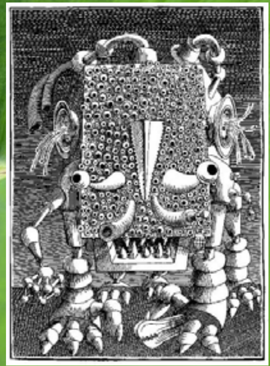
Do czego służą studnie, druty, kropki kwantowe?



Jacek.Szczytko@fuw.edu.pl Wydział Fizyki UW

Jak TO działa? http://www.fuw.edu.pl/~szczytko/

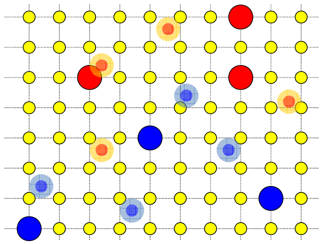
Google: **Jacek Szczytko**
Login: **student**
Hasło: *******

Półprzewodniki

II	III	IV	V	VI
Be	B	C	N	O
Mg	Al	Si	P	S
Zn	Ga	Ge	As	Se
Cd	In	Sn	Sb	Te

Nośniki:
dziury +
elektrony -

Domieszki:
Akceptory (typ p)
Donory (typ n)



Grupa IV: diament, Si, Ge
Grupy III-V: GaAs, AlAs, InSb, InAs...
Grupy II-VI: ZnSe, CdTe, ZnO, SdS...

Heterostruktury półprzewodnikowe

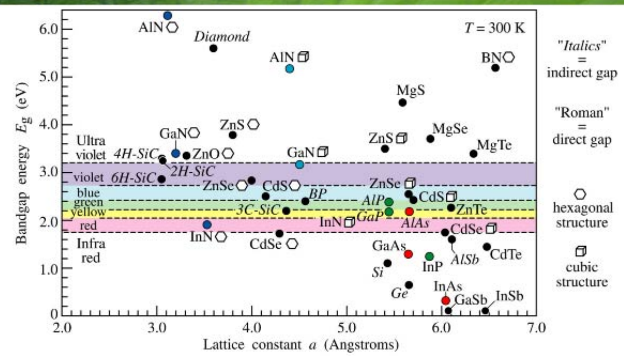
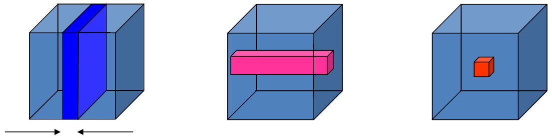


Fig. 11.4. Room-temperature bandgap energy versus lattice constant of common elemental and binary compound semiconductors.

Struktury niskowymiarowe

Low-dimensional Semiconductor Systems

Studnie kwantowe — Druty kwantowe — Kropki kwantowe



t

2D — 1D — "0D"

Dyskretna struktura elektronowa

Hubert J. Krenner

Jak się robi heterostruktury?

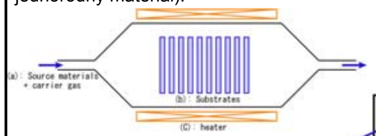
Liquid-phase (LPE)
wzrost z fazy ciekłej na podłożu w temperaturach niższych od temperatury topnienia hodowanego materiału. Półprzewodnik jest rozpuszczony w cieczy innego materiału, wzrost w warunkach bliskich równowagi roztworu i depozycji; prędkości wzrostu 0.1 to 1 μm/min.

Vapor-phase (VPE, CVD)
wzrost z fazy gazowej dzięki reakcjom chemicznym prekursorów na powierzchni, często dzielony ze względu na źródłowe gazy na wodorkową VPE i metalorganiczną VPE (MOCVD); prędkości wzrostu >10 -20 nm/min.

Molecular-beam (MBE)
Materiał źródłowy podgrzewany w komórkach produkuje strumień cząsteczek. W wysokiej próżni (10^{-8} Pa) cząsteczki docierają do podłoża i osadzają się na nim; prędkości wzrostu < 1 monowarstwa/s (1 μm/h).

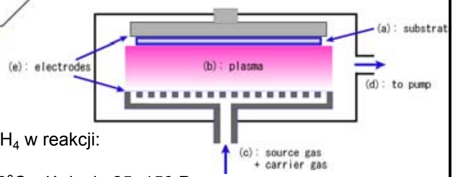
Jak się robi heterostruktury?

Chemical Vapor Deposition (CVD) – proces chemiczny, w którym do obszaru, gdzie znajduje się podłoże doprowadzone są jeden lub więcej prekursorów reagujących z podłożem w wyniku czego powstaje pożądany materiał. Jest to często stowarzyszone z lotnymi produktami, które usuwane są strumieniem gazu przepływającego przez komorę. (Si, SiC, SiN, dielektryki, diament syntetyczny).
Proces może przebiegać w ciśnieniu normalnym lub obniżonym (wolniej, bardziej jednorodny materiał).



Hot-wall thermal CVD

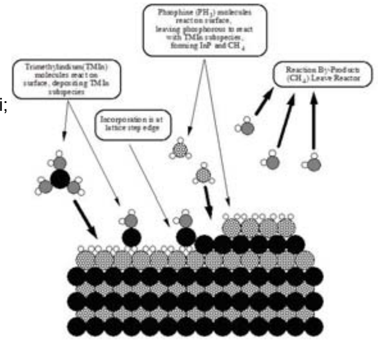
Plasma assisted CVD



Krzem polikrystaliczny z silanu SiH_4 w reakcji:
$SiH_4 \rightarrow Si + 2 H_2$
LPCVD, temperatura 600 and 650^{0}C, ciśnienie 25 -150 Pa, prędkość wzrostu 10 -20 nm/min.

Jak się robi heterostruktury?

Metalorganic chemical vapor deposition (MOCVD) – proces CVD reakcji chemicznych na powierzchni z zastosowaniem związków organicznych, metalorganicznych oraz wodorków metali; zachodzi z gazu pod obniżonym ciśnieniem (2-100 kPa);
np. InP z trymetylu indu $In(CH_3)_3$ i fosfinu PH_3;
główna metoda dla produkcji diod, diod laserowych, złącz fotowoltaicznych



$In(CH_3)_{3gas}+PH_{3gas}$

$\rightarrow InP_{solid}+3CH_{4gas}$

Jak się robi heterostruktury?

Metalorganic chemical vapor deposition (MOCVD) –

TurboDisc MaxBright M GaN MOCVD Multi-Reactor System

Jak się robi heterostruktury?

TurboDisc K465i Animation

Jak się robi heterostruktury?

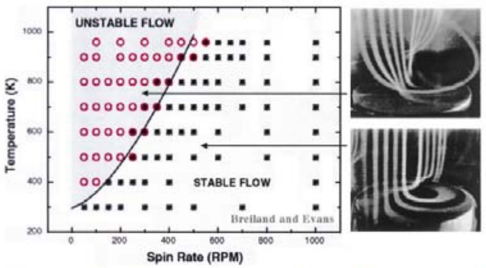
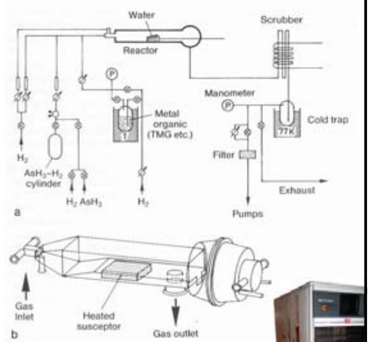


Fig. 10. Plot of the results of flow visualization experiments for a heated, spinning disk. Asterisks indicate that the flow is stable with a steady-state, fixed pattern, as illustrated in the lower right photo. Open circles indicate unstable, time-dependent flow patterns, as illustrated in the upper right photo. The transition from unstable to stable flow is characterized by the mixed convection parameter (MCP) defined by Eq. (27).

Organometallic vapor phase epitaxy (OMVPE) Materials Science and Engineering, R24 (1999) 241-274

Jak się robi heterostruktury?

Podłoże umieszczone na podgrzewanym piecykiem indukcyjnym RF graficie wewnątrz komory reakcyjnej. Typowe temperatury 500°C do 800°C. Wzrost w atmosferze wodoru i ciśnieniu 100 - 700 Torr. Prekursory reagują się w kontakcie z gorącym podłożem i tworzą warstwę. Prekursory grupy V: AsH_3 (arsin), PH_3 (fosfin), grupy III: $Ga(CH_3)_3$ Trimethylgallium (TMG), $Al(CH_3)_3$ Trimethylaluminium (TMA), $In(CH_3)_3$ trimethylindium (TMI), Domieszkowanie: SiH_4 Silane, $Zn(C_2H_5)_2$ Diethylzinc (DEZ).

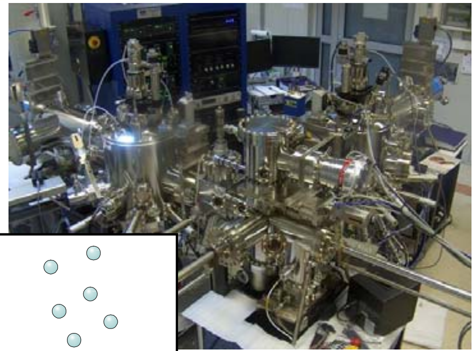


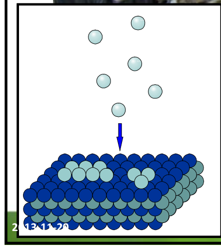
Jak się robi heterostruktury?

Reaktor Metal-Organic Chemical Vapour Epitaxy (MOCVD) w Zakładzie Fizyki Ciała Stałego

Heterostruktury GaInSb, AlGaInAs and AlGaN.

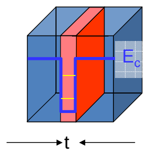
Jak się robi heterostruktury?

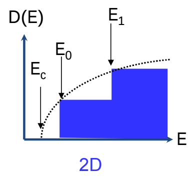




MBE→ Osadzanie z atomową precyzją warstw o różnym składzie lub domieszkowaniu

Quantum Well

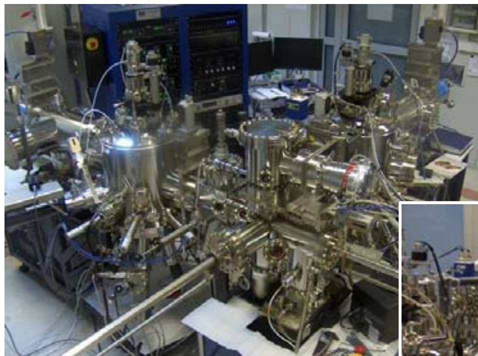




Hubert J. Krenner

Jak się robi heterostruktury?

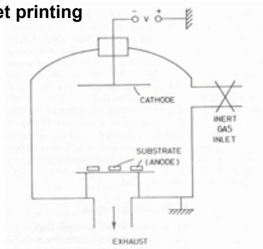
Jak się robi heterostruktury?



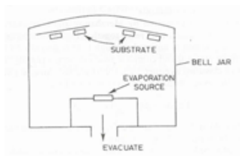
MBE na Wydziale Fizyki UW

Jak się robi heterostruktury?

W dzisiejszych dla otrzymywania cienkich warstw czasach często stosuje się również tanie technologie:
- elektrochemiczne (elektrolityczne nakładanie metali, elektrolityczne utlenianie),
- sputteringowe
- naparowywania warstw.
- ink-jet printing



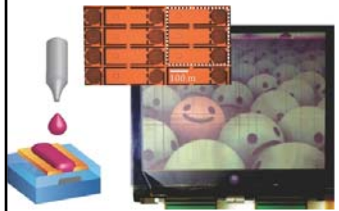
Sputtering katodowy
obniżone ciśnienie 10^{-1}-10^{-2} Torr gazu obojętnego
przy napięcie kilkunastu kV jony dodatnie wybijają materiał katody i osadzają go na m.in. materiale podłożowym



Naparowywanie warstw
w próżni $<10^{-6}$ Torr materiał źródłowy jest zamieniany w fazę gazową przez podgrzanie lub bombardowanie i deponuje się na m.in. materiale podłożowym

Jak się robi heterostruktury?

W dzisiejszych dla otrzymywania cienkich warstw czasach często stosuje się również tanie technologie:
- elektrochemiczne (elektrolityczne nakładanie metali, elektrolityczne utlenianie),
- sputteringowe
- naparowywania warstw.
- ink-jet printing



Reliable and Uniform Thin-Film Transistor Arrays Based on Inkjet-Printed Polymer Semiconductors for Full Color Reflective Displays

Jiyoul Lee, Do Hwan Kim, Joo-Young Kim, Byungwook Yoo, Jong Won Chung, Jeong-Il Park, Bang-Lin Lee, Ji Young Jung, Joon Seok Park, Bonwon Koo, Seongil Im,* Jung Woo Kim, Byungkwon Song, Myung-Hoon Jung, Jae Eun Jang, Yong Wan Jin, and Sang-Yoon Lee*

polymer light-emitting-diode (PLED)

Jak się robi heterostruktury?

- ink-jet printing

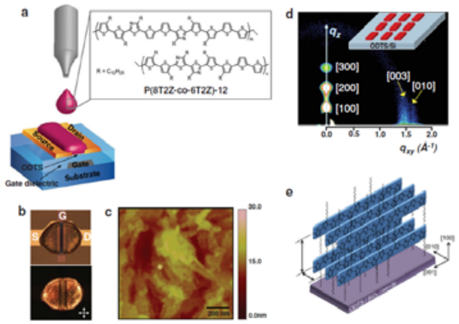


Figure 1. a) Inkjet printing scheme of OTFT and molecular design for polymer semiconductor **P(8T2Z-co-6T2Z)-12** with charge-transfer moieties used in this system. b) Optical vs. polarized microscopy of the inkjet-printed OTFT device. c) Atomic force microscopy image of active channel area of the printed OTFT (right). d) Molecular packing and orientation of inkjet-printed **P(8T2Z-co-6T2Z)-12** films characterized by 2D-GIXD. Film was post-annealed at 150 °C on ODTS treated SiO_2 gate dielectrics. e) Schematic illustration of molecular ordering in inkjet-printed **P(8T2Z-co-6T2Z)-12** polymer semiconductor film.

Jak się robi heterostruktury?

- ink-jet printing

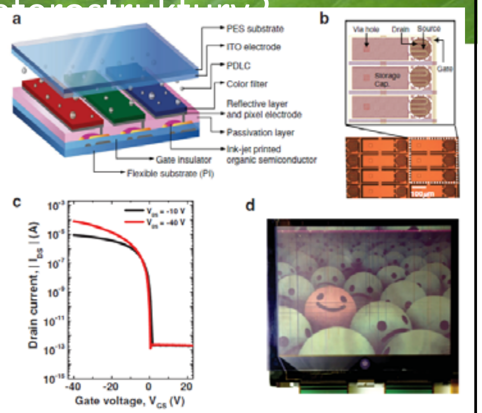


Figure 4. a) Schematic 3-dimensional view of one PDLC display pixel including OTFT drivers for red, green, and blue color display. b) Pixel array photos taken from optical microscopy, along with detailed scheme of one pixel that contains storage capacitors and three TFTs with interdigitized channels. c) Our TFTs display decent transfer characteristics with high mobility even after completion of all the backplane processes. d) 4.8-inch QVGA color reflective PDLC Display driven by inkjet-printed OTFTs.

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IR Detectors - Comparison Table
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Accessories
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mars.jpl.nasa.gov/msl/
Rover
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View of Curiosity's First Scoop Also Shows Bright Object
This image from the right Mast Camera (Mastcam) of NASA's Mars rover Curiosity shows a scoop full of sand and dust lifted by the rover's first use of the scoop on its robotic arm. More >
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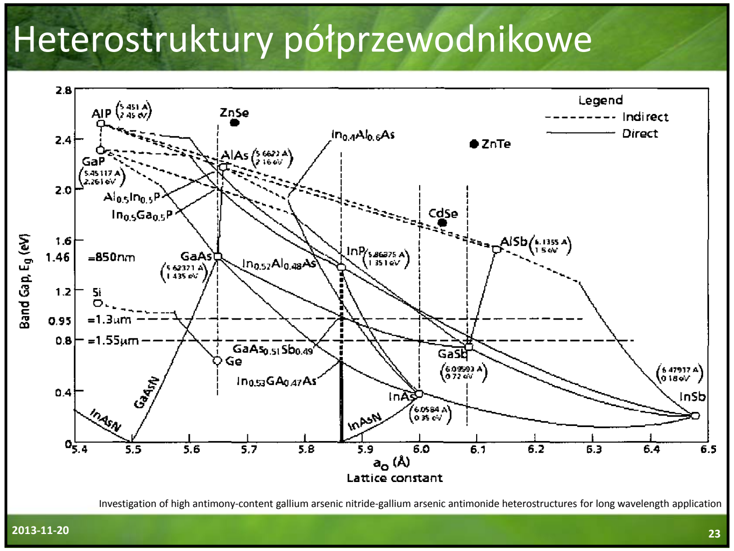
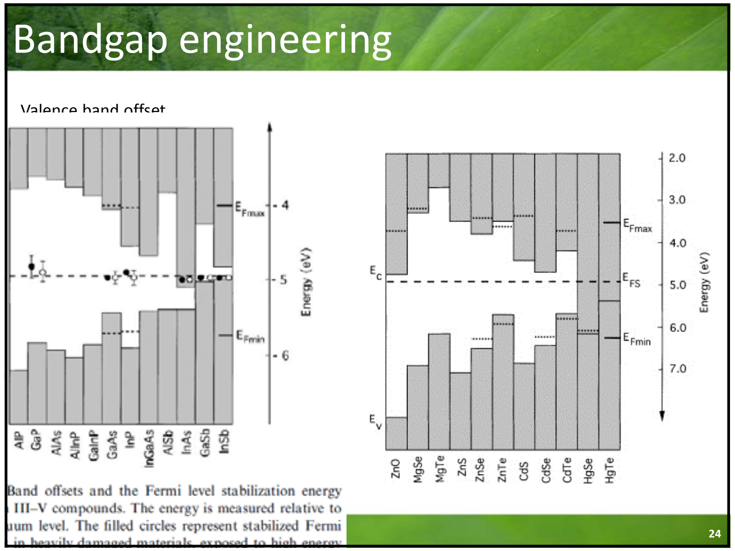


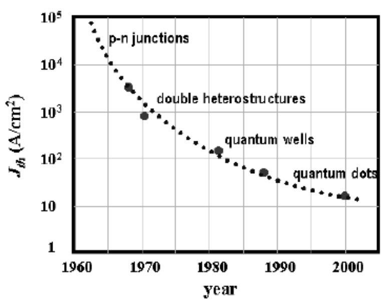
Heterostruktury półprzewodnikowe
Legend
Indirect
Direct
Band Gap, Eg (eV)
ao (Å)
Lattice constant
AlP ZnSe GaP AlAs ZnTe CdSe InP AlSb GaAs Si Ge GaSb InAs InSb InAsN GaAsN
≈850nm ≈1.3μm ≈1.55μm
Investigation of high antimony-content gallium arsenic nitride-gallium arsenic antimonide heterostructures for long wavelength application
2013-11-20
23



Bandgap engineering
Valence band offset
Energy (eV)
AlP GaP AlAs AlInP GaInP GaAs InP InGaAs AlSb InAs GaSb InSb
ZnO MgSe MgTe ZnS ZnSe ZnTe CdS CdSe CdTe HgSe HgTe
Band offsets and the Fermi level stabilization energy III–V compounds. The energy is measured relative to um level. The filled circles represent stabilized Fermi
24

Druty kwantowe

Figure 8 The trend of the reduction of semiconductor laser threshold



Nanotechnologia

CO?

- Studnie, druty, kropki

JAK?

- Top-down, czyli (nano)technologia
- Bottom-up, czyli samoorganizacja

Nanotechnologia

CO?

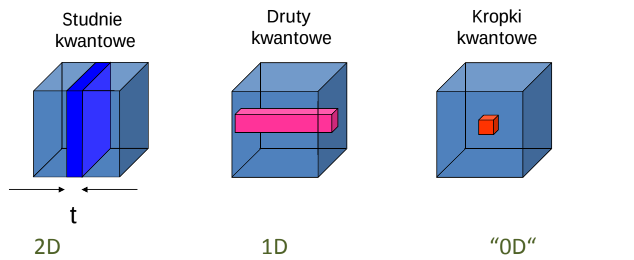
- Studnie, druty, kropki

JAK?

- Top-down, czyli (nano)technologia
- Bottom-up, czyli samoorganizacja

Struktury niskowymiarowe

Low-dimensional Semiconductor Systems

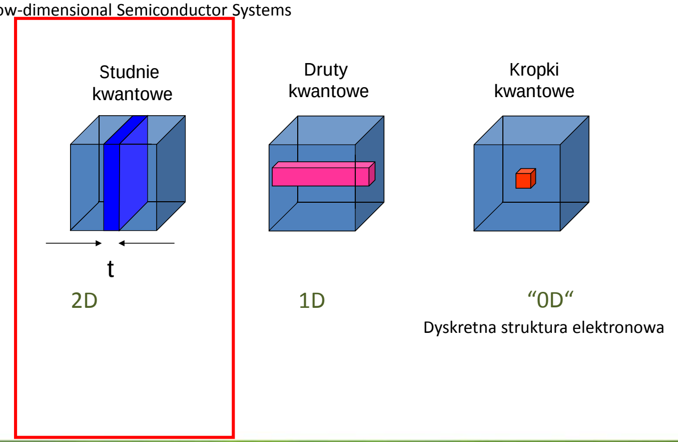


Dyskretna struktura elektronowa

Hubert J. Krenner

Struktury niskowymiarowe

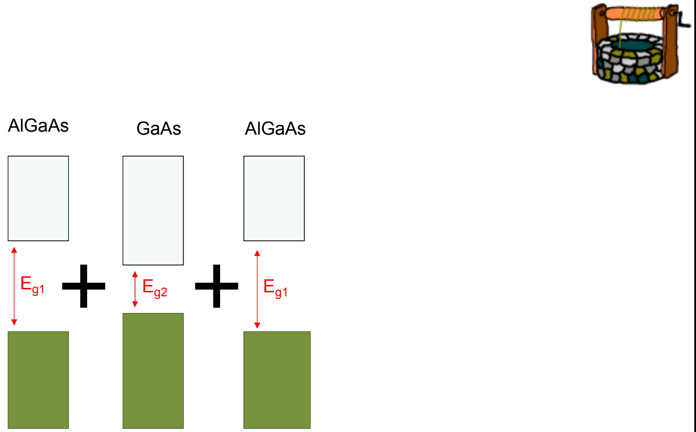
Low-dimensional Semiconductor Systems



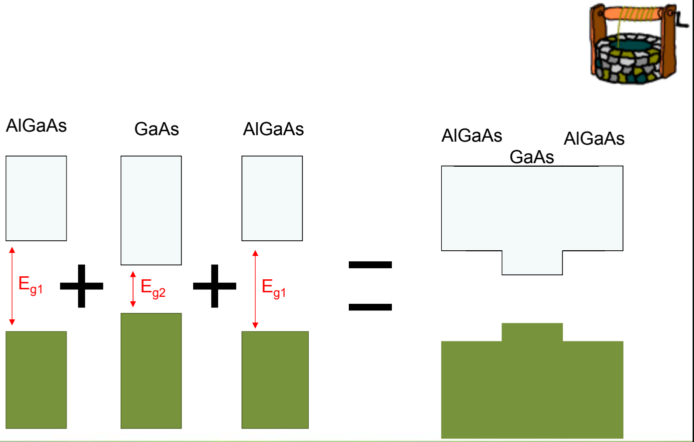
Dyskretna struktura elektronowa

Hubert J. Krenner

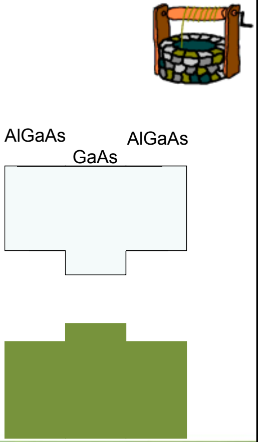
Studnia Kwantowa



Studnia Kwantowa



Studnia Kwantowa



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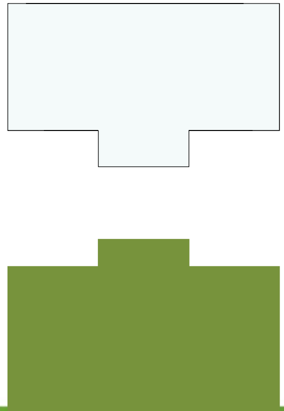

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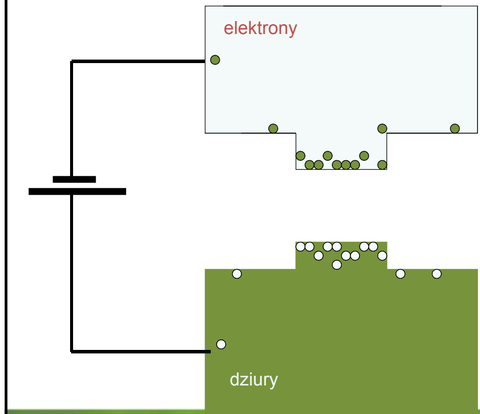

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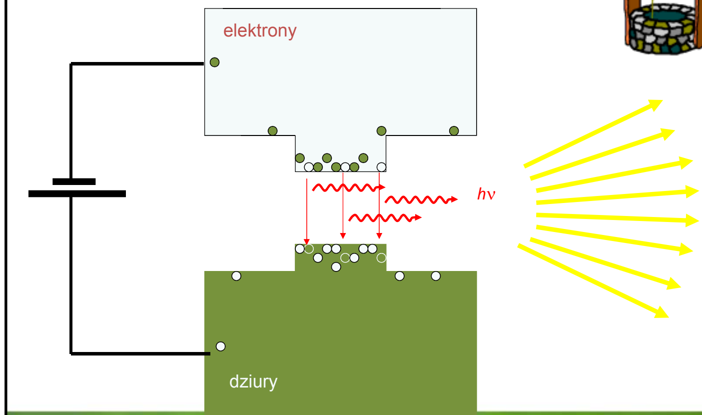
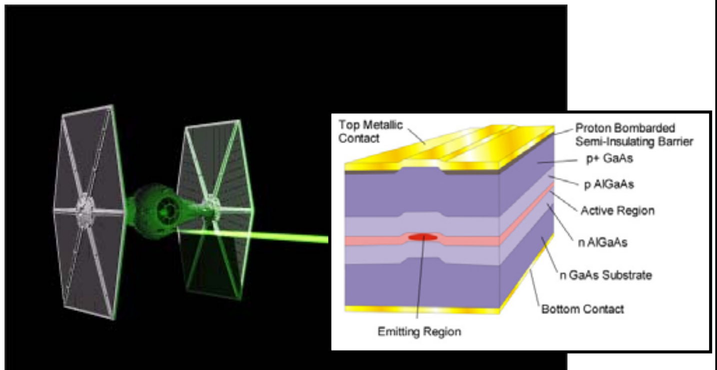


Studnia Kwantowa

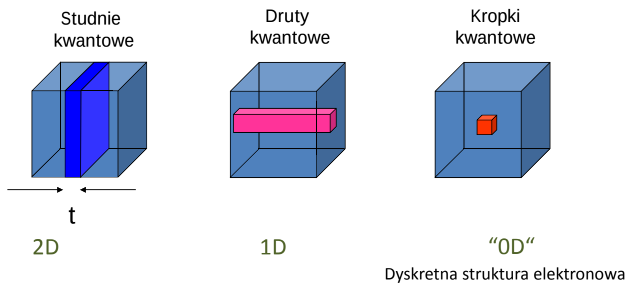
Lasery półprzewodnikowe



Dioda laserowa zawiera ok. 400 różnych warstw

Struktury niskowymiarowe

Low-dimensional Semiconductor Systems



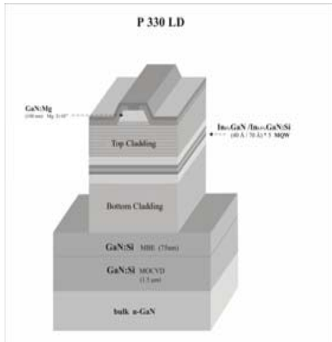
Hubert J. Krenner

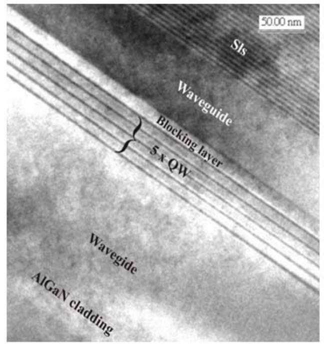
Studnia kwantowa

Więcej: **http://britneyspears.ac/lasers.htm**

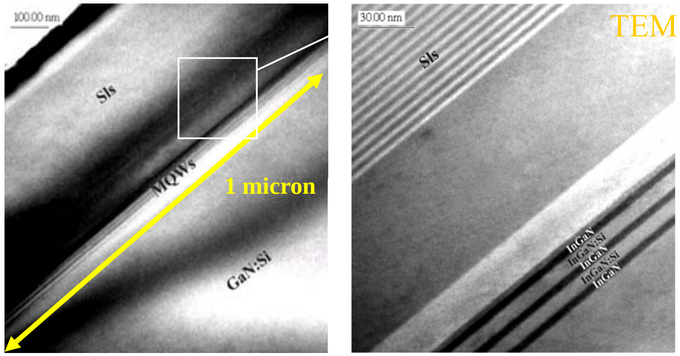
S... a

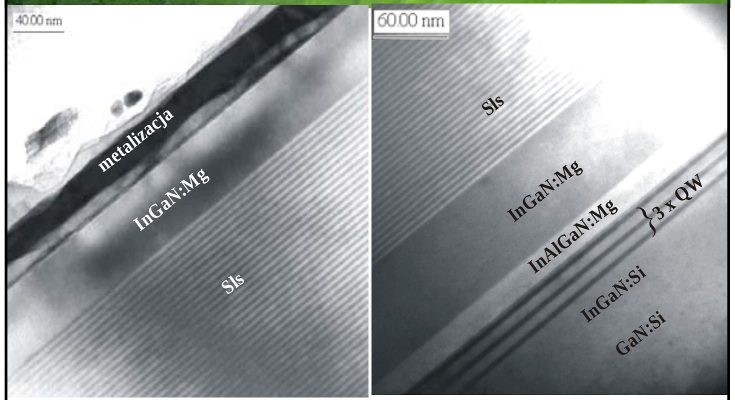
Dioda laserowa wykonana metodą MBE



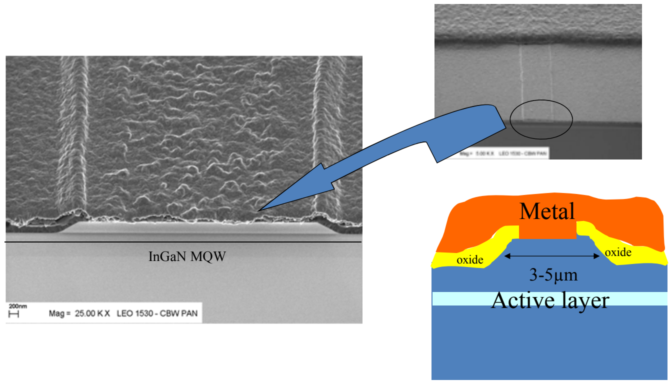


TEM



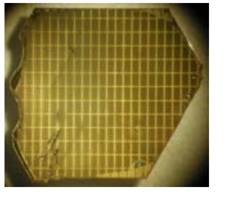


Processing laserów na azotku galu

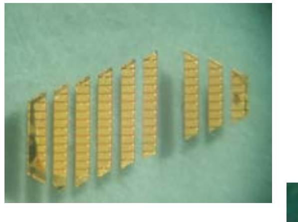


Processing laserów na azotku galu

Struktura laserowa po processingu



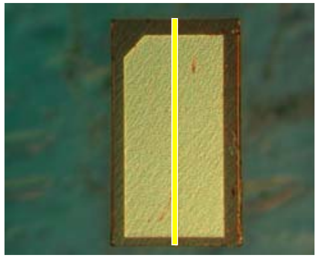
Łupanie na linijki laserowe



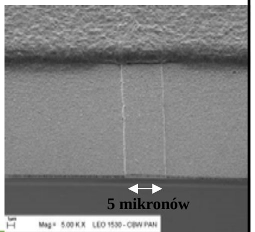
Pojedynczy przyrząd

Lasery półprzewodnikowe są bardzo małe

Szerokość kostki = 0.3 mm



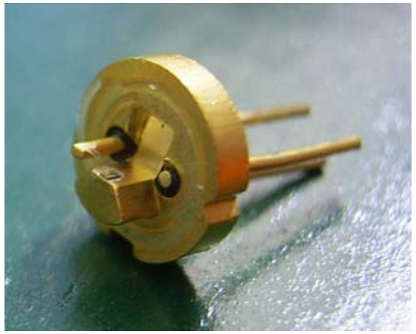
Długość lasera = 0.5 - 1 mm



Szerokość lasera = 0.001 – 0.02 mm !! (1 µm - 20µm)

IWC PAN, UNIPRESS

Montaż laserów – wersja impulsowa



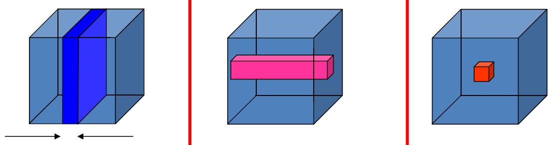
www.topgan.fr.pl

Czesław Skierbiszewski *UNIPRESS*

Struktury niskowymiarowe

Low-dimensional Semiconductor Systems

Studnie kwantowe	Druty kwantowe	Kropki kwantowe

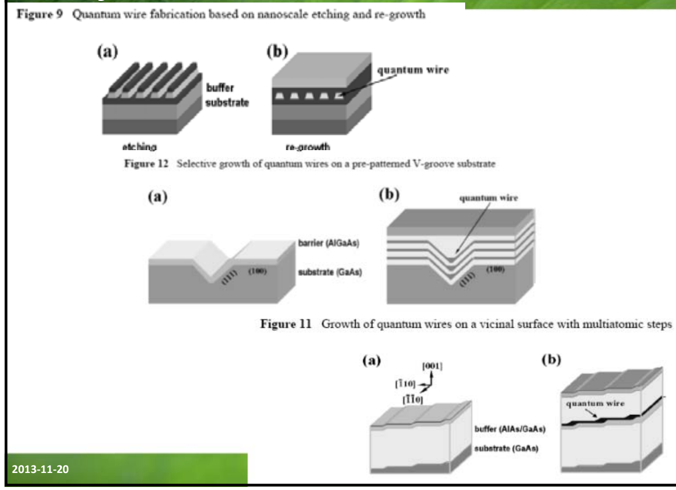


2D	1D	"0D" Dyskretna struktura elektronowa

Hubert J. Krenner

2013-11-20 47

Druty kwantowe



2013-11-20 48

Druty kwantowe

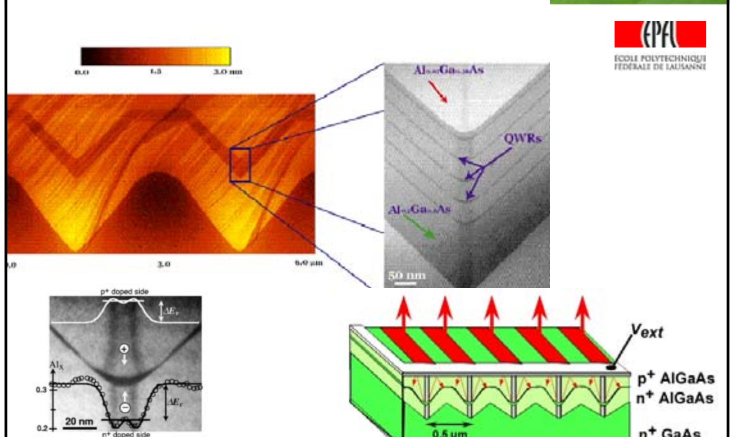
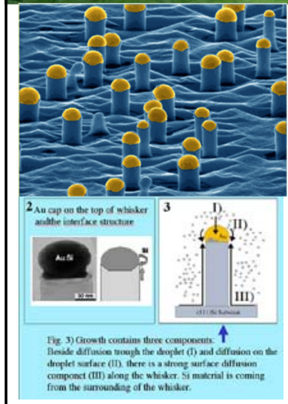
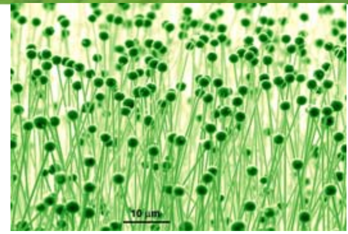


FIG. 1. TEM cross section of the V-groove QWR LED schematically showing the vertical electron and hole injection via the self-ordered VQW. Measured Al composition (open circles) and calculated conduction- (solid black curve) and valence-band potential (solid white curve) of the triple-branch VQW, is shown as a function of lateral distance.

Druty kwantowe



http://www.mpi-halle.mpg.de/~mbe/



www.ece.odu.edu/g_seminar.htm

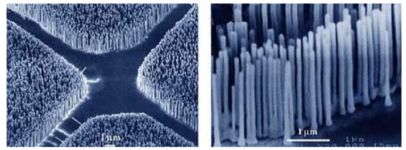


Photo by Peidong Yang/UC Berkeley, courtesy of *Science*

Druty kwantowe

P.X. Gao et al. / Chemical Physics Letters 408 (2005) 174–178 175

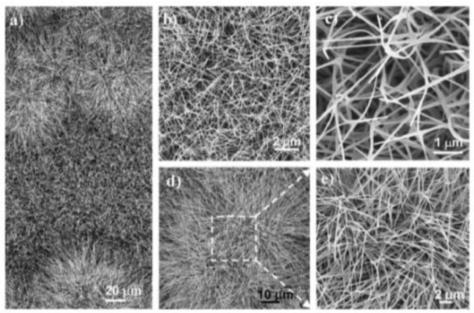
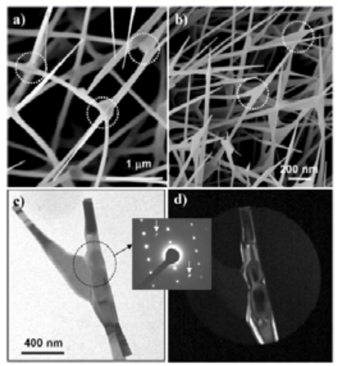


Fig. 1. (a) A typical low magnification SEM image of the as-grown networks of ZnO nanowires and nanorods consisting two types of morphologies, as indicated by area b (b,c) and c (d,e). (b,c) Enlarged SEM images of uniform networks of ZnO nanowires and nanorods. (d,e) Enlarged SEM images of clumps of nanowires showing the interconnected nanowires and nanorods.

Druty kwantowe



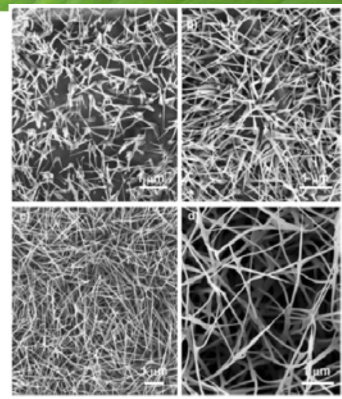


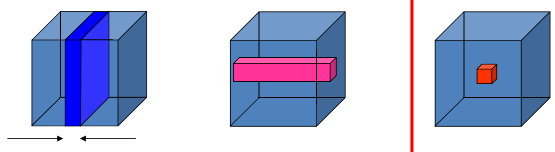
Fig. 5. Formation process of the 3D network. (a) The initial stage of interconnected nanorods growth. (b) The first layer of networking between short nanowires and nanorods. (c) The beginning of the second layer of networking. (d) Highly magnified SEM image giving a clear description about the 3D ZnO networks with mesh space around 2 × 2 × 2 (µm).

Fig. 4. (a,b) Interconnection types of ZnO nanowires in the nano-network. (c,d) Bright-field and dark-field TEM images of two nanowires interconnected with each other, indicating that the two nanowires are single crystals but they have no orientation relationship. The circle area is used for recording the selected area electron diffraction pattern (inset).

Struktury niskowymiarowe

Low-dimensional Semiconductor Systems

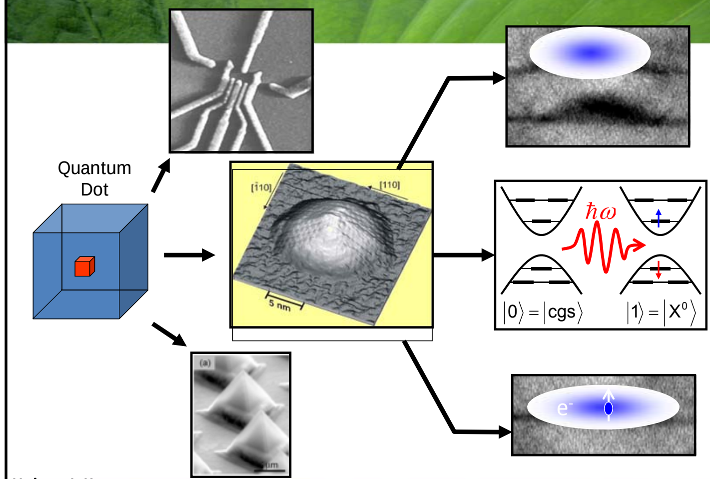
Studnie kwantowe | Druty kwantowe | Kropki kwantowe



2D | 1D | "0D"

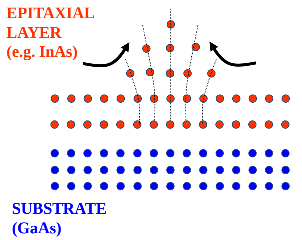
Dyskretna struktura elektronowa

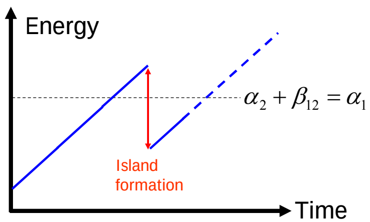
Hubert J. Krenner

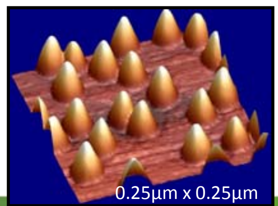


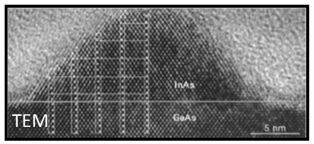
Hubert J. Krenner
Walter Schottky Institut and Physik Department E24, TU München

Potencjał harmoniczny



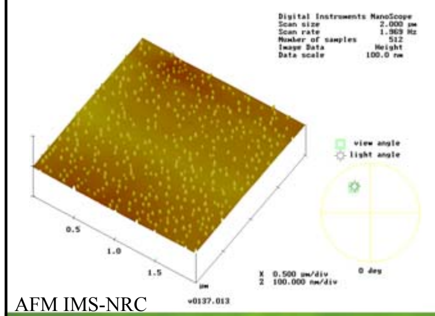


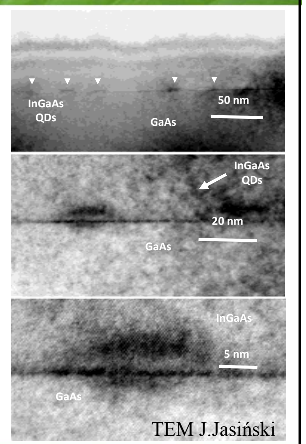




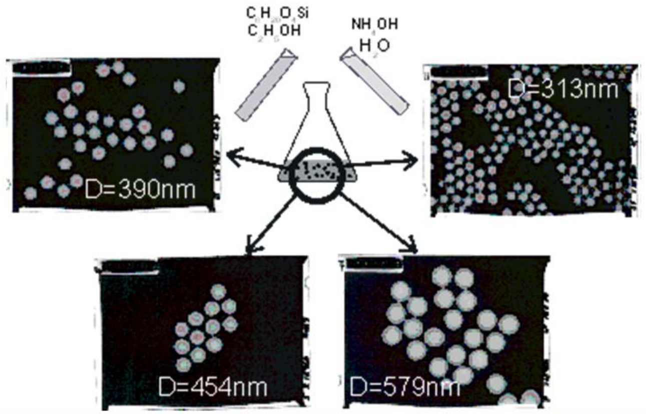
- Defect-free semiconductor "clusters" on a 2D quantum well wetting layer

Potencjał harmoniczny 2D





Synteza kropek kwantowych

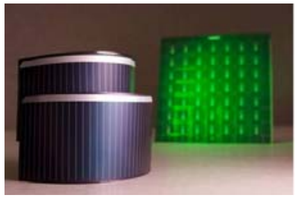


http://www.icmm.csic.es/cefe/Fab/synthesis.html

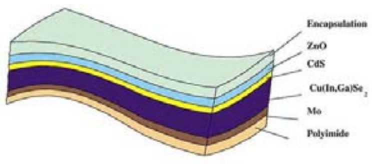
Synteza kropek kwantowych

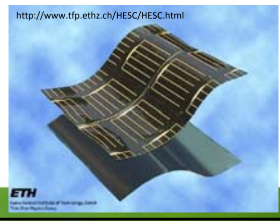
Energia

http://www.daystartech.com/lightfoil.cfm



Cu(In,Ga)Se_2 (also called CIGS) compound semiconductor solar electricity conversion efficiency of 12.8%





Nanotechnologia

CO?

- Studnie, druty, kropki

JAK?

- Top-down, czyli (nano)technologia
- Bottom-up, czyli samoorganizacja

Nanotechnologia

CO?

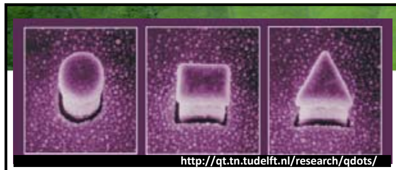
- Studnie, druty, kropki

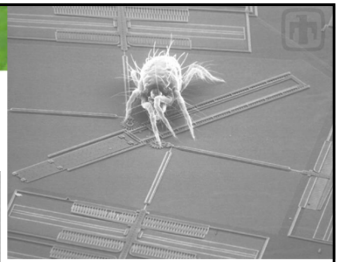
JAK?

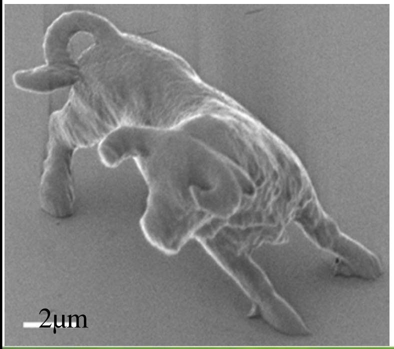
- Top-down, czyli (nano)technologia
- Bottom-up, czyli samoorganizacja

Top-down ↓

Vincent Laforet/The New York Times







Nano Tech Web

[S. Kawata *et al.*, *Nature* **412**, 697 (2001)]

7µm

(3 hours to make)

λ = 780nm

resolution = 150nm

Jak To jest zrobione?

Focus Ion Beam

JEM-9320 Focused Ion Beam System

http://www.norsam.com/

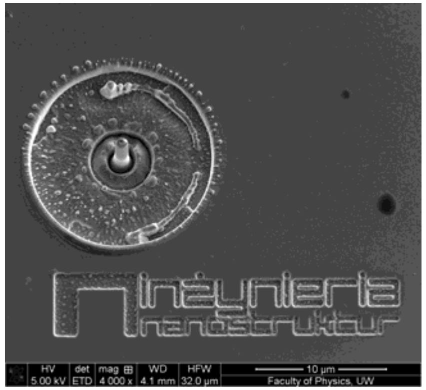
Jak To jest zrobione?

Focus Ion Beam

http://www.fei.com/products/fib/vion/

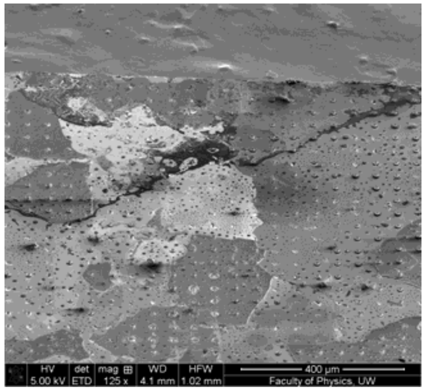
Jak To jest zrobione?

Focus Ion Beam



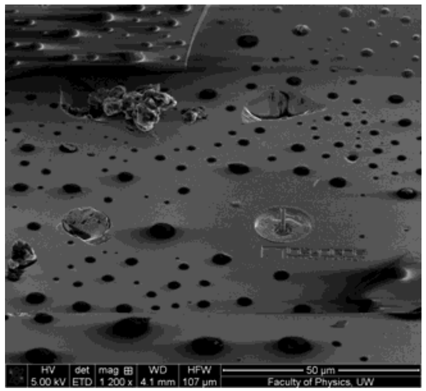
Jak To jest zrobione?

Focus Ion Beam



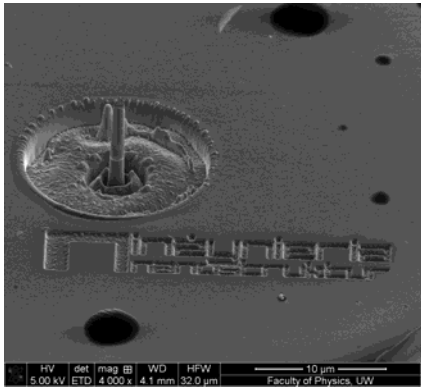
Jak To jest zrobione?

Focus Ion Beam



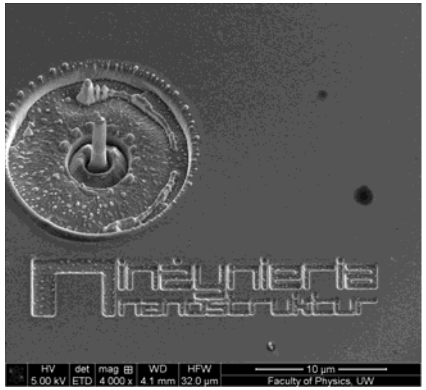
Jak To jest zrobione?

Focus Ion Beam



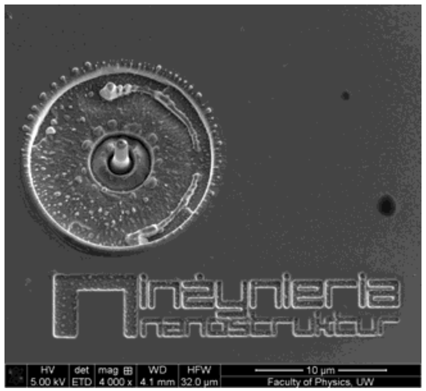
Jak To jest zrobione?

Focus Ion Beam



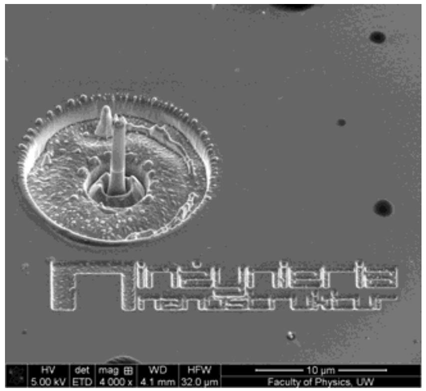
Jak To jest zrobione?

Focus Ion Beam



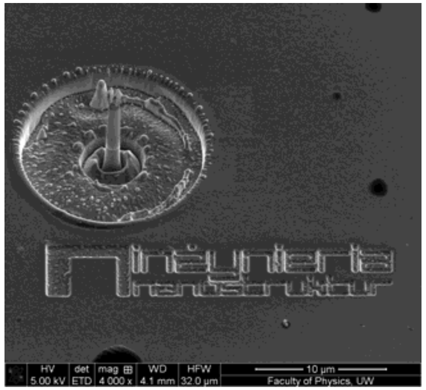
Jak To jest zrobione?

Focus Ion Beam



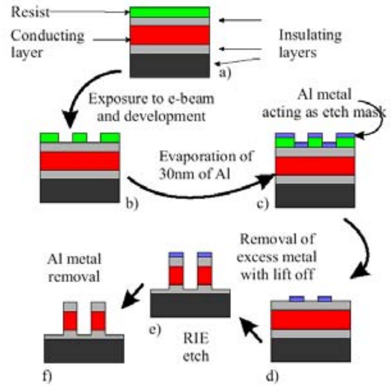
Jak To jest zrobione?

Focus Ion Beam



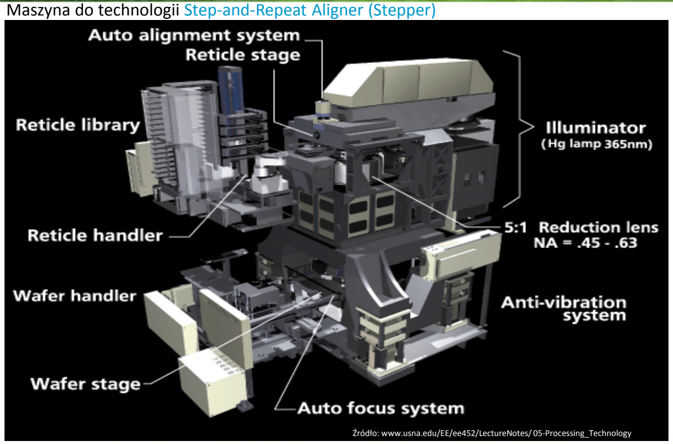
Jak To jest zrobione?

1. **Dominuje technologia krzemowa**
2. **Obecne układy ~ 10^9 - 10^{10} tranzystorów**
3. **Podłoża - 300mm, ~ 10^3 chipów**
4. **Fotolitografia, naświetlanie, trawienie etc**
5. **Typowo ~20 masek, 150 - 200 kroków procesów**



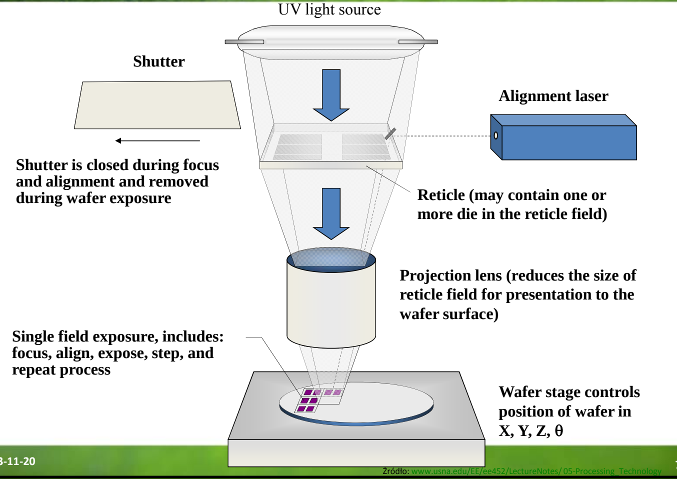
Jak To jest zrobione?

Maszyna do technologii Step-and-Repeat Aligner (Stepper)



Źródło: www.usna.edu/EE/ee452/LectureNotes/05-Processing_Technology

Jak To jest zrobione?



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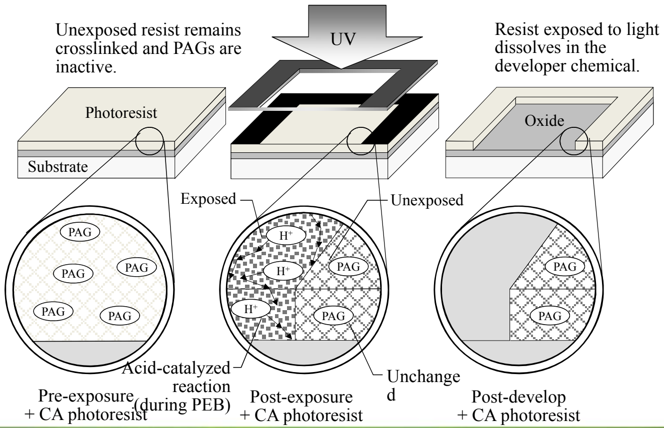

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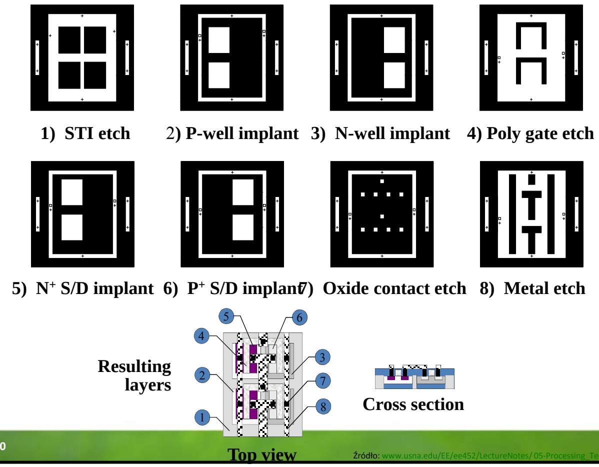

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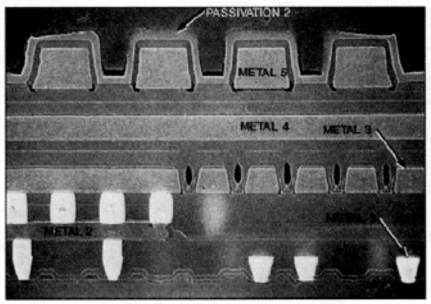
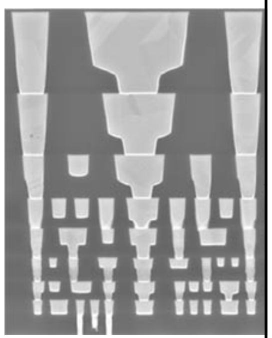
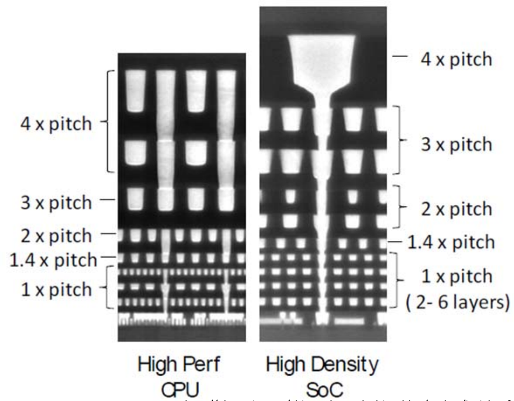


1997



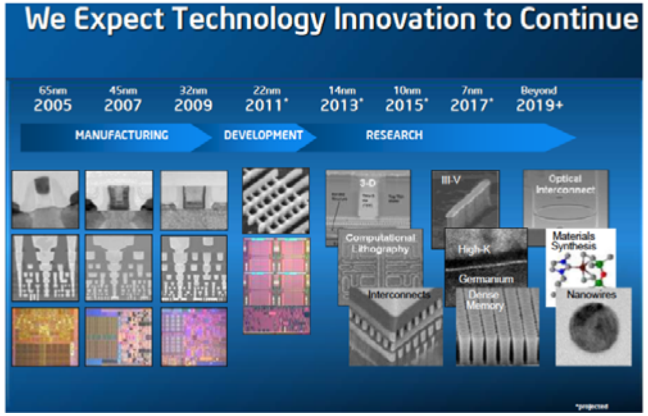
2006

Jak To jest zrobione?



http://electroiq.com/chipworks_real_chips_blog/author/insights-from-leading-edge/

Jak To jest zrobione?



Źródło: www.usna.edu/EE/ee452/LectureNotes/05-Processing_Technology

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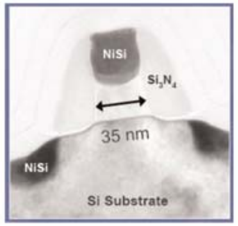
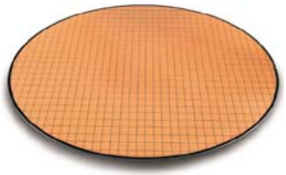
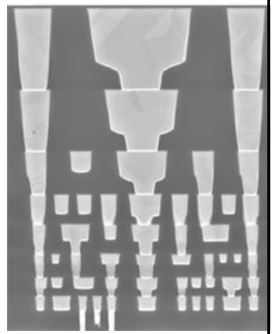






2006

Intel strained silicon (top) and a 65-nm wafer of Intel® Core™ Duo processors (bottom).

Źródło: www.usna.edu/EE/ee452/LectureNotes/05-Processing_Technology

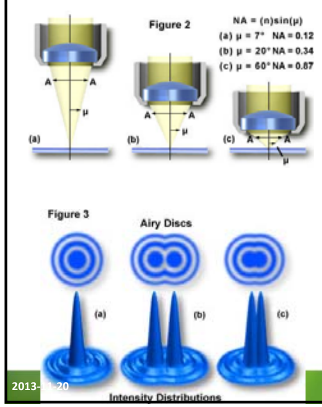
Litografia

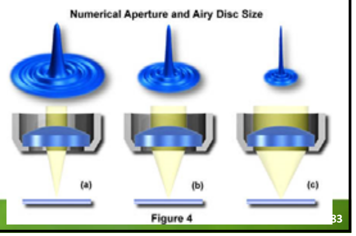
http://www.microscopyu.com/

Zdolność rozdzielcza (kryterium Rayleigha)
W – najmniejszy rozmiar dostępny w litografi, mikroskopii etc.

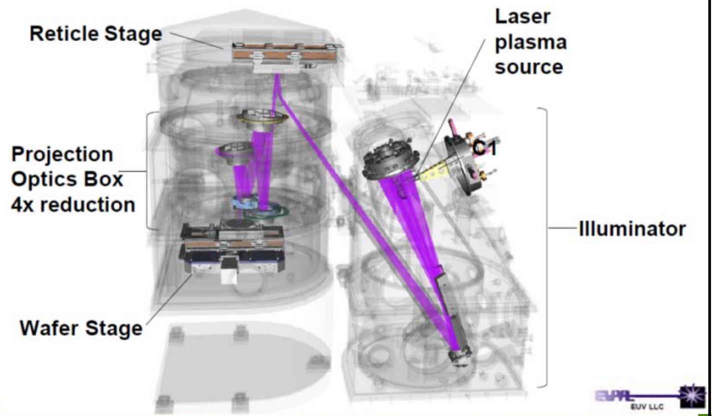
$$NA = n\sin\alpha = d/(2f)$$

$$W = \frac{k_1 \lambda}{NA}$$





Litografia



Źródło:

Litografia

Litografia

ETS | ENGINEERING

Experts Recruiting for

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World's First 450mm Semiconductor Manufacturing Facility Being Developed by Intel

09 Aug 2013

Intel are starting a $2 billion expansion on their facility in Oregon (USA) which will be the world's first semiconductor factory producing 450mm wafers. It has been stated as their D1X Module 2 Development - this will be used specifically for development purposes and will start a whole new era within the semiconductor industry.

"mm" is the size of the silicon wafers which chips are produced on. The current state-of-the art fab is 300mm which powers our everyday electrical equipment such as smartphones, PCs, and even home held appliances. The construction of the D1X module will continue with the production of 300mm wafers but will be capable of producing 450mm. It is believed the process will take us up to 2015 before any 450mm wafers are introduced after an estimated 2 year construction.

As wafer sizes increase so does the size of the machinery needed to handle and process larger wafers which will result in increased investment costs to build a single factory which not all companies within the semiconductor industry will be able to do and the time of development would take too long to recoup their investment. 450mm wafers will require significant engineering, time and cost.

However there are benefits and pros to the larger wafers. Chips for advanced devices will be more affordable over a period of time and they will enhance productivity, generating more chips on a single wafer - which is the main purpose of the upcoming Intel development.

(photo copyright from Wikipedia)

Litografia

© MICRODESIGN RESOURCES JUNE 19, 2000 MICROPROCESSOR REPORT

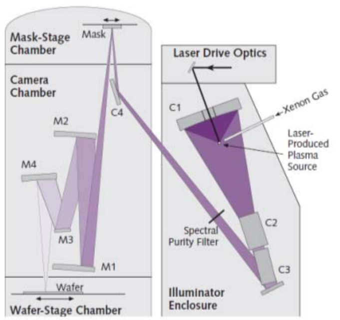


Figure 1. EUV light is generated from a 45eV plasma created when a 1,700W pulsed YAG solid-state laser illuminates a supersonic jet of xenon gas. The EUV light is collected and focused on a 4x reflective mask by a series of condenser mirrors (C1–C4). The mask image is projected onto the wafer by a 4x reduction camera (M1–M4) while the mask and wafer are simultaneously scanned. The entire operation takes place in high-vacuum environmental enclosures.

Figure 2. This engineering prototype of the engineering test stand (ETS) illuminator shows the LPP light source and the C1 condenser assembly (top center). Small trapezoidally shaped doors protect the six C1-mirror petals when the ETS is not in operation. The entire condenser weldment, which also holds C2 and C3, is isolated from its environmental chamber to eliminate motion and vibration from the vacuum pumps. (Photo courtesy of Sandia National Lab)

Litografia

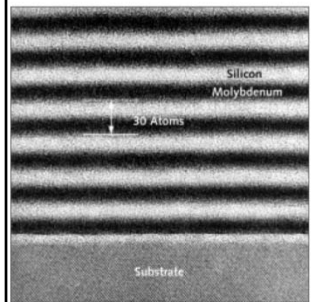


Figure 5. Each of the seven normal-incidence mirrors (including the mask) in the ETS is coated with 40 bilayers of molybdenum and silicon that are $\lambda/2$ (30 atoms) thick, creating a distributed Bragg reflector. Total reflectance at 13.5nm is 70%. (Source: Lawrence Livermore Lab)

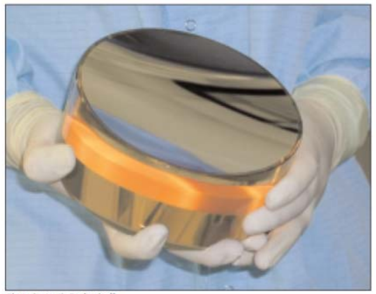


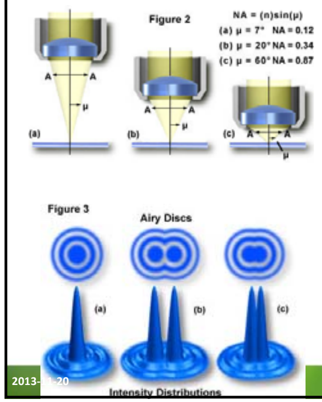
Photo by Keith Diefendorff

Figure 7. This photograph shows a polished and coated M4 mirror from the ETS camera. For people who appreciate ultrahigh precision, the mirror is a thing of beauty.

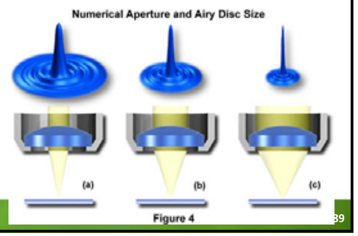
Litografia imersyjna

http://www.microscopy.fsu.edu/

Zdolność rozdzielcza (kryterium Rayleigha)
W – najmniejszy rozmiar dostępny w litografi, mikroskopii etc.

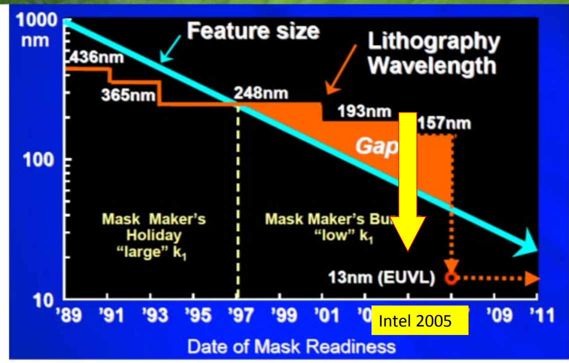


$$W = \frac{k_1 \lambda}{NA}$$



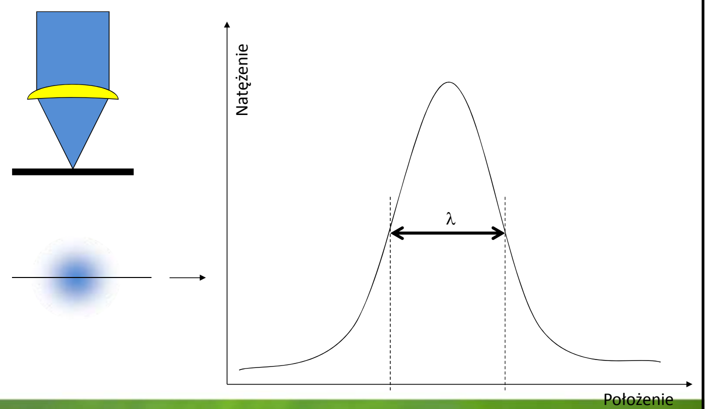
Litografia

Intel, 2003

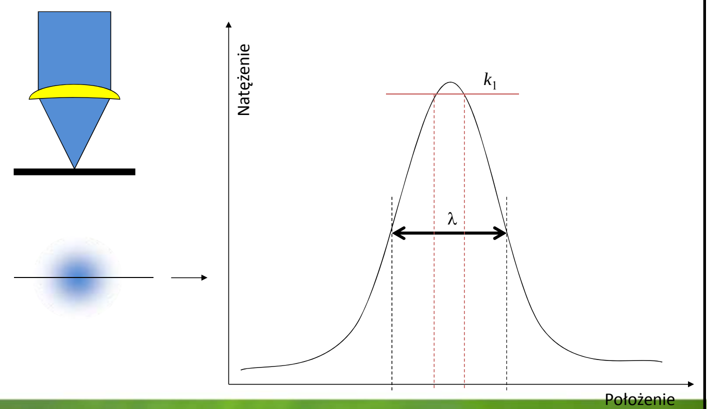


Litografia	90nm	65nm	45nm	32nm
Produkcja	2003	2005	2007	2009

Litografia

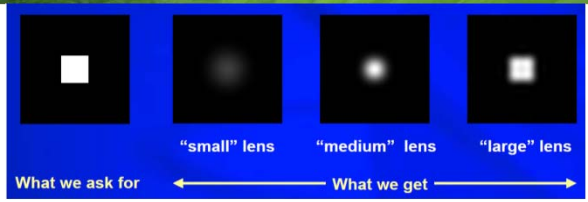


Litografia

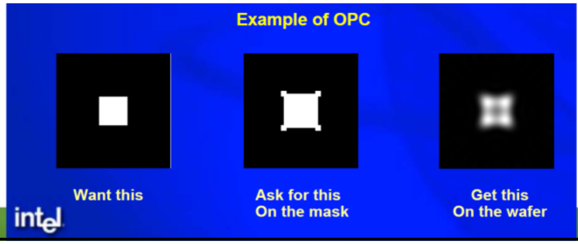


Litografia

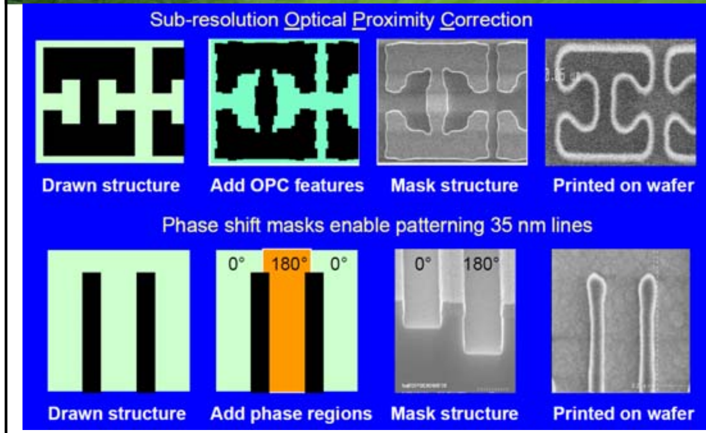
Mask Making Tutorial
Barry Lieberman, Ph.D.
Engineering Manager
Intel Mask Operation



OPC – Optical Proximity Corrections

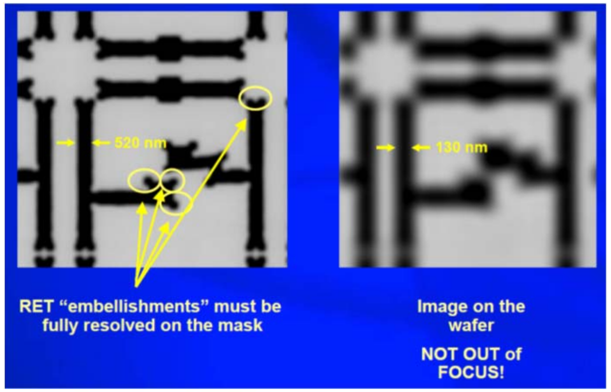


Litografia



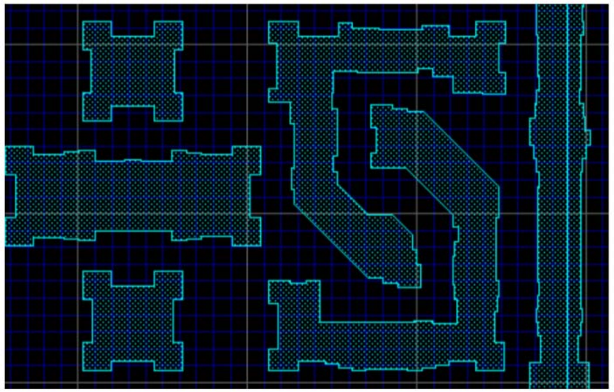
Litografia

OPC – Optical Proximity Corrections



Litografia

OPC – Optical Proximity Corrections



Litografia

Some Mask-Making Metrics and Comparisons

•Pixels:
- –On a 90 nm technology node mask: 1,000,000,000,000
- –In a high quality digital photo: 4,000,000

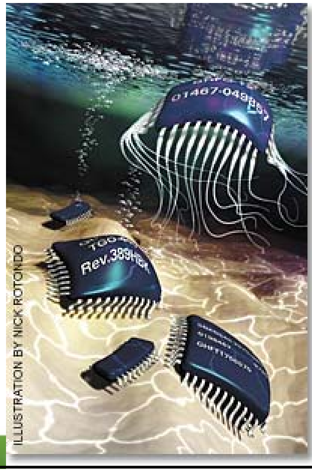
•Defects:
- –Size that must be found and repaired 0.1 micron
- –Number of such defects allowed: 0
- –Size ratio: defect to the mask area: size of a basketball / area of California

•Data
- –Typical number of mask layers for 90 nm generation logic product: 22—25
- –Total file size needed to specify all these layers: 200 GB
- –Time to transmit (design site to mask shop) using T1 line (1.4 MB/sec): ~1.5 days
- –Time using T3 line (40 MB/sec): ~1.5 hours

•Cost
- –Cost to lease a T3 line: $70K/month
- –Capital cost to build a 90 nm node capable mask shop (capacity of 200 sets/year @50-70% yield): $200-250M
- –Yearly cost to operate such a shop: $60-100M
- –Cost to make a 90 nm node mask set (depreciation, labor, etc): ~$800K-1.3M

intel

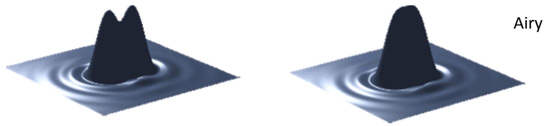
Litografia imersyjna



$$W = \frac{k_1 \lambda}{NA}$$

Litografia imersyjna

Zdolność rozdzielcza (kryterium Rayleigha)
W – najmniejszy rozmiar dostępny w litografi, mikroskopii etc.



Airy disks

The third element in the Rayleigh equation is k_1. k_1 is a complex factor of several variables in the photolithography process such as the quality of the photoresist and the use of resolution enhancement techniques such as phase shift masks, off-axis illumination and optical proximity correction. While exposure wavelengths have been falling and NA rising, k_1 has been falling as well, see figure 2. The practical lower limit for k_1 is thought to be >0.25.

$$NA = n \sin\alpha = d/(2f)$$

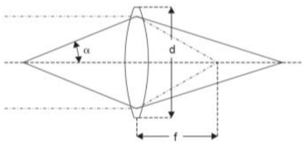


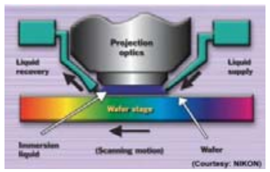
Figure 3. Numerical aperture.

$$W = \frac{k_1 \lambda}{NA}$$

$$W = \frac{0.25 \times 193}{0.93} = 52nm$$

$$W = \frac{k_1 \lambda}{n \sin\alpha} = \frac{0.25 \times 193}{1.47 \times 0.93} = 35nm$$

Litografia imersyjna



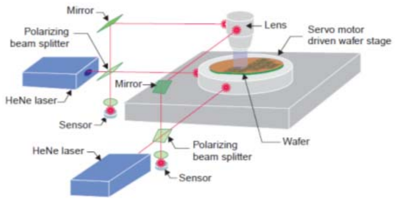
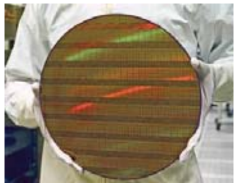


Figure 4. Stepping exposure system stage control



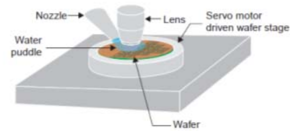
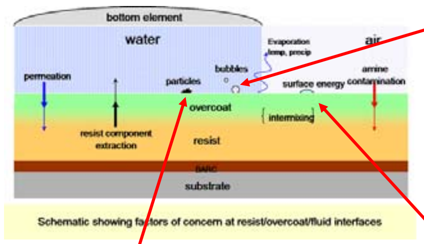


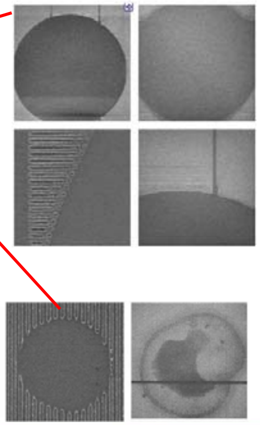
Figure 5. Immersion lithography. Stage control omitted for clarity.

http://www.smalltimes.com/articles/stm_print_screen.cfm?ARTICLE_ID=260007

Litografia imersyjna



http://www.almaden.ibm.com/st/chemistry/lithography/immersion/resist_development/



2013-11-20 http://www.microelectronics.be/wwwinter/mediacenter/en/SR2005/html/142296.html 101

Litografia imersyjna

2013-11-20 102

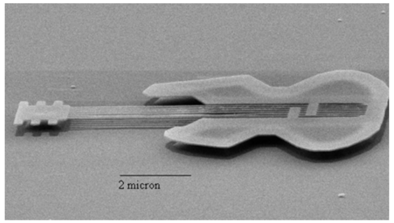
Litografia imersyjna

2013-11-20 103

Inne

Litografia 3D

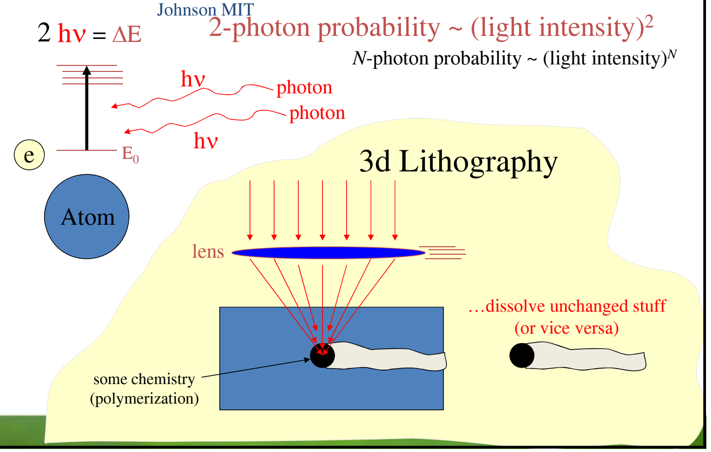
Lasery ekscymerowe



Electron-microscope image of the world's smallest guitar, based roughly on the design for the Fender Stratocaster, a popular electric guitar. Its length is 10 millionths of a meter-- approximately the size of a red blood cell and about 1/20th the width of a single human hair. Its strings have a width of about 50 billionths of a meter (the size of approximately 100 atoms). Plucking the tiny strings would produce a high-pitched sound at the inaudible frequency of approximately 10 megahertz. Made by Cornell researchers with a single silicon crystal, this tiny guitar is a playful example of nanotechnology, in which scientists are building machines and structures on the scale of billionths of a meter to perform useful technological functions and study processes at the submicroscopic level.
(Image courtesy Dustin W. Carr and Harold G. Craighead, Cornell.)

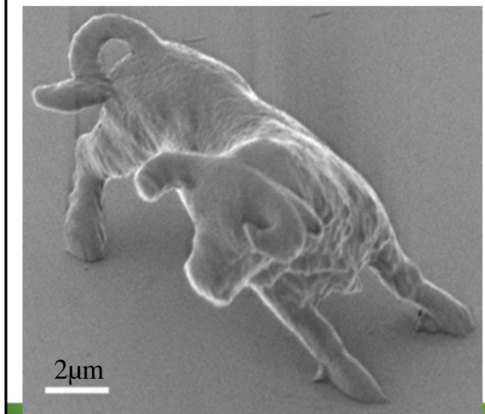
Litografia 3D

Photonic Crystals:Periodic Surprises in Electromagnetism Steven G. Johnson MIT



Litografia 3D

[S. Kawata *et al.*, *Nature* **412**, 697 (2001)]



λ = 780nm

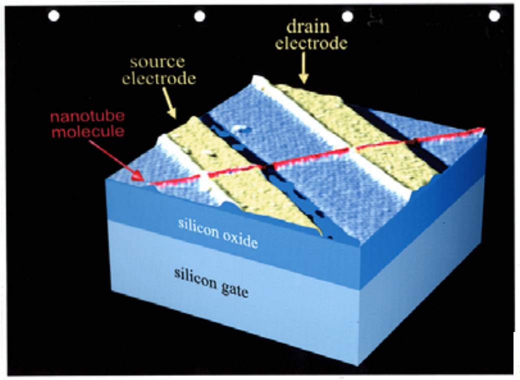
resolution = 150nm

7μm

(3 hours to make)

Jak To jest zrobione?

Nanotubes as molecular quantum wires



Cees Dekker

TU Delft DIMES

2013-11-20 108

Nanotechnologia

CO?

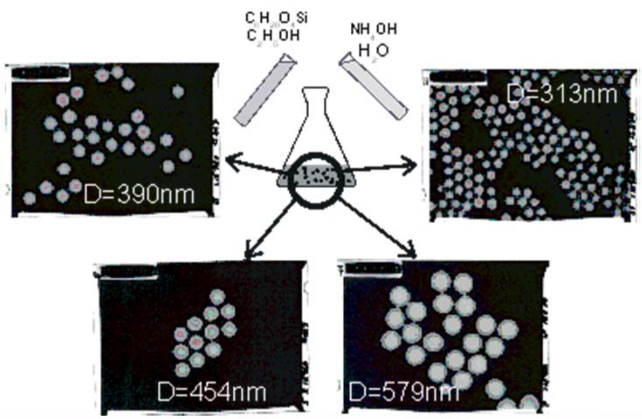
- Studnie, druty, kropki

JAK?

- Top-down, czyli (nano)technologia
- Bottom-up, czyli samoorganizacja

Bottom-up ↑

Synteza kropek kwantowych



http://www.icmm.csic.es/cefe/Fab/synthesis.html

Synteza kropek kwantowych