Be^{++} FIB [31].

S. Matsui, nanotechnology, 7 (1996) 247.

S. Matsui, J. Vac. Sci. Tech. B9 (1991) 2622.

Fabrication of Nano Structure-lithography

❑ Focused ion beam (FIB) lithography

- deposition
- etching
  - physical sputter
  - chemical assisted

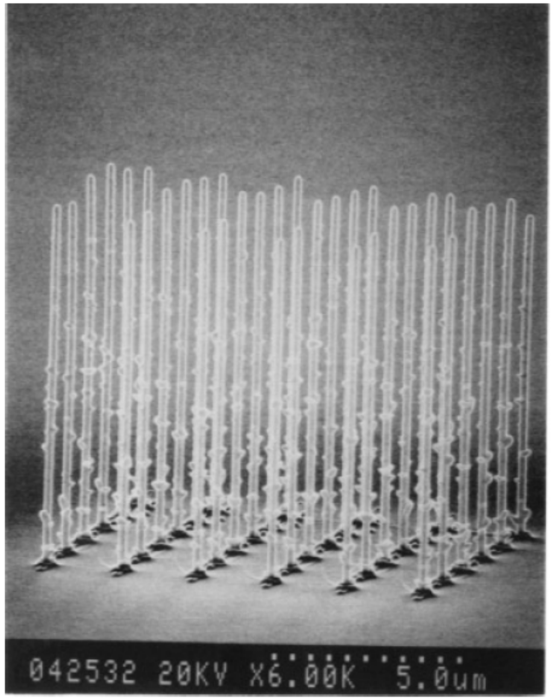


Fig. 7.6. SEM image showing a regular array of 36 gold pillars in each corresponding to an individual ion beam spot created using chemical assisted FIB deposition. [A. Wargner, J.P. Levin, J.L. Mauer, P.G. Blauner, S.J. Kirch, and P. Longo, *J. Vac. Sci. Technol.* **B8**, 1557 (1990).]

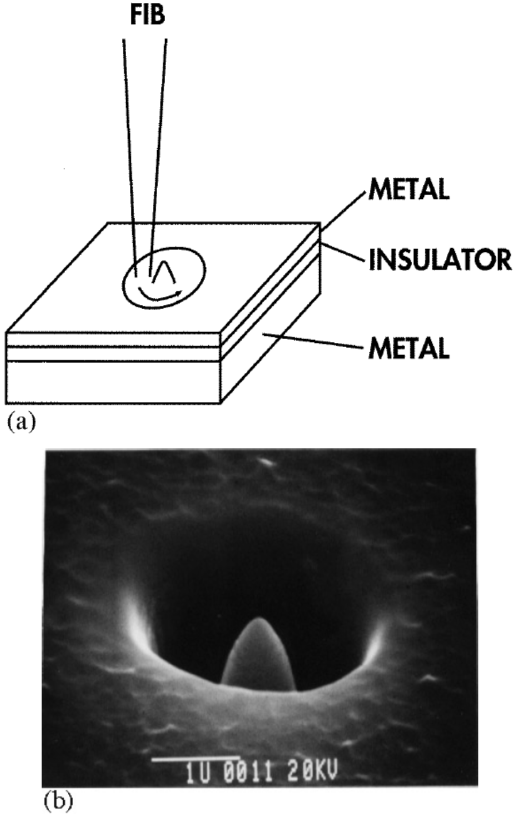


Figure 9. (*a*) Schematics of the fabrication process of a vertical-type field emitter by FIB etching [53].
(*b*) Vertical-type field emitter fabricated by FIB etching [53].

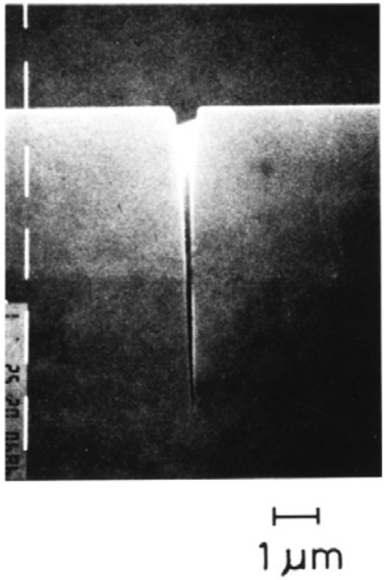


Figure 10. SEM micrograph of a deep groove formed on Si substrate by 35 keV Ga⁺ FIB assisted etching [64].

22 *Nanomaterials*

A. Wagner, J. Vac. Sci. Tech. B8 (1990) 1557.

S. Matsui, nanotechnology, 7 (1996) 247.

Fabrication of Nano Structure-lithography

❑ Focused ion beam (FIB) lithography

- nanomagnetic probe

etching
Ni45Fe55

deposition
W

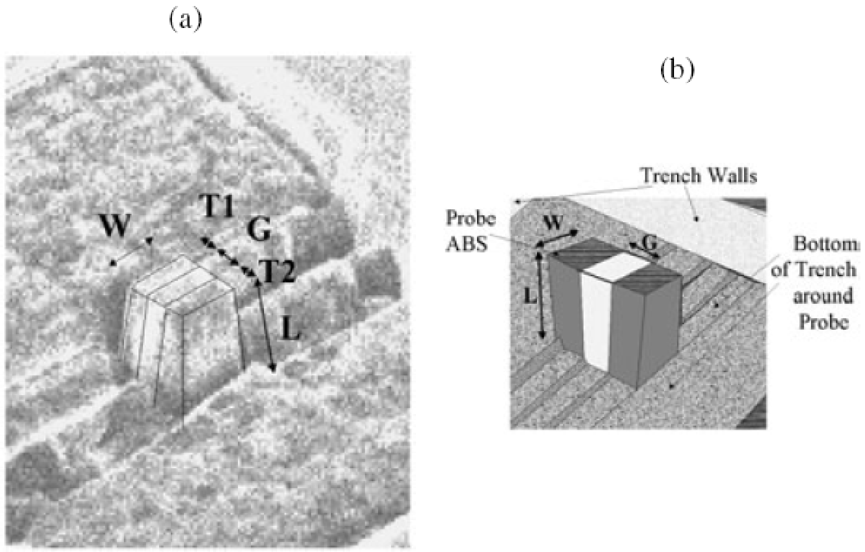


Figure 3. (a) A FIB image of the probe with two narrow pole tips each with a cross-section, $W \times T$, of 140×60 nm^2 and separated by a 60 nm gap length, as viewed from the ABS at a 40° tilt. (b) A schematic diagram.

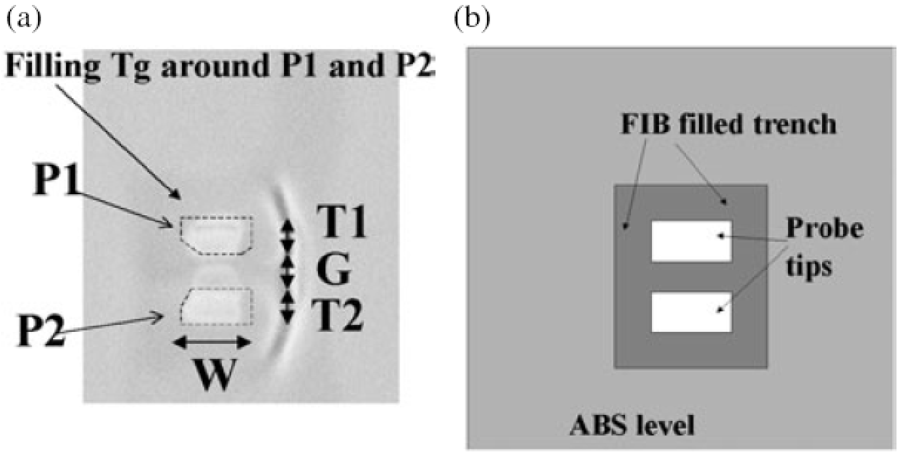


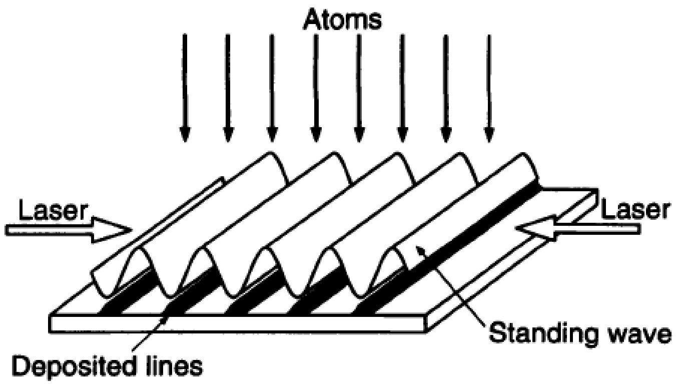
Figure 4. (a) A FIB image of the probe with narrow pole tips each with a cross-section of 140×60 nm^2 and separated by a 60 nm gap length, as viewed from the ABS. (b) A schematic diagram of the probe, as viewed from the ABS.

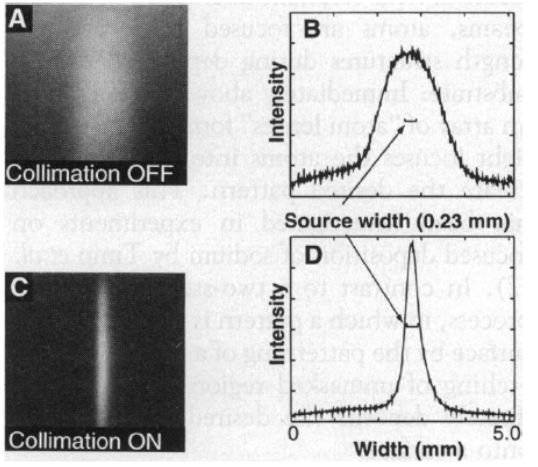
S. Khizroev, Nanotechnology, 13 (2002) 619.

Fabrication of Nano Structure-lithography

❑ Neutral atomic beam lithography

- neutral atom- no space charge, divergent
- neutral atom + laser light → focusing
- direct patterning- neutral chromium atoms





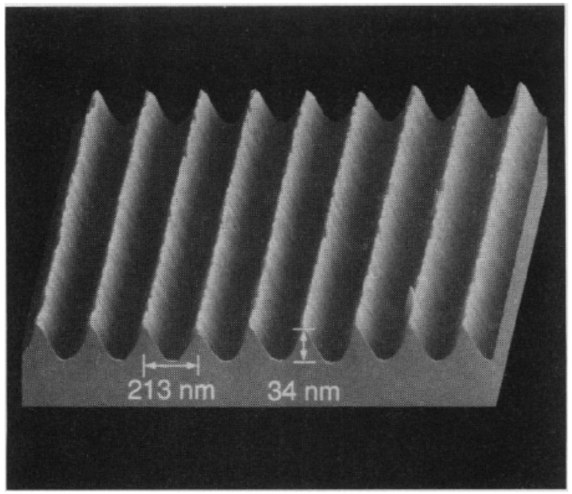


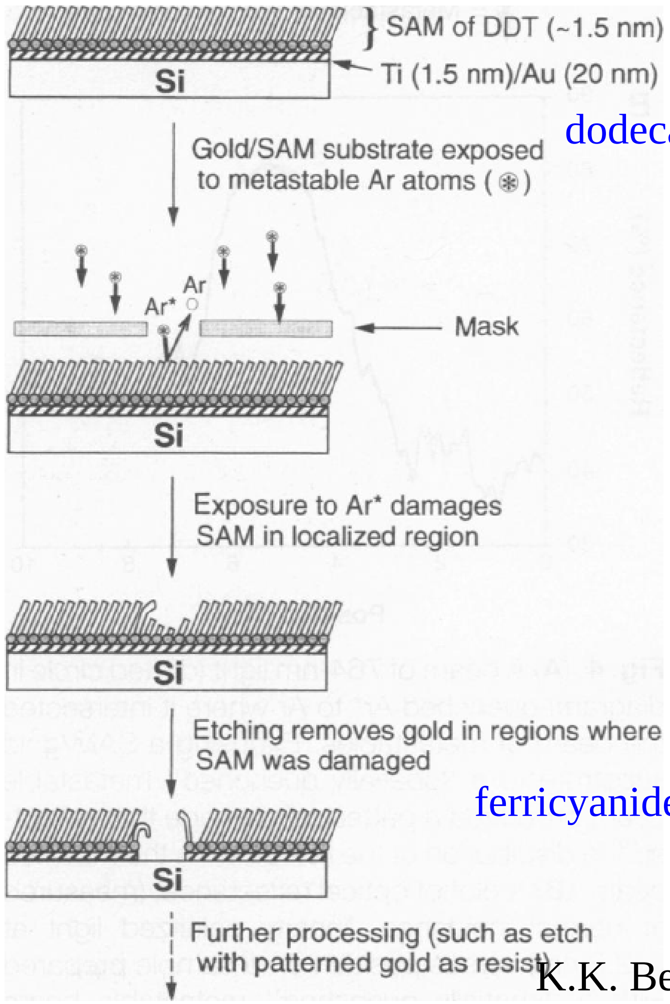
Fig. 4. A typical AFM image of chromium lines created by laser-focused atomic deposition. The image shows a 2 μm by 2 μm region of the lines, which cover a 0.4 mm by 1 mm area of the substrate. The sample was fabricated with an incident laser power of 20 ± 2 mW in the incoming standing wave beam and a blue detuning of 198 ± 2 MHz. The laser beam profile was approximately Gaussian with some ellipticity. The $1/e^2$ full widths were 0.39 ± 0.02 mm perpendicular to the silicon surface and 0.47 ± 0.02 mm parallel to the surface.

J.J. McClelland, Science, 262 (1993) 877.

Fabrication of Nano Structure-lithography

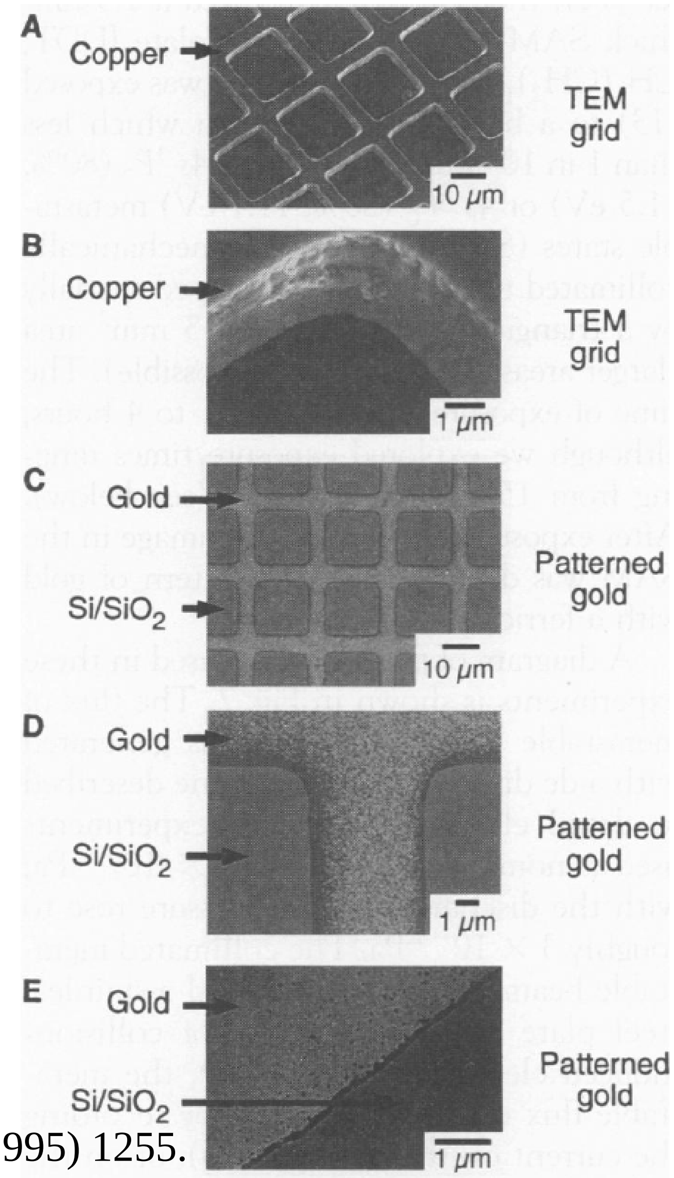
❑ Neutral atomic beam lithography

- patterning of a special resist- argon atom



dodecanethiolate

ferricyanide etch



K.K. Berggren, Science, 269 (1995) 1255.

Fabrication of Nano Structure-lithography

❑ Neutral atomic beam lithography

- neutral chromium atoms

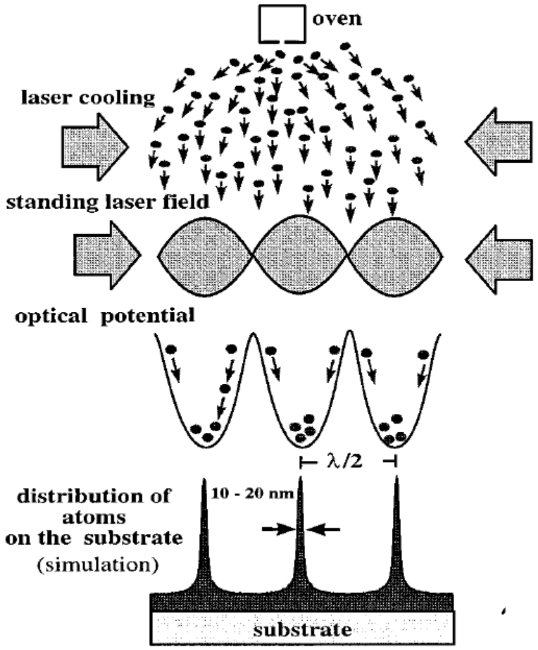


FIG. 1. Basic principle of atom lithography with light forces. A description is given in the text.

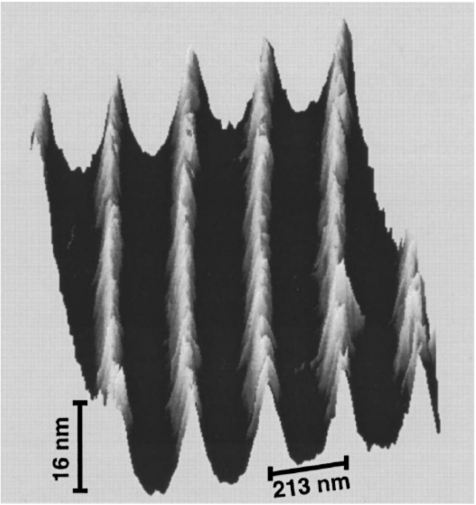


FIG. 4. Chromium lines with a period of 212.78 nm on a silicon substrate. The FWHM linewidth of the chromium lines is 64±6 nm. This value is determined by averaging along the lines in this extracted area.

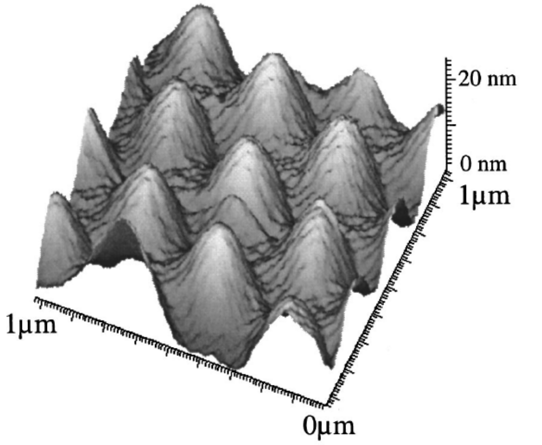


FIG. 5. Atomic-force microscope analysis of a two-dimensional chromium structure with a lattice constant of 284 nm. A small central part of the structured region is shown. The laser frequency was detuned from atomic resonance by $\delta=-120$ MHz so that the dipole potential minima, where chromium dots formed, coincided with the intensity maxima as shown in Fig. 3.

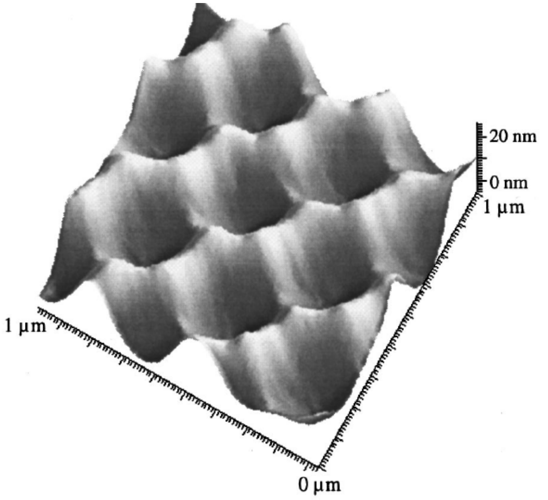


FIG. 6. In the generation of this chromium structure, only the laser detuning was changed to $\delta=+280$ MHz in comparison to Fig. 5. The inverted potential led to an approximately inverted chromium structure.

B. Brezger, J. Vac. Sci. Tech. B15 (1997) 2905.

Fabrication of Nano Structure-lithography

❑ Neutral atomic beam lithography

- neutral chromium atoms

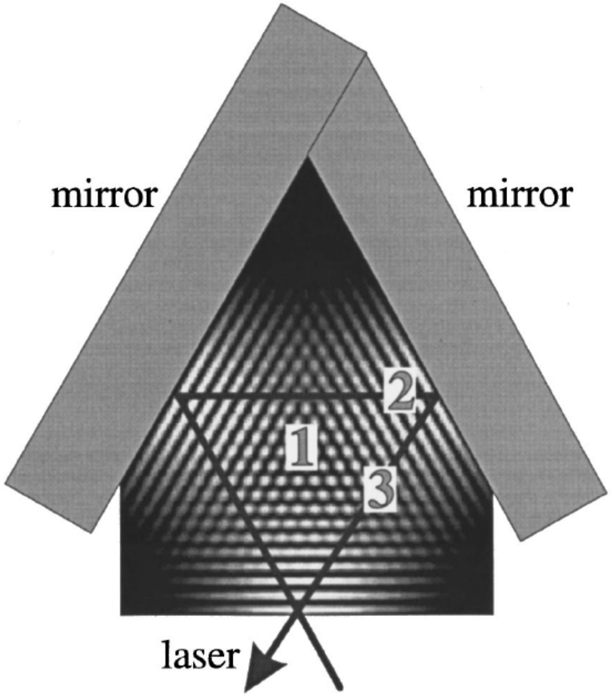
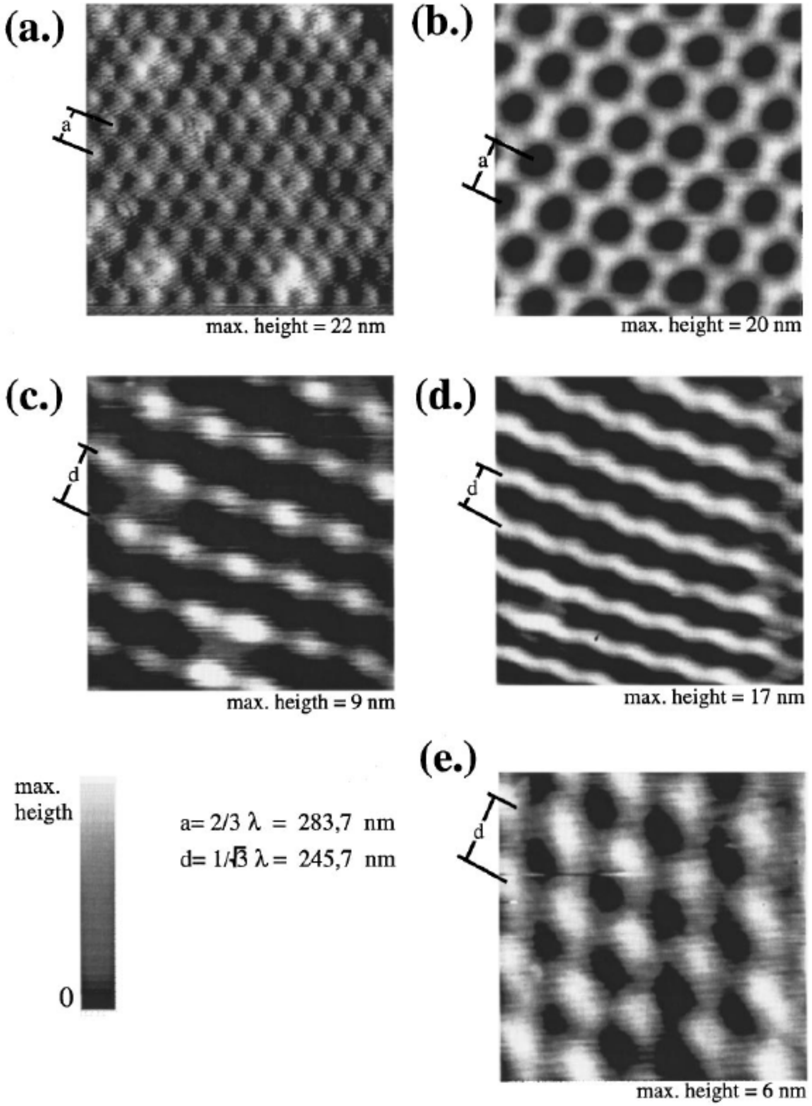


FIG. 3. Optical setup for the two-dimensional standing wave, as viewed along the atomic beam. The incoming laser beam is reflected twice with uniform polarization perpendicular to the image plane. The calculated intensity distribution for a laser waist adapted to the drawing size but with an extremely enlarged wavelength is shown to give an impression on the overall nodal pattern.



$a = 2/3\ \lambda = 283{,}7$ nm

$d = 1/\sqrt{3}\ \lambda = 245{,}7$ nm

B. Brezger, J. Vac. Sci. Tech. B15 (1997) 2905.

Fabrication of Nano Structure-lithography

❑ Technological trends in lithography

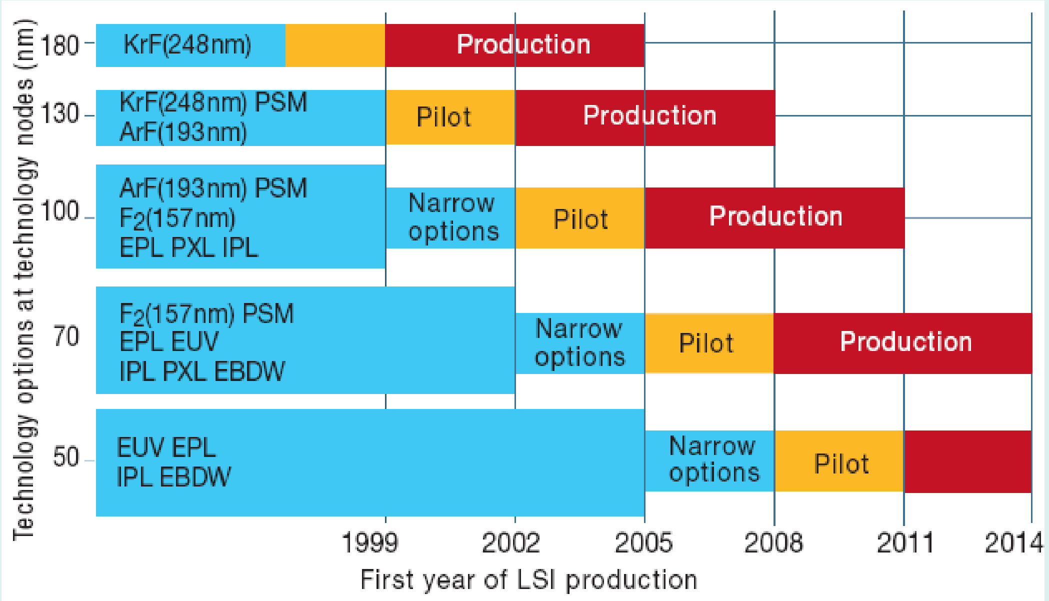


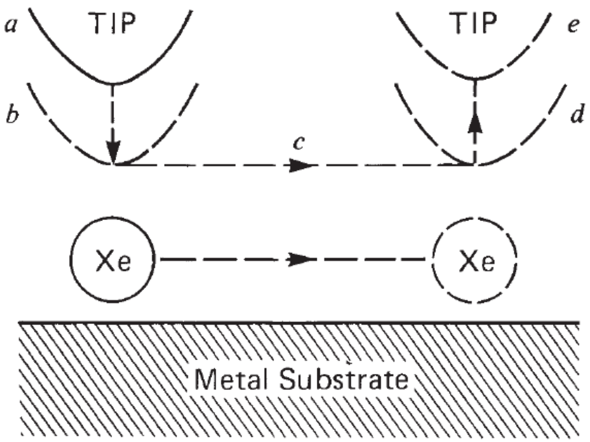
Figure 1 Technological trends in lithography. Shown are the various technologies under investigation for the development of pilot and production lines of LSI circuitry. These include: KrF (248 nm), KrF excimer laser lithography with wavelength 248 nm; ArF (193 nm), ArF excimer laser lithography with wavelength 193 nm; F_2 (157 nm), F_2 excimer laser lithography with a wavelength of 157 nm; PSM, phase-shifting mask applied to KrF, ArF and F_2; EPL, electron-projection lithography; PXL, proximity X-ray lithography; IPL, ion-projection lithography; EBDW, electron-beam direct writing.

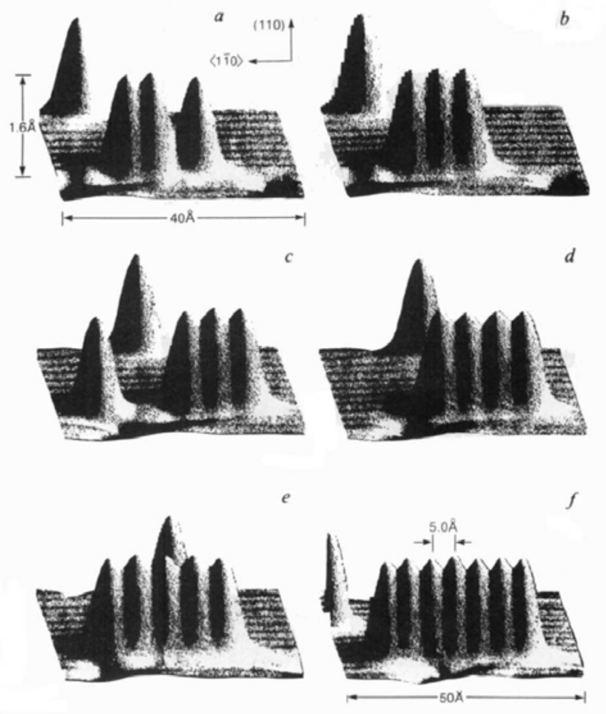
T. Ito, Nature, 406 (2000) 1027.

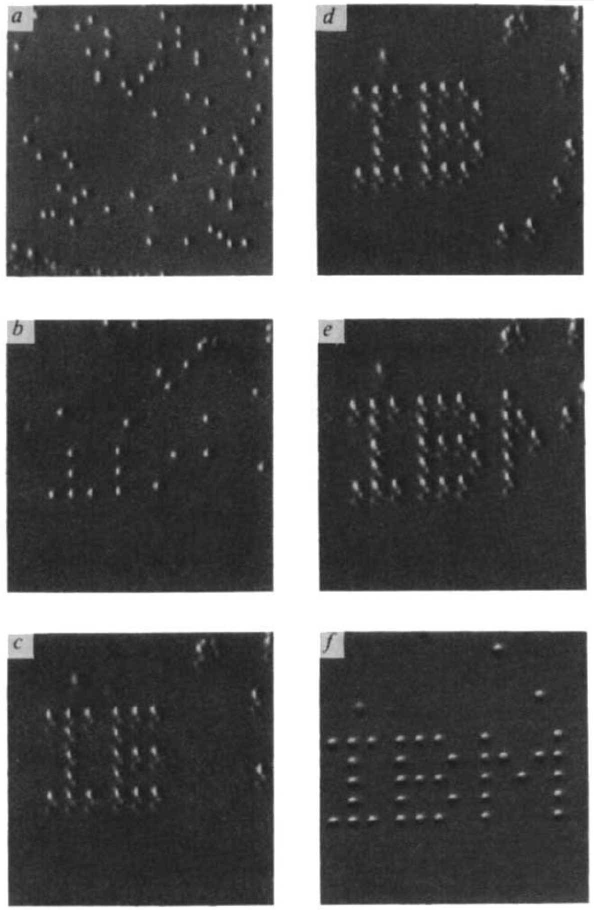
Fabrication of Nano Structure-nanomanipulation

❑ STM

- xenon atoms on an single crystal nickel surface
- parallel processes- field assisted diffusion
  sliding
- perpendicular process- transfer near or on contact
  - field evaporation
  -electromigration





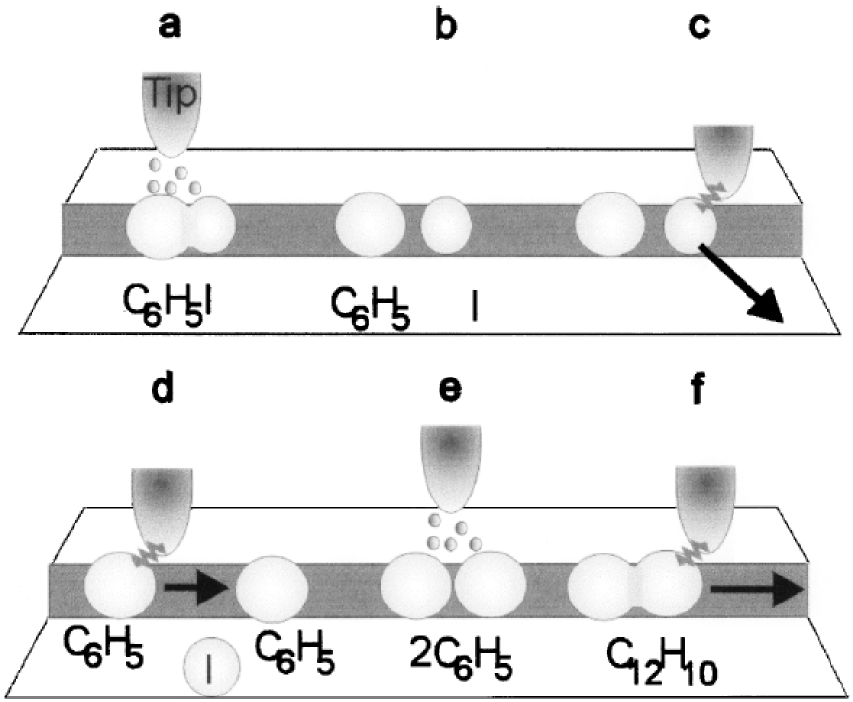


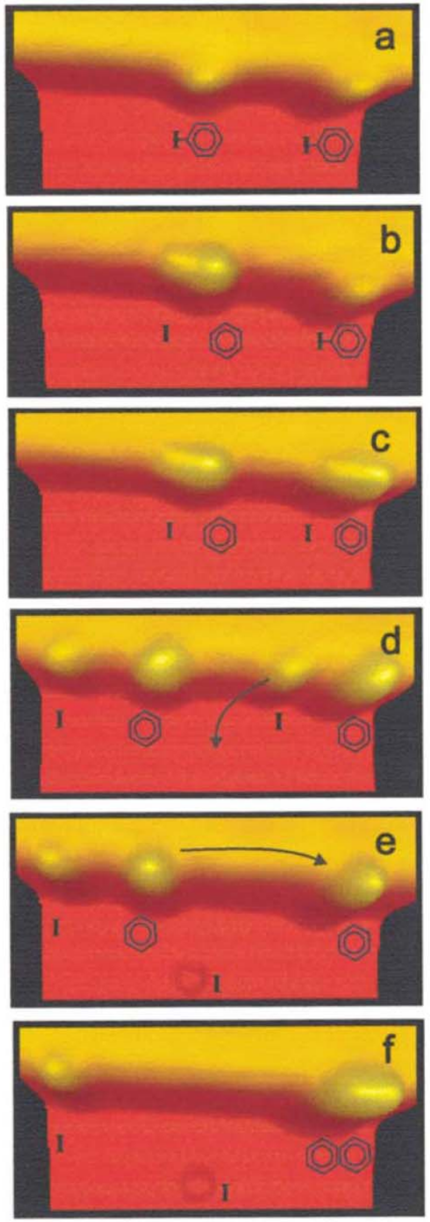
D.E. Eigler, Nature, 344 (1990) 524.

Fabrication of Nano Structure-nanomanipulation

❑ STM

- chemical reaction





S.W. Hla, Phys. Rev. Lett. 85 (2000) 2775.

Fabrication of Nano Structure-nanomanipulation

❑ AFM

- mechanical pushing

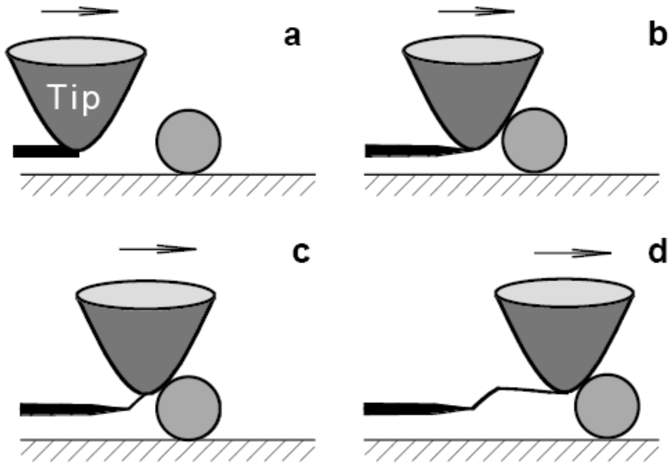


Figure 3. Schematic diagram of the relative motion of the tip and nanoparticle during manipulation. The full heavy line is the path of the tip apex, and the line thickness indicates the tip vibration amplitude.

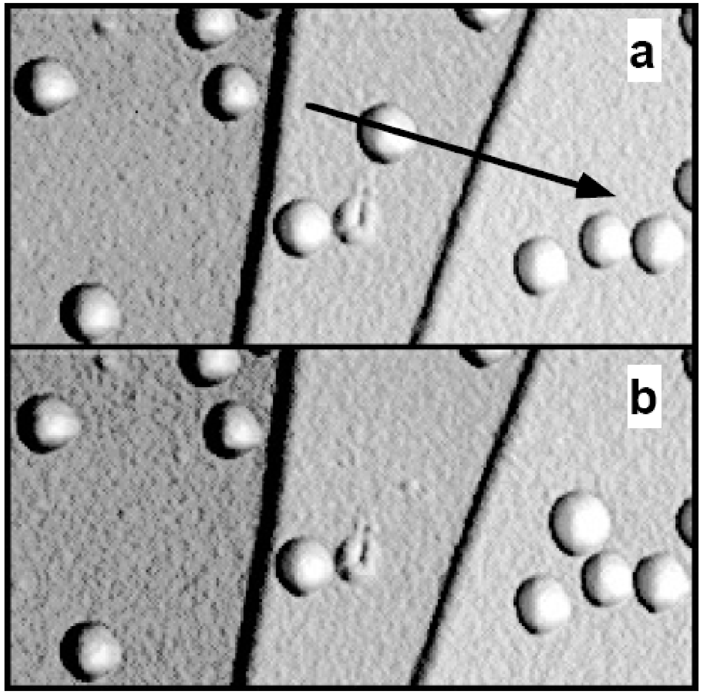


Figure 5. A 30 nm Au particle before (*a*) and after (*b*) being pushed over a 10 nm high step along the direction indicated by the arrow. Image sizes are both 1 × 0.5 μm.

C. Baur, nanotechnology, 9 (1998) 360.

Fabrication of Nano Structure-nanolithography

❑ STM

- field evaporation by bias pulse on Si(111)

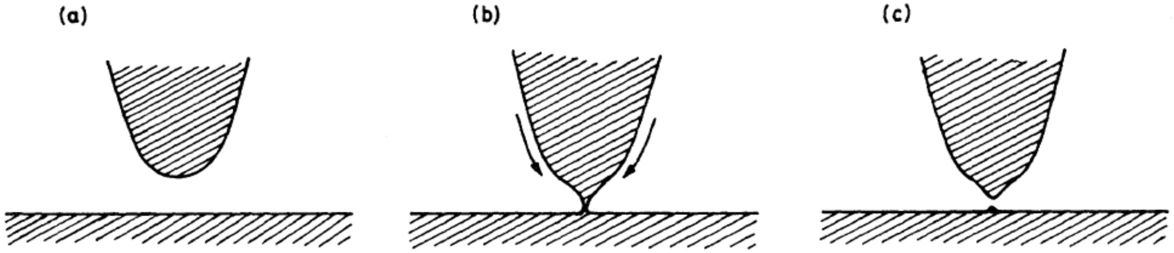


FIG. 5. Diagrams illustrating how piles of metal atoms can be deposited on a sample surface by applying either negative or positive voltage pulses to either the sample or the tip. When a high voltage pulse is applied, field electrons are emitted either from the tip or the sample according to the polarity of the pulse. This electron current will heat up or even melt the tip. Because of the field gradient existing at the tip surface, atoms will migrate from the tip shank to the tip apex either by a directional surface diffusion or by a hydrodynamic flow of atoms, resulted in the formation of a liquidlike-metal cone, which will touch the sample. When the pulse is over and the liquidlike-metal cone cools down, the neck is broken by surface tension leaving a mount of tip atoms on the sample surface.

T.T. Tsong, Phys. Rev. B44 (1991)13703).

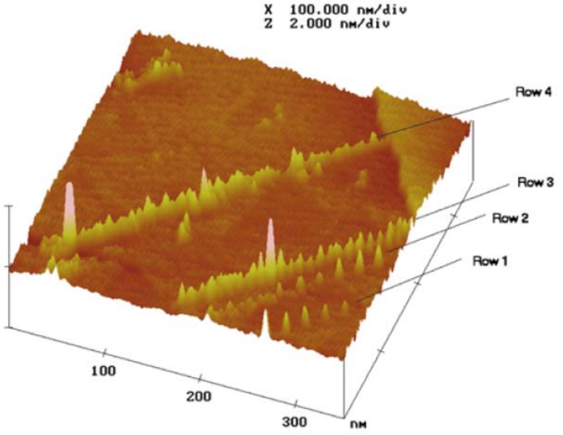


Figure 1. Au nano-dots and lines deposited on a clean stepped Si(111) surface. The distances between adjacent nano-dots are 20, 20, 10 and 5 nm in rows 1, 2, 3 and 4 respectively. Continuous nano-lines have been formed in rows 3 and 4.

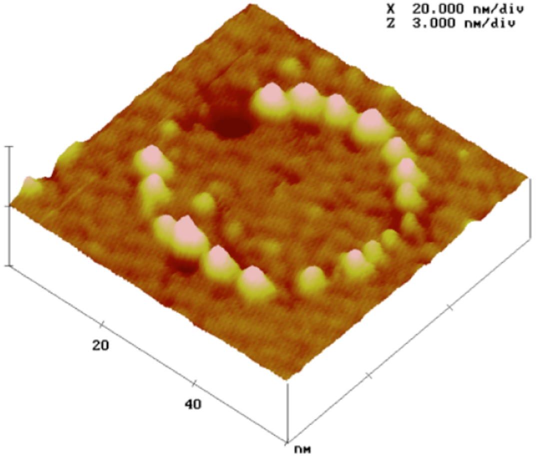


Figure 2. A nano-corral of about 40 nm in diameter formed by Au dots of a few nm in diameter on a clean Si(111) surface. Some clusters are double imaged.

X. Hu, Nanotechnology, 10 (1999) 209.

Fabrication of Nano Structure-nanolithography

❑ AFM

- scratching

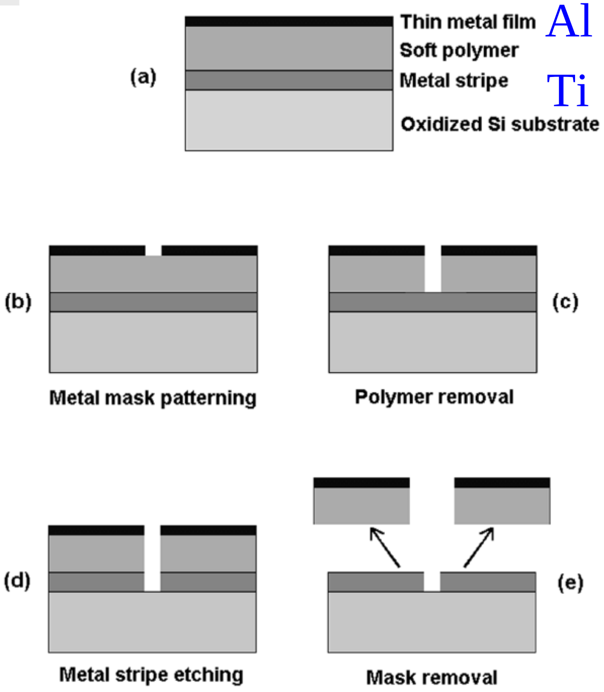
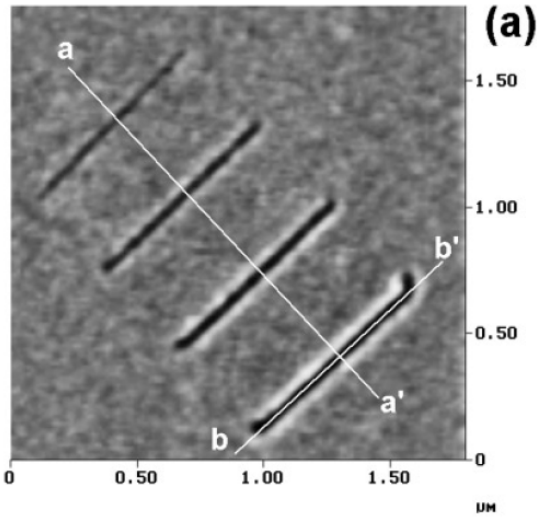
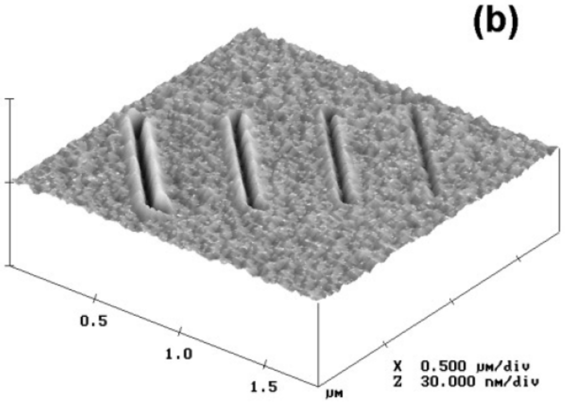
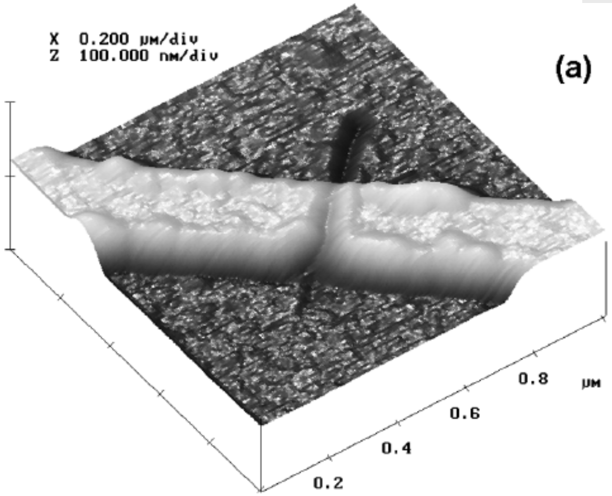
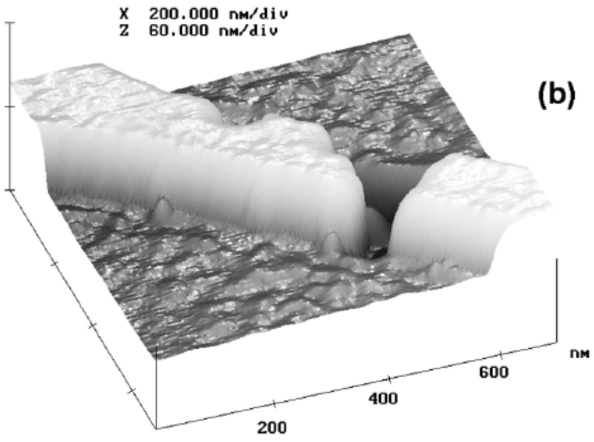


Figure 3. Layout of the sample and the process steps: (*a*) sample multilayer structure; (*b*) thin metal mask patterning; (*c*) polymer removal in plasma oxygen; (*d*) titanium stripe etching; and (*e*) resulting electrodes after sacrificial layers removal.







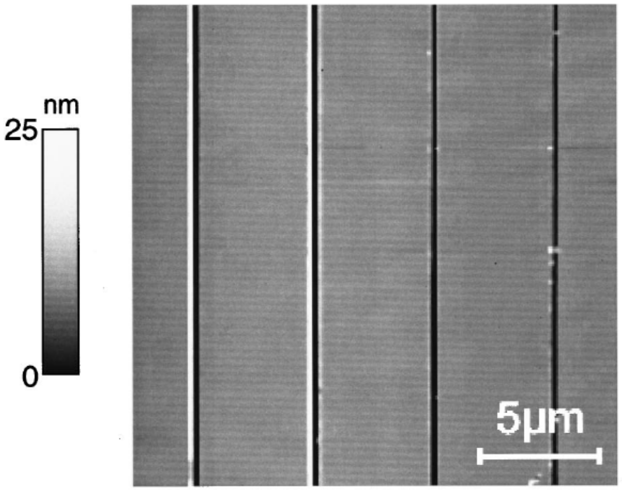


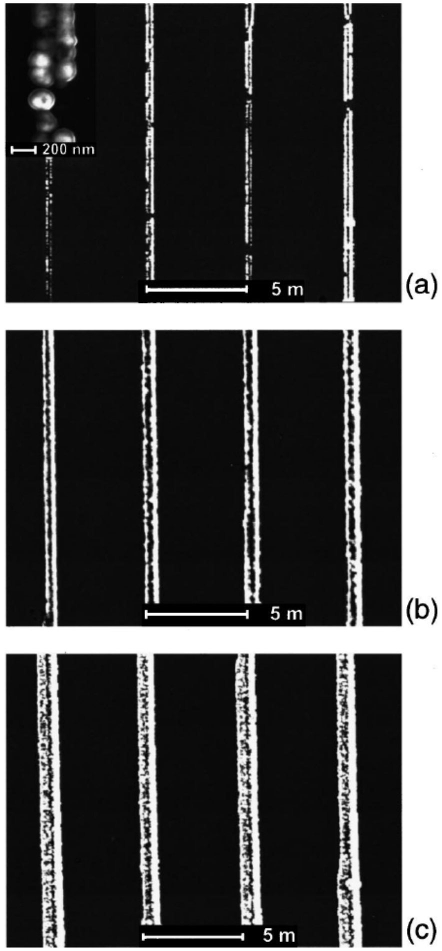
A. Notargiacomo, Nanotechnology, 10 (1999) 458.

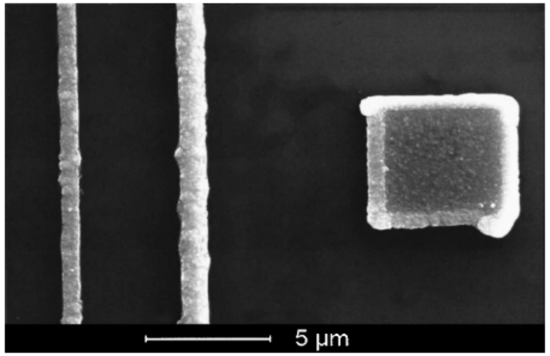
Fabrication of Nano Structure-nanolithography

❑ AFM

- scratching the native oxide covered Si by AFM (diamond-coated tip) and electrodeposition of Cu





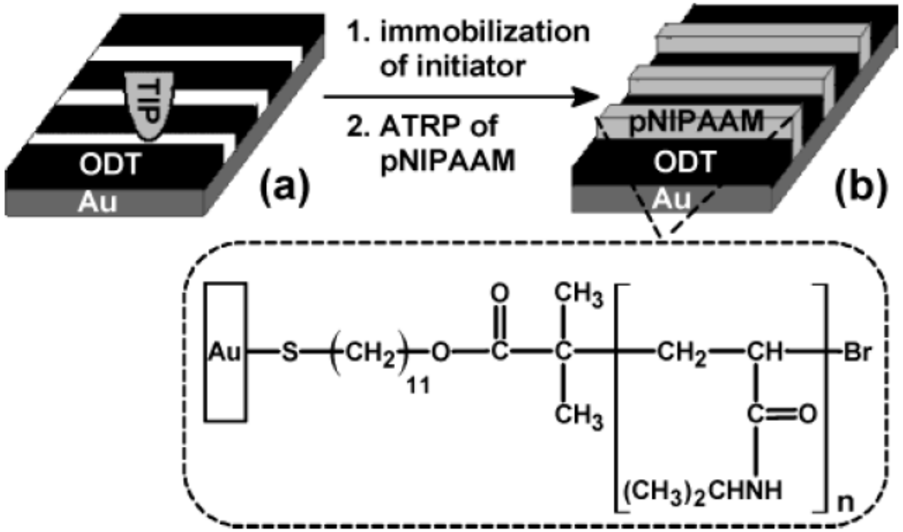


L. Santinacci, Appl. Phys. Lett. 79(2001)1882.

Fabrication of Nano Structure-nanolithography

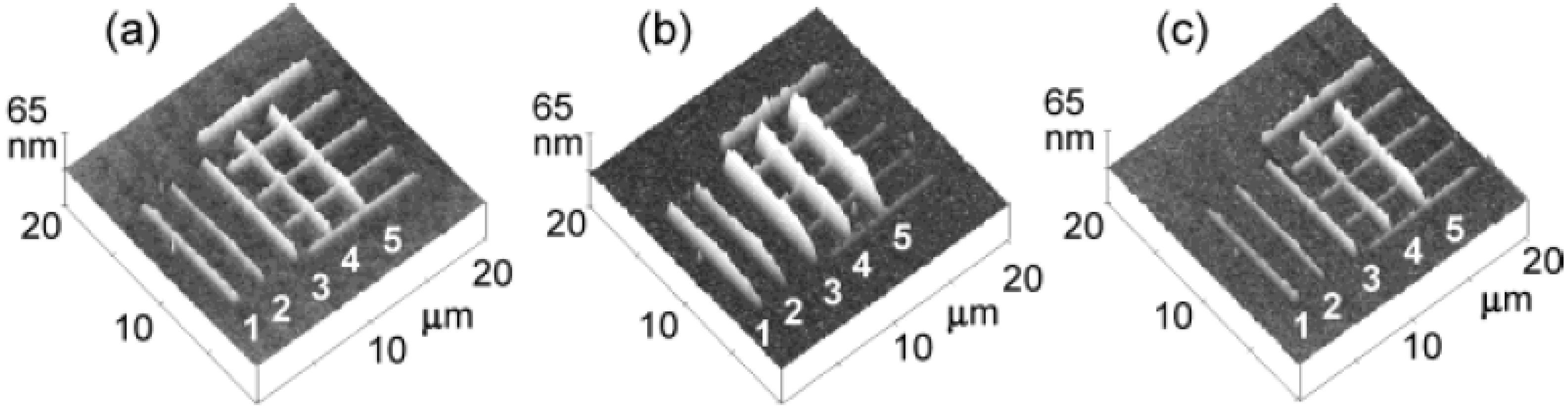
❑ AFM

- nanoshaving by AFM+ surface initiated polymerization



thiol initiator
poly(N-isopropylacrylamide)

M. Kaholek, Nanoletter, 4(2004)373.



Fabrication of Nano Structure-soft lithography

☐ Soft lithography

- a set of non-photolithographic techniques for microfabrication that are based on printing of SAMs and molding of liquid precursors
- reviews

  Y. Xia, Chem. Review, 99, 1823 (1999).
  Y. Xia, Angew. Chem. Int. Ed. 37, 550 (1998).
  Y. Xia, Annu. Rev. Mater. Sci. 28, 153 (1998).
  M. Geissler, Adv. Mater. 16, 1249 (2004).

Fabrication of Nano Structure-soft lithography

❑ Microcontact printing

- use an elastomeric stamp with relief on its surface to generate SAMs on the surface of planar and curved substrate
- SAM- highly ordered molecular assemblies that form spontaneously by chemisorption of functionalized long chain molecules on the surface of appropriate substrate

  ex) alkaneithiolates on Au, Ag, Cu

$$X(CH_2)_nSH + Au^0 \longrightarrow X(CH_2)_nS^-Au^I + 1/2\ H_2$$

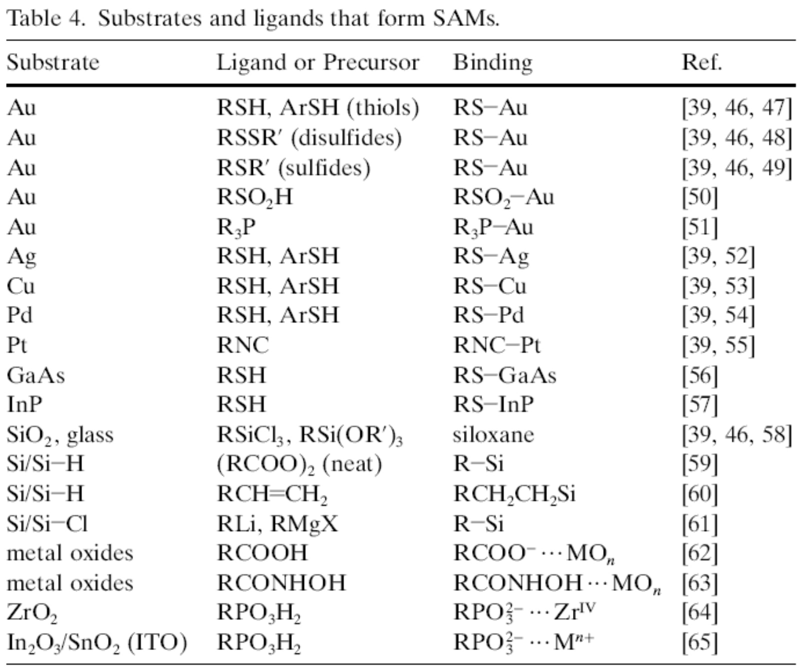
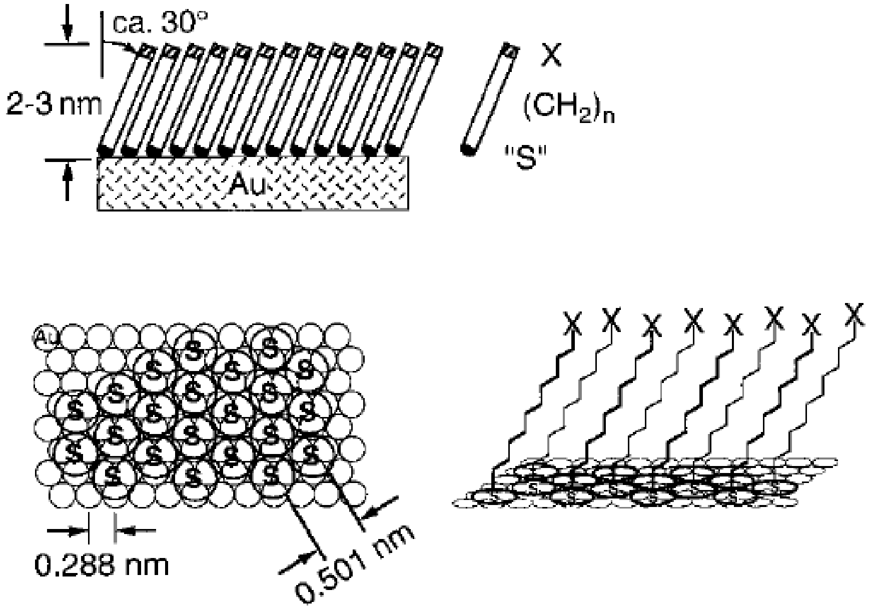


Table 4. Substrates and ligands that form SAMs.

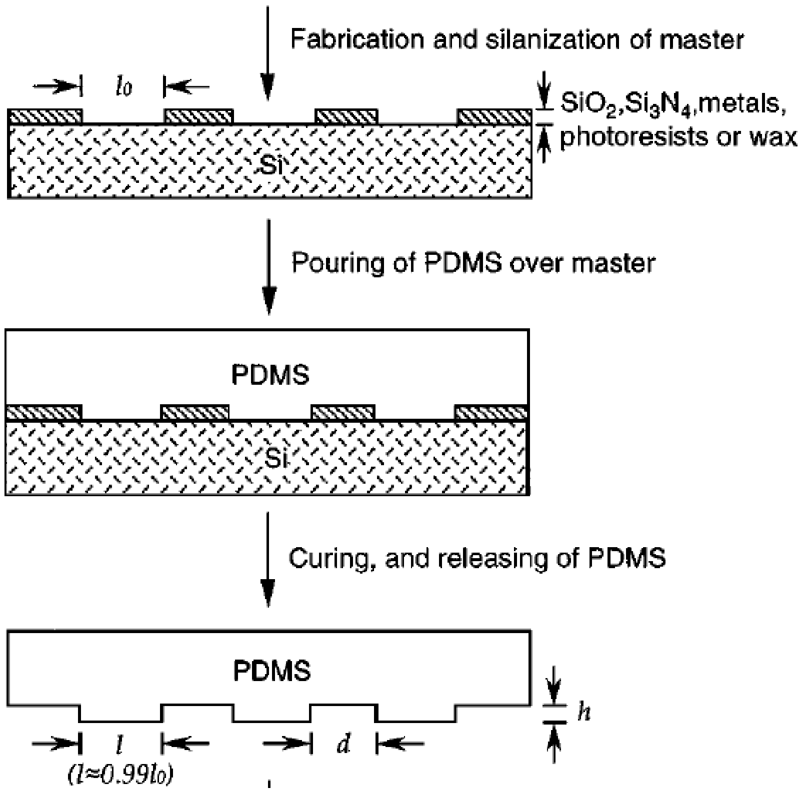
Substrate	Ligand or Precursor	Binding	Ref.
Au	RSH, ArSH (thiols)	RS–Au	[39, 46, 47]
Au	RSSR′ (disulfides)	RS–Au	[39, 46, 48]
Au	RSR′ (sulfides)	RS–Au	[39, 46, 49]
Au	RSO_2H	RSO_2–Au	[50]
Au	R_3P	R_3P–Au	[51]
Ag	RSH, ArSH	RS–Ag	[39, 52]
Cu	RSH, ArSH	RS–Cu	[39, 53]
Pd	RSH, ArSH	RS–Pd	[39, 54]
Pt	RNC	RNC–Pt	[39, 55]
GaAs	RSH	RS–GaAs	[56]
InP	RSH	RS–InP	[57]
SiO_2, glass	$RSiCl_3$, $RSi(OR')_3$	siloxane	[39, 46, 58]
Si/Si–H	$(RCOO)_2$ (neat)	R–Si	[59]
Si/Si–H	$RCH{=}CH_2$	RCH_2CH_2Si	[60]
Si/Si–Cl	RLi, RMgX	R–Si	[61]
metal oxides	RCOOH	$RCOO^- \cdots MO_n$	[62]
metal oxides	RCONHOH	$RCONHOH \cdots MO_n$	[63]
ZrO_2	RPO_3H_2	$RPO_3^{2-} \cdots Zr^{IV}$	[64]
In_2O_3/SnO_2 (ITO)	RPO_3H_2	$RPO_3^{2-} \cdots M^{n+}$	[65]

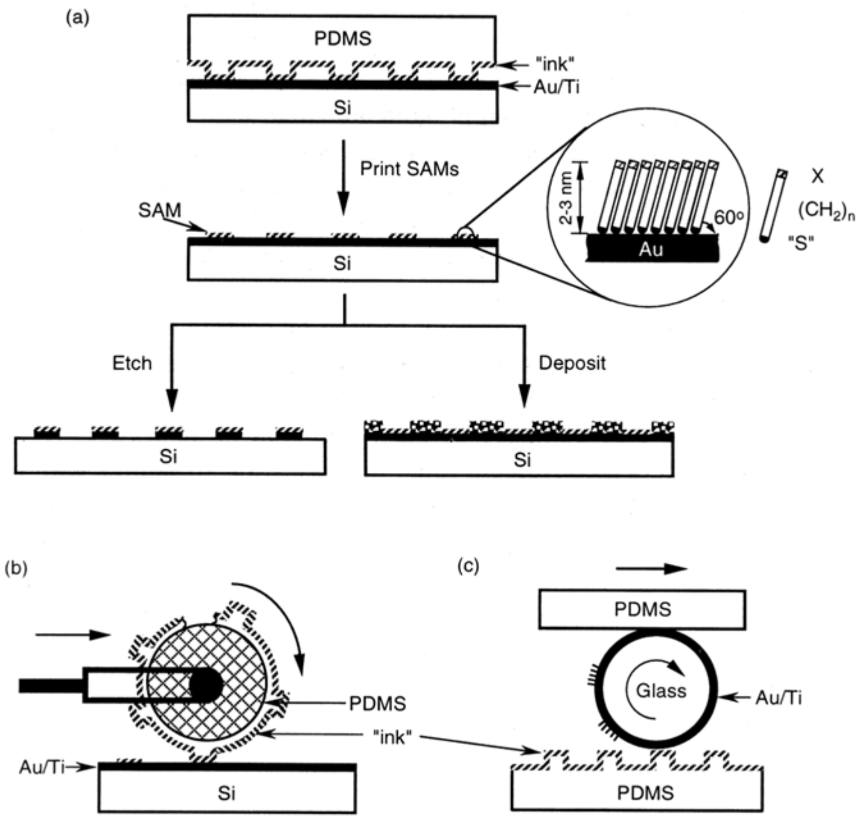


Fabrication of Nano Structure-soft lithography

❑ Microcontact printing

- procedures





Fabrication of Nano Structure-soft lithography

☐ Microcontact printing

- examples

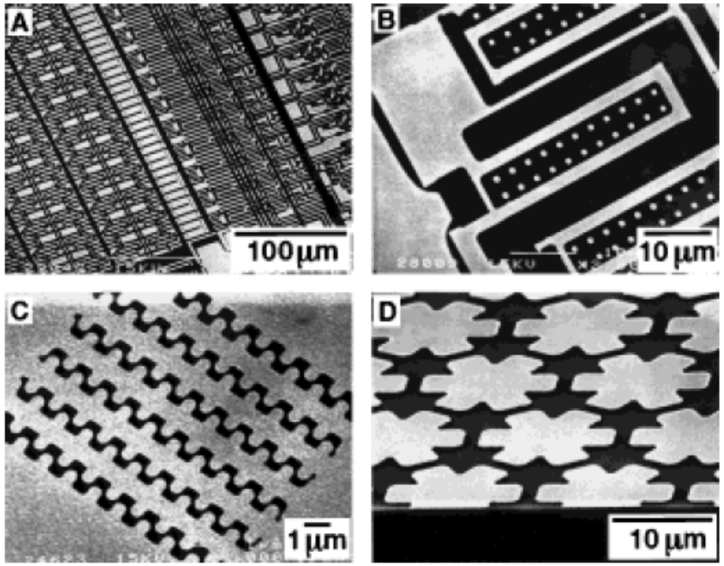


Figure 12. SEM images of test patterns on layers of silver (A, B, C: 50 nm thick; D: 200 nm thick) that were fabricated by µCP with HDT followed by chemical etching in an aqueous solution of ferricyanide. The patterns in A and B were printed with rolling stamps,[147] and those in C and D with planar stamps.[86a] The bright regions represent silver, and the dark regions Si/SiO_2 in which unprotected silver has dissolved.

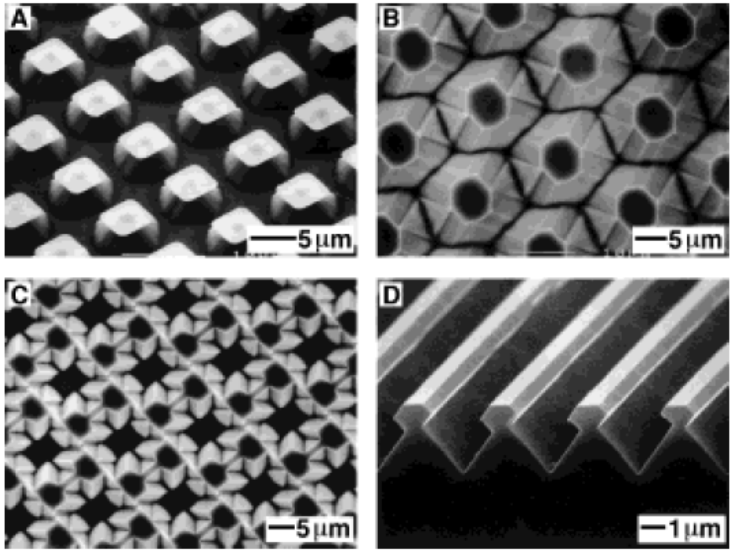
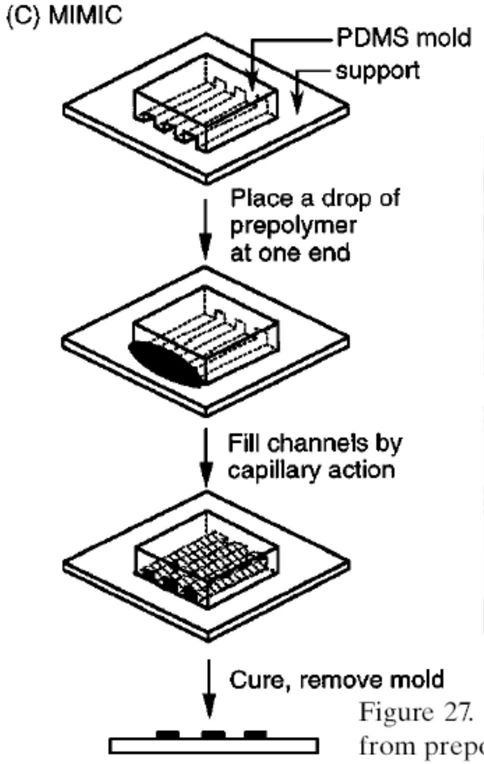


Figure 13. SEM images of silicon structures generated by anisotropic etching of Si(100) with patterned structures of silver or gold as masks.[86a, 120] The metal mask is still on the surface in A; it has been removed by immersion in aqua regia for B, C, and D. The structure in D was fabricated by a combination of shadow evaporation and anisotropic etching of Si(100).[153]

Fabrication of Nano Structure-soft lithography

❑ Molding

- micromolding in capillary



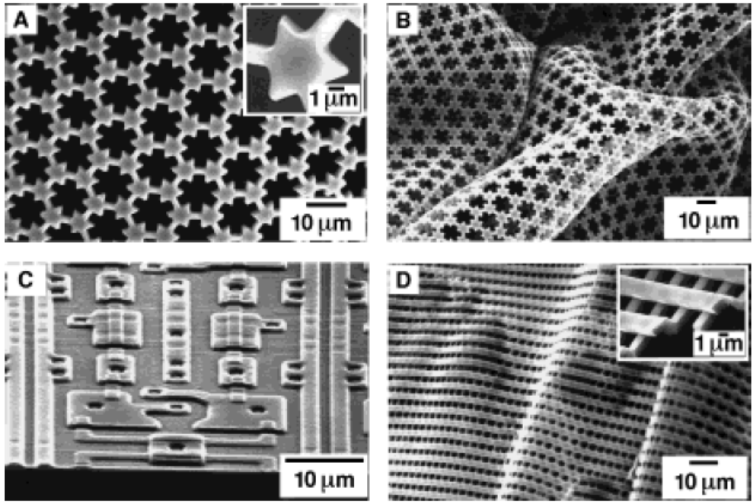


Figure 27. SEM images of polymeric microstructures fabricated by MIMIC from prepolymer of polyacrylate (A, C) and polyurethane (B, D) without solvents.[37, 179] The structures in B and D are freestanding; the buckling occurred during sample preparation and demonstrated their strength.

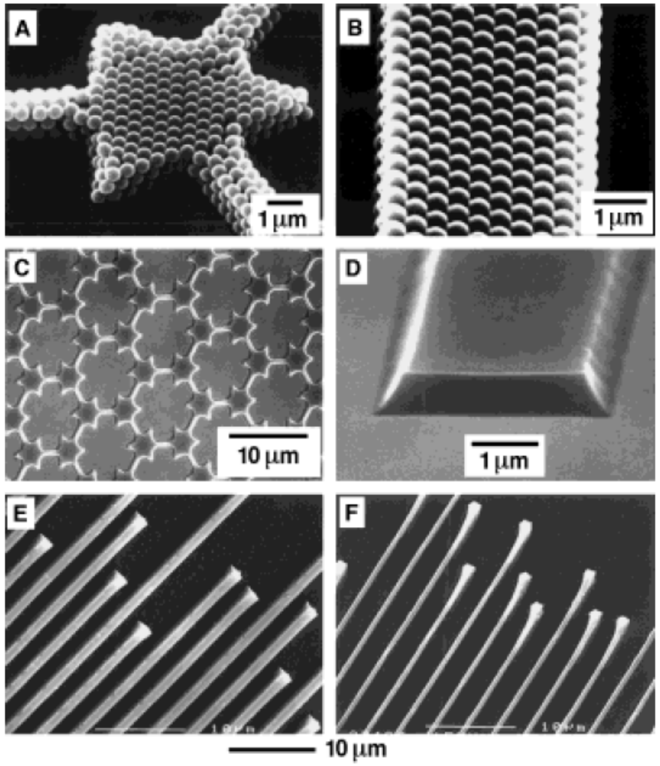
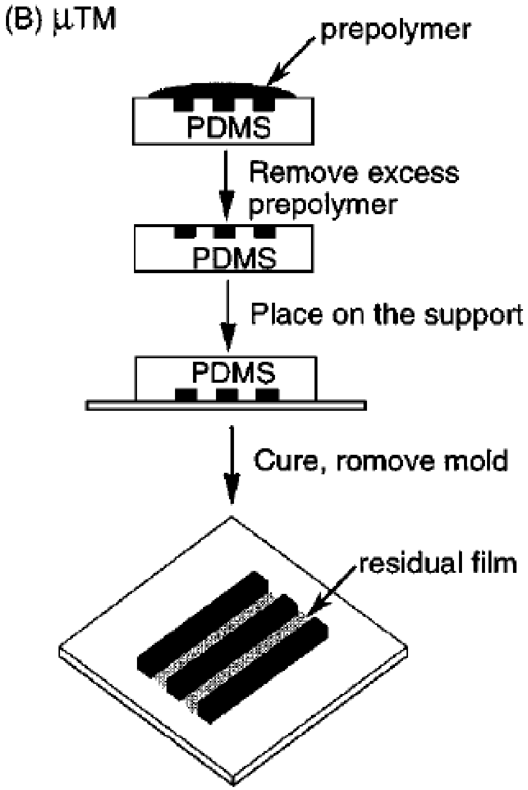


Figure 28. SEM images of patterned microstructures of A, B) polymer beads,[183] C, D) polyaniline emeraldine HCl salt,[182] and E, F) zirconium oxide[180] fabricated by MIMIC from their solutions in water, *N*-methyl-2-pyrrolidone, and ethanol, respectively. The crystallization of the polymer

Fabrication of Nano Structure-soft lithography

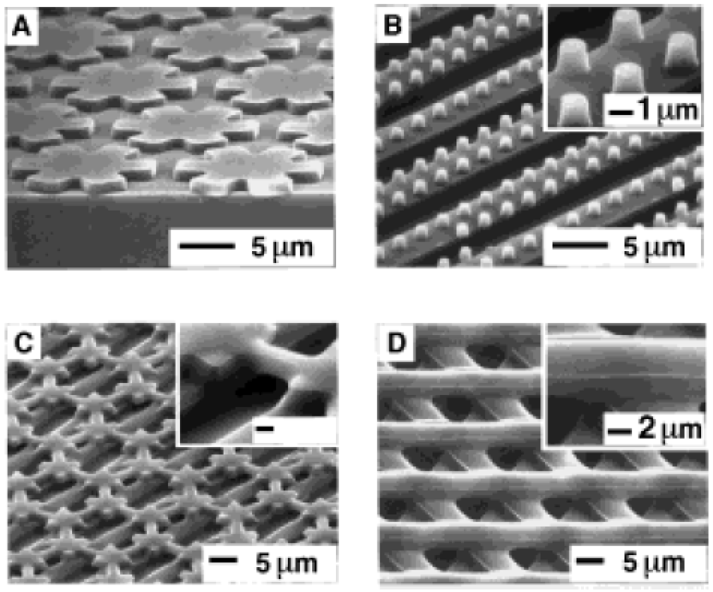
❑ Molding

- microtransfer molding



PU on silver

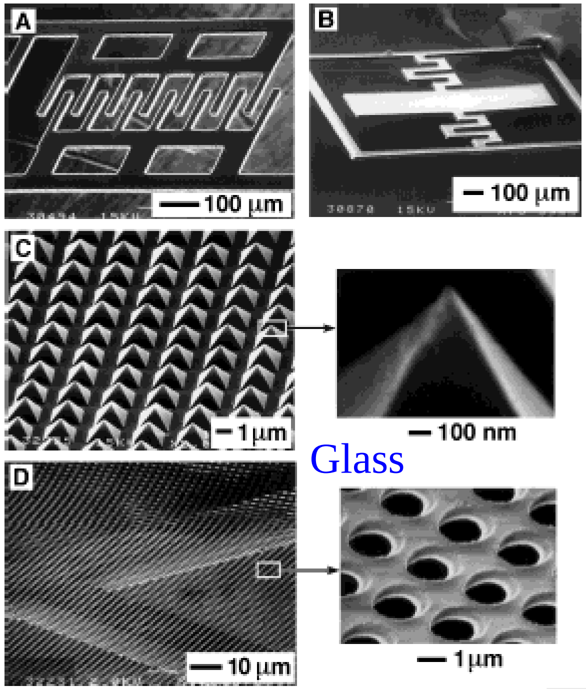
Epoxy on glass



Epoxy on glass

Epoxy on glass

Glassy carbon

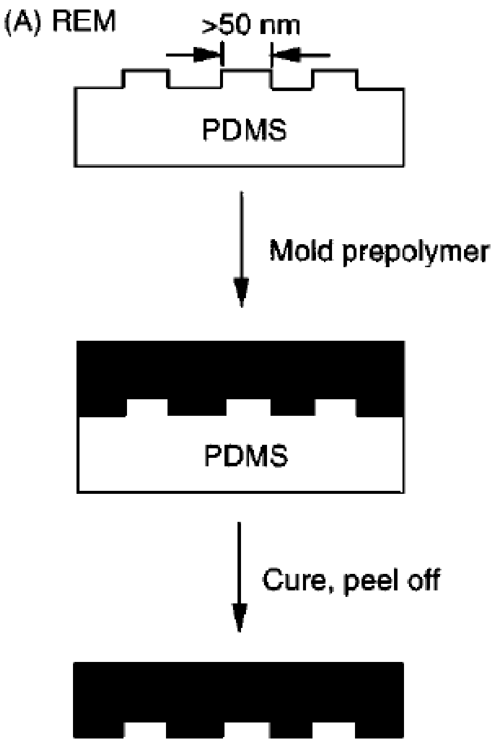


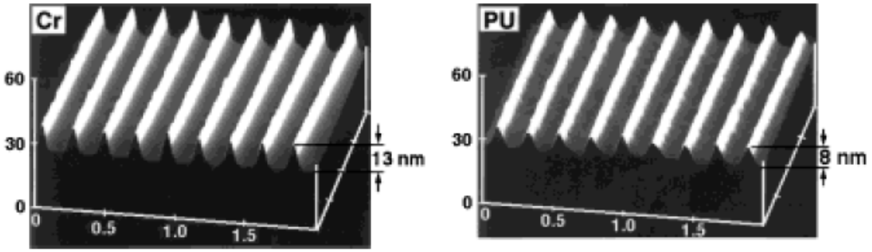
Glass

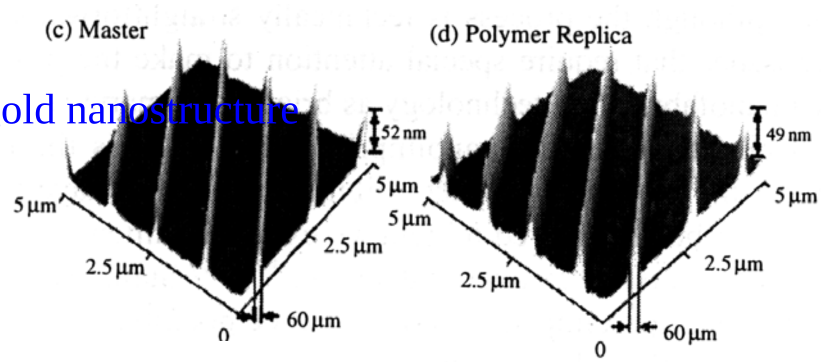
Fabrication of Nano Structure-soft lithography

❑ Molding

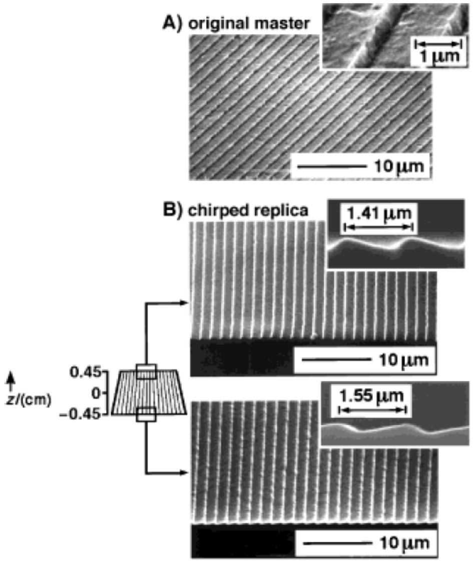
- replica molding

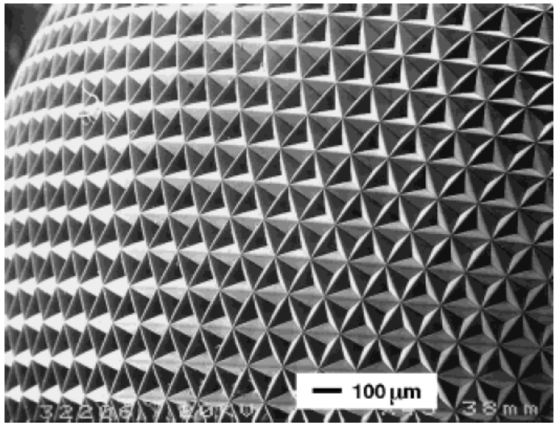






gold nanostructure

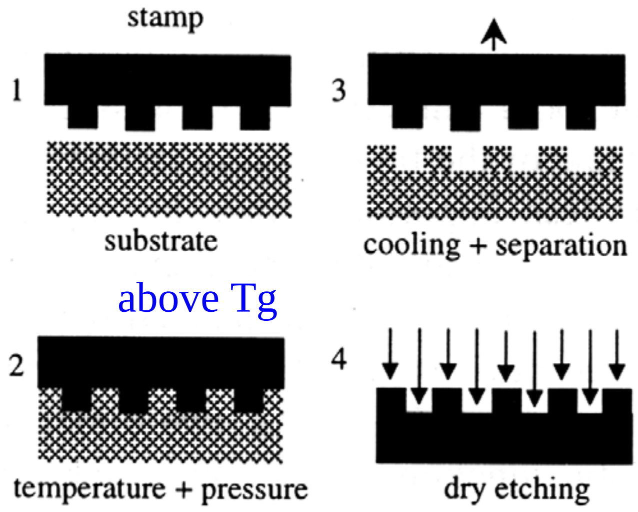




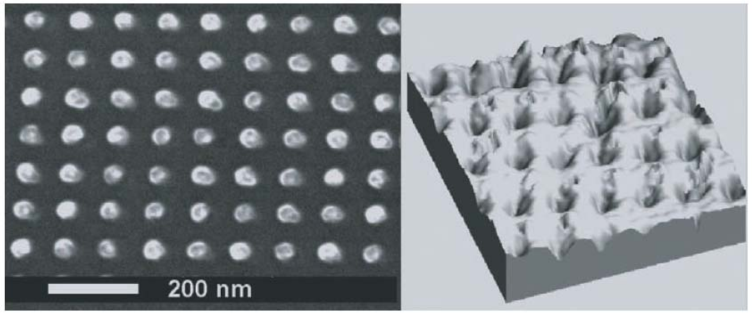
Fabrication of Nano Structure-soft lithography

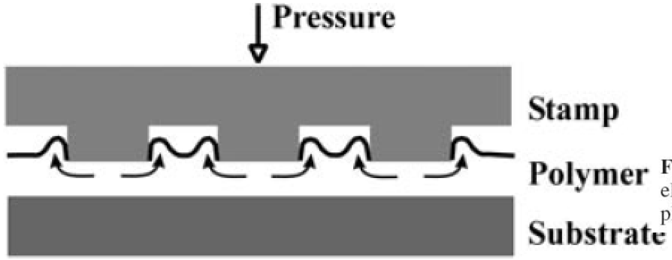
☐ Nanoimprint

-



Cr stamp PMMA





Cr mask

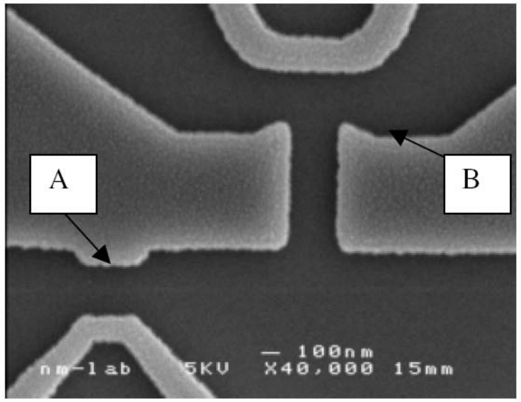


Figure 1. A top-view SEM image of the SiO$_2$/Si stamp with an electron waveguide area (A) and a TBJ area (B). The dark part is the plasma-etched region.

ZEP520A7 resist

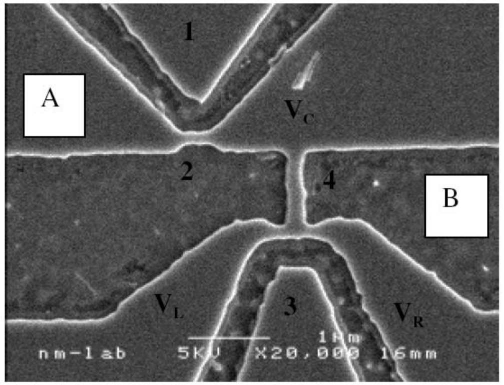


Figure 2. The final device structure in InP/GaInAs with electron waveguide (A) and TBJ (B) areas after NIL, 60 s ashing and wet etching. Electrode (1) is a side gate used to control electron waveguide (2); gate (3) controls the TBJ (4) device. The voltages on the TBJ electrodes are denoted V_L, V_R and V_C.

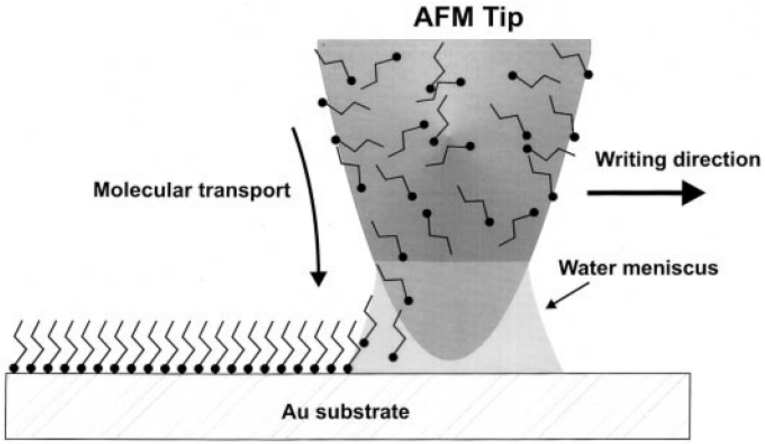
S. Zankovych, Nanotechnology, 12 (2001) 91.

I. Maximov, 13 (2002) 666.

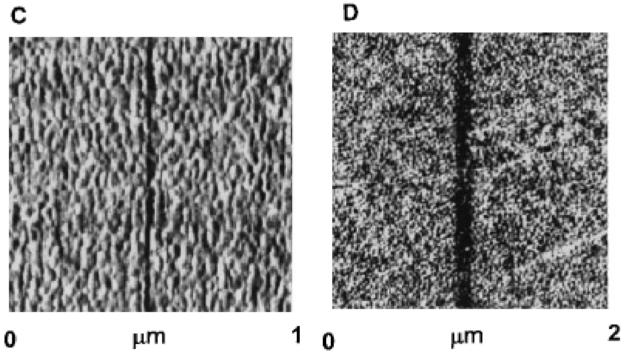
Fabrication of Nano Structure-soft lithography

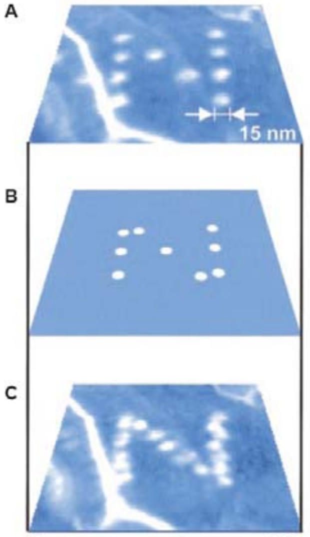
❑ Dip-pen lithography

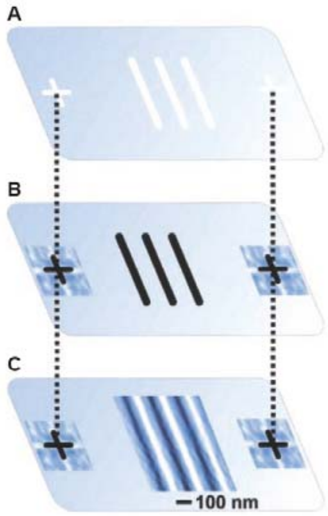
- direct writing based on AFM and works under ambient conditions
- chemisorption acts as a driving force for moving the molecules from AFM tip to the substrate via water filled capillary when the tip is scanned across a substrate

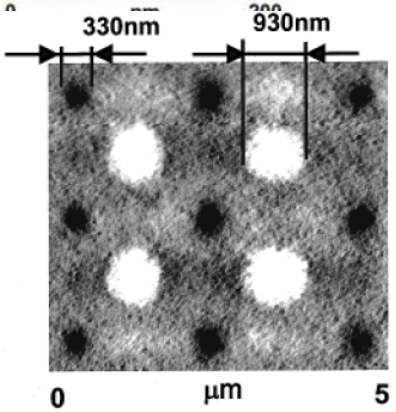


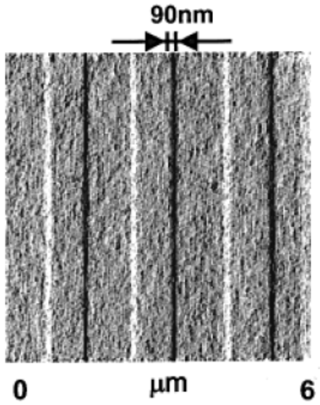
ODT on Au(111)/mica











R.D. Piner, Science 283 (1999) 661.

Fabrication of Nano Structure-soft lithography

☐ Dip-pen lithography

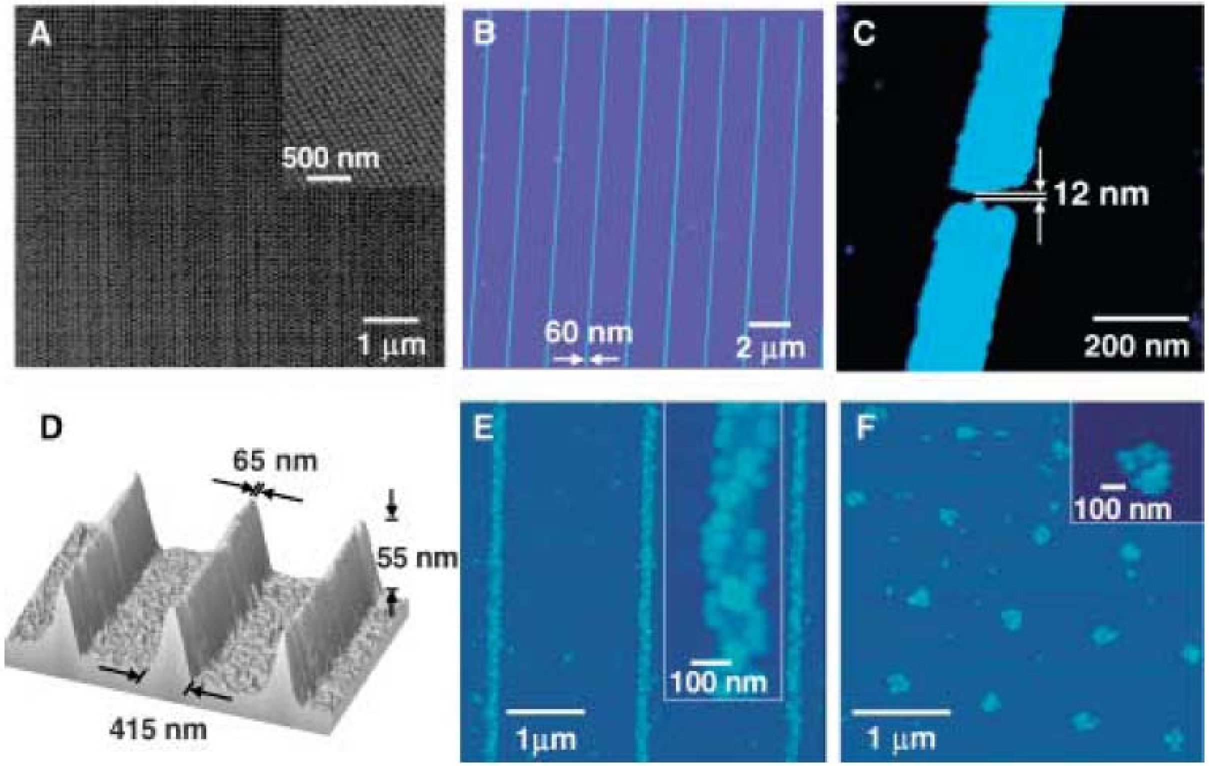


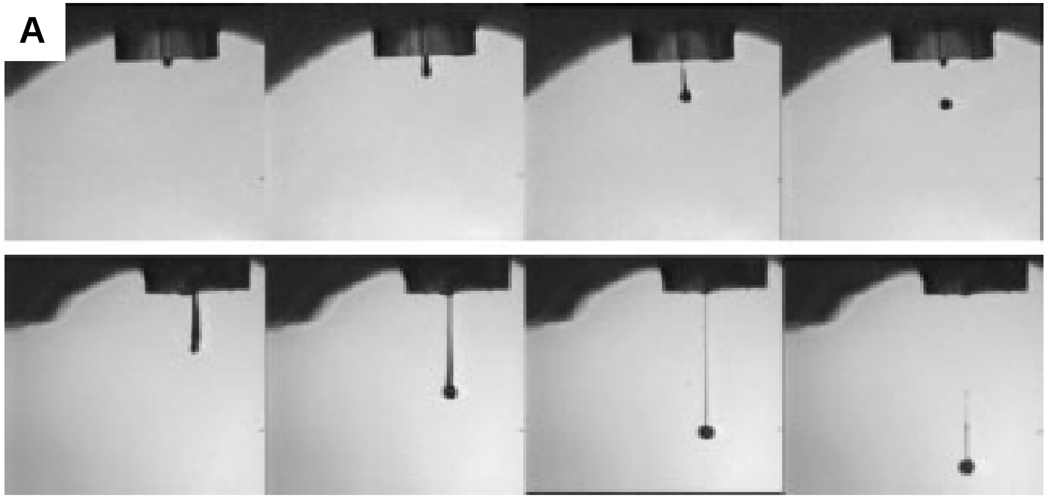
Figure 12. Etched nanostructures. A) SEM image of 45-nm gold nanodots (reproduced with permission from ref. [6]), B) TM-AFM image of 60-nm gold nanolines (reproduced with permission from ref. [77]) and C) 12-nm gold nanogap (reproduced with permission from ref. [6]) on a Si/SiO$_x$ surface. D) 3D Si(100) nanostructures[4]). TM-AFM image of DNA-modified line (E), and dot (F), features after hybridization with complementary DNA-modified nanoparticles; insert: high-resolution TM-AFM images.[5]

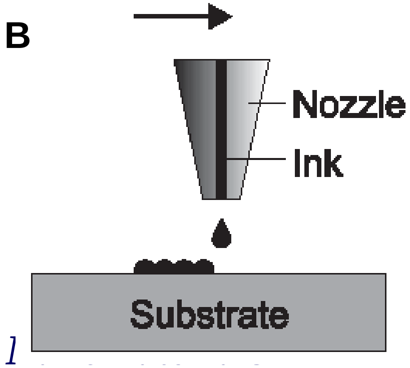
D.S. Ginger, Angew. Chem. Int. Ed. 43(2004) 30.

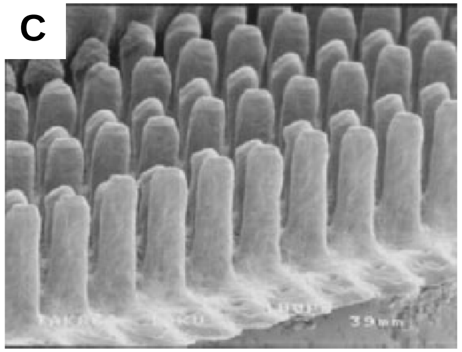
Fabrication of Nano Structure-soft lithography

❑ Ink Jet Printing

- an attractive technique for depositing materials on surfaces with a good spatial control







A) Droplet during inkjet printing

B) Patterning on a substrate

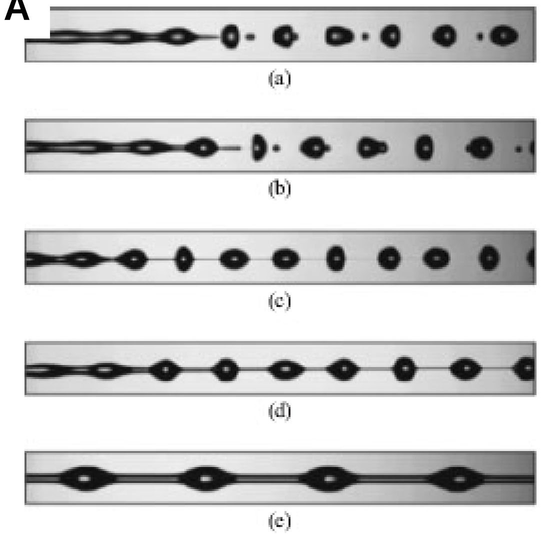
C) Pillar formation of
lead zirconium titanate

B-J de Gans, Adv. Mater. 16 (2004) 203.

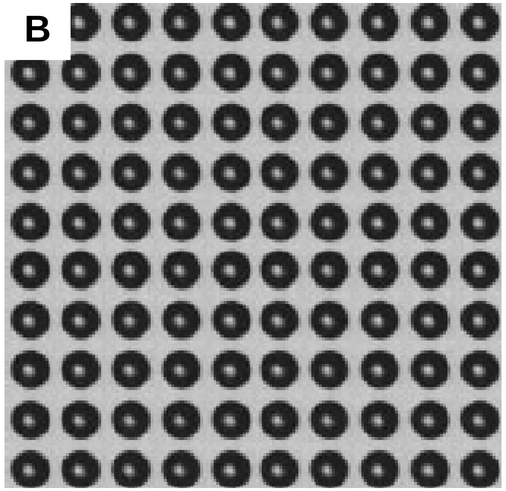
Fabrication of Nano Structure-soft lithography

❑ Ink Jet Printing

A



B



C

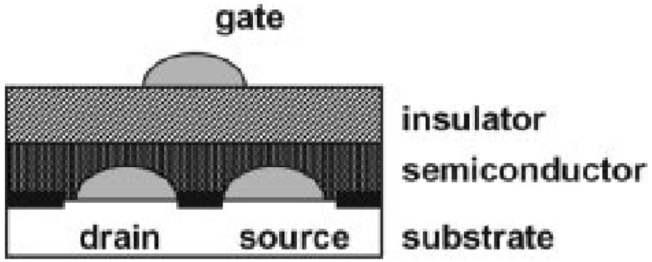


Figure 5. Schematic picture of inkjet printed all-polymer thin film transistor, as constructed by Sirringhaus et al. [41]. Source and drain electrode, consisting of PEDOT/PPS are inkjet printed on a pre-patterned surface. Two spin-coated layers of semiconducting and insulating polymer respectively cover the electrodes. Finally the gate electrode is printed on top.

A) Dependence on the viscosity of solution

B) Patterning on a substrate

C) transistor fabrication (gate) using ink jet printing

B-J de Gans, Adv. Mater. 16 (2004) 203.