Grafen i magia dwuwymiarowych kryształów

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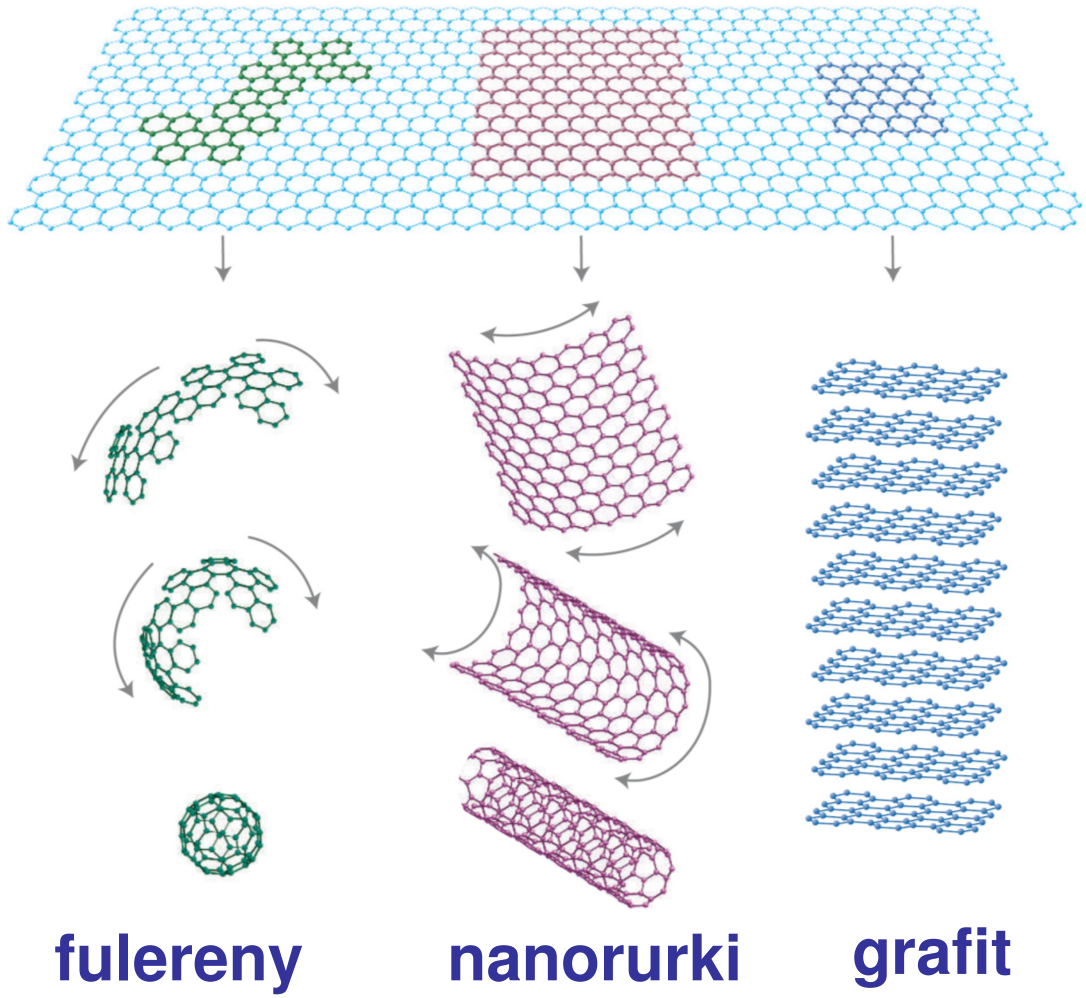
Wydział Fizyki Uniwersytetu Warszawskiego

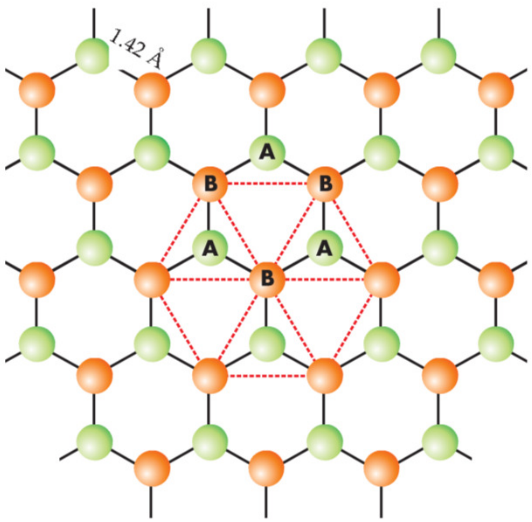
Grafen - pojedyncza warstwa grafitu…

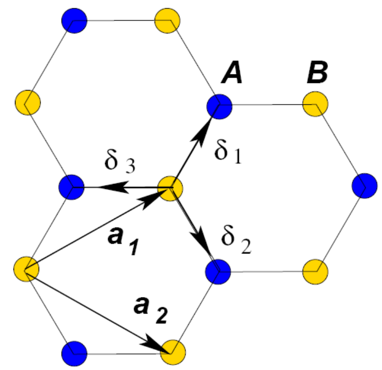


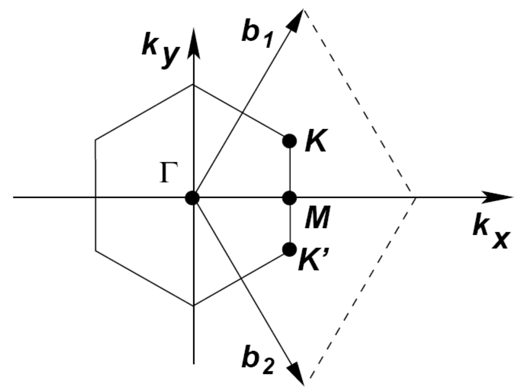
Podstawowy budulec dla struktur węglowych….

Struktura pasmowa grafenu

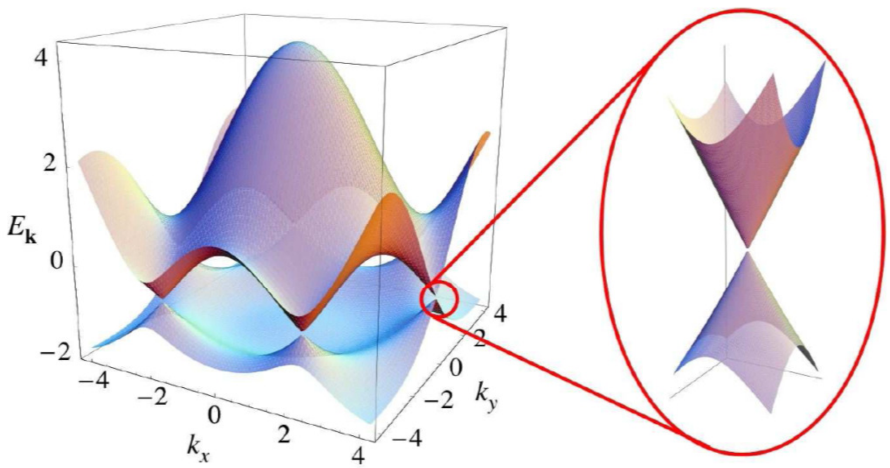
…znana od lat: (*P.R. Wallace, Phys. Rev. (1947)*)





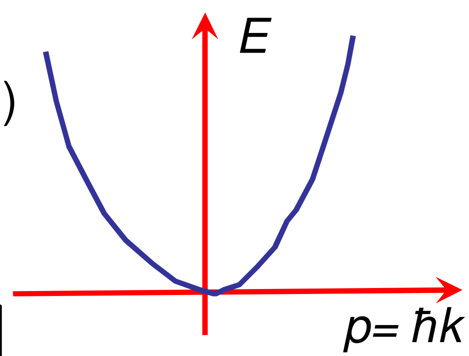


$$\boldsymbol{a}_1 = \frac{a}{2}(3, \sqrt{3}), \qquad \boldsymbol{a}_2 = \frac{a}{2}(3, -\sqrt{3}) \qquad \boldsymbol{b}_1 = \frac{2\pi}{3a}(1, \sqrt{3}), \qquad \boldsymbol{b}_2 = \frac{2\pi}{3a}(1, -\sqrt{3})$$



$$\boldsymbol{K} = \left(\frac{2\pi}{3a}, \frac{2\pi}{3\sqrt{3}a}\right), \qquad \boldsymbol{K}' = \left(\frac{2\pi}{3a}, -\frac{2\pi}{3\sqrt{3}a}\right)$$

E= ½ mv^2 =$p^2/(2\mathrm{m})$



$$\varepsilon = \pm \tilde{c} \cdot \left| \vec{p} \right|$$

$$E_{\pm}(\mathbf{k}) = \pm t\sqrt{3 + f(\mathbf{k})}\,.$$

$$f(\mathbf{k}) = 2\cos\left(\sqrt{3}k_y a\right) + 4\cos\left(\frac{\sqrt{3}}{2}k_y a\right)\cos\left(\frac{3}{2}k_x a\right)$$

A.H. Castro Neto et al., Rev. Mod. Phys. (2009)

phys. stat. sol. 20, 113 (1967)

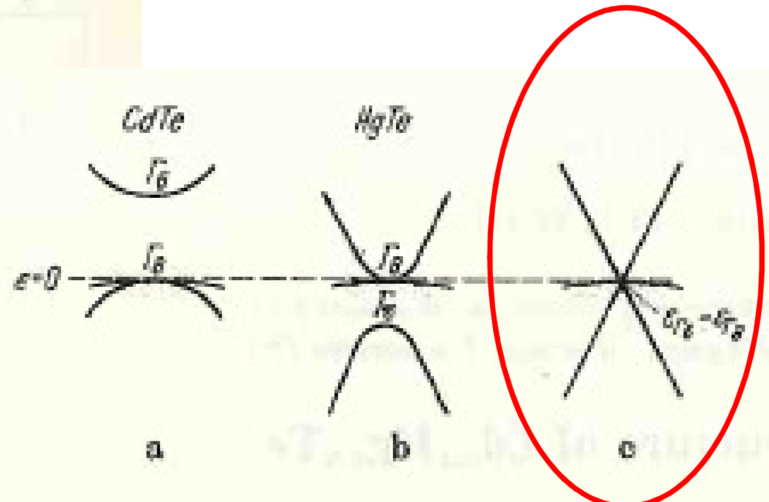
Subject classification: 13.1; 22.4.3

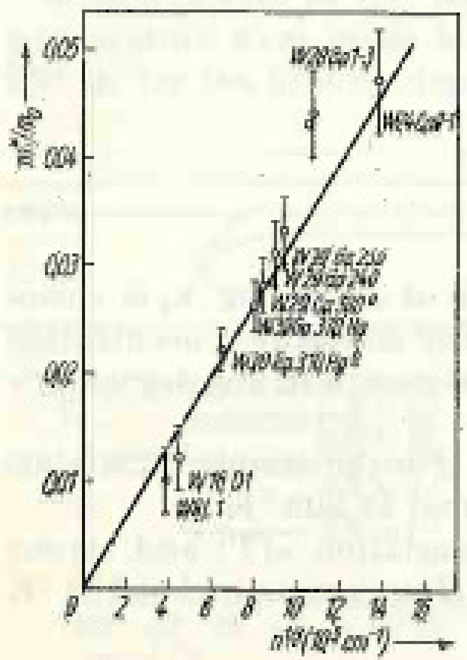
Institute of Physics, Polish Academy of Sciences, Warsaw (a)
and Institute of Experimental Physics, Warsaw University (b)

Conduction Band Structure of $Cd_{0.1}Hg_{0.9}Te$

By

R. R. Gałązka (a) and L. Sosnowski (a, b)





of $\Delta\alpha$ ($H = \infty$).

As equation (2) indic
the effective mass m^* i
centration.

The results given in Table 1 may be presented in graphical form (Fig. 5).

Fig. 5 gives a linear variation of the effective mass with k in the measured range of concentration.

Fig. 5. Experimental dependence of the effective mass on $n^{1/3}$ (in the case of strong degeneracy $n^{1/3} \sim k$)

Materiały z zerową przerwą energetyczną

grafen

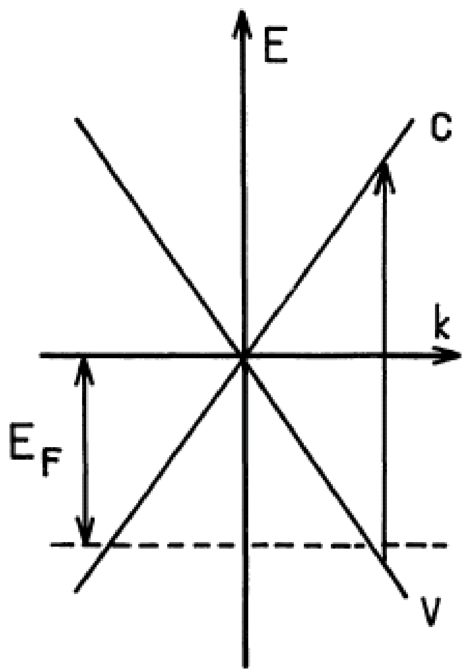


Fig. 4. — Zero gap band structure of the first stage.

J. Blinowski et al.,
J. Physique 41 (1980) 47-58

HgTe

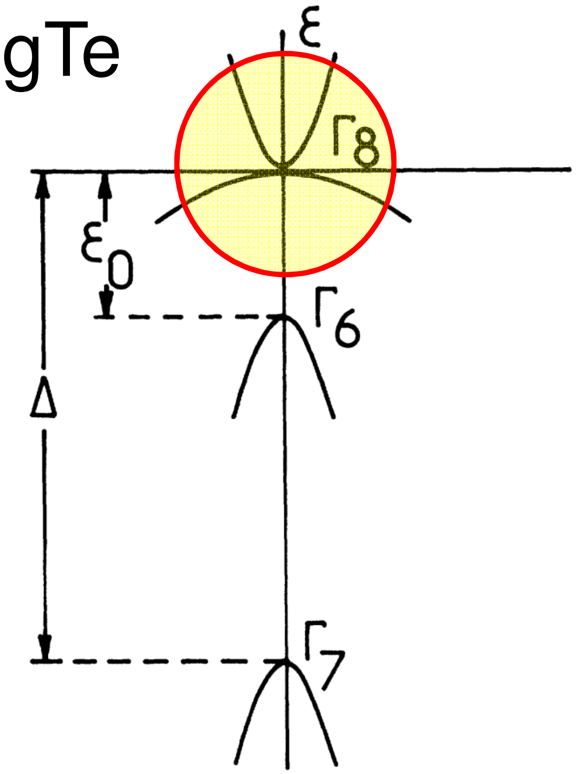


FIG. 1. Inverted band structure of HgTe.

Y. Guldner, …M. Grynberg,…
Phys. Rev. B 8, 3875 (1973)

Grafit przekładany (interkalowany)

Intercalation compounds of graphite

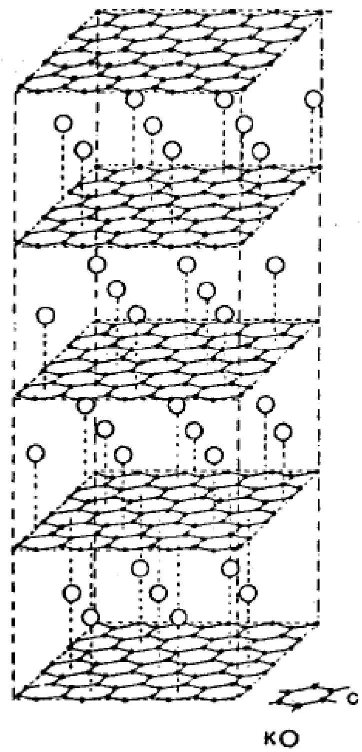
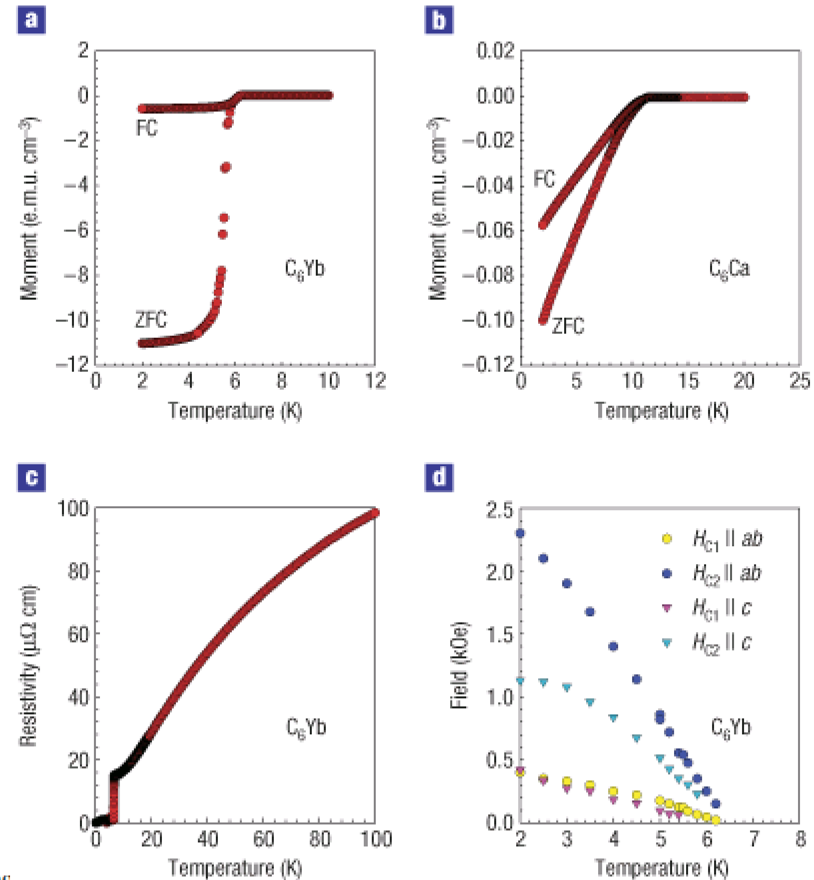


Figure 1. Model for C_8K according to Rüdorff and Schulze (1954) showing the stacking of graphite layers (networks of small solid balls) and of potassium layers (networks of large hollow balls). The graphite and intercalate layers are arranged in an $A\alpha A\beta A\gamma A\delta$ stacking sequence, where A refers to the graphite layers and the Greek letters to the intercalate layers.

M. S. Dresselhaus and G. Dresselhaus
*Advances in Physics, **51**, 1 (2002)*



T_c=11.5 K

T. E. Weller et al.
Nature Physics 1, 39 - 41 (2005)

XC_6 for small ones (X = Li, Sr, Ba, Eu, Yb and Ca)
nadprzewodnictwo, baterie litowo-jonowe…

Reprinted from "Proceedings of the Fifth Conference on Carbon"
PERGAMON PRESS
OXFORD . LONDON . NEW YORK . PARIS
1962

SURFACE PROPERTIES OF EXTREMELY THIN GRAPHITE LAMELLAE

H. P. Boehm, A. Clauss, G. Fischer and U. Hofmann

Anorganisch-Chemisches Institut der Universität, Heidelberg, Germany

(Manuscript received September 15, 1961)

Extremely thin lamellae of carbon were obtained either by deflagration of graphitic oxide on heating or by reduction of graphitic oxide in alkaline suspension. These lamellae consist of very few carbon layers as was estimated from the absorbance in the electron microscope. The crystallite dimensions and the specific surface area also show the existence of very thin carbon sheets. The adsorption of nitrogen, phenol and methylene blue was measured as well as the catalytic efficiency in the hydrogen bromide synthesis. The *reduction* product had the maximum surface area while still in aqueous suspension. On drying the lamellae showed a tendency to stick together with a corresponding decrease of the specific surface area. Higher surface areas were measured by the "wet" methods in comparison to the "dry" methods (e.g. N_2 adsorption) because of partial redispersion of the lamellae. With the *deflagration* product, in contrast, roughly identical surface values were obtained by all methods, in-

This observation confirms the assumption that the thinnest of the lamellae really consisted of single carbon layers.

Surface Science 48 (1975) 463–472

LEED AND AUGER ELECTRON OBSERVATIONS OF THE SiC (0001) SURFACE

A.J. VAN BOMMEL, J.E. CROMBEEN and A. VAN TOOREN
Philips Research Laboratories, Eindhoven, The Netherlands

Received 12 August 1974; revised manuscript received 21 October 1974

LEED and AES experiments of the SiC {0001} crystal surfaces show that on heat-treatment these surfaces are easily "covered" with a layer of graphite by evaporation of silicon. The graphite layer, which has a distinct crystallographic relation to the SiC crystal, is monocrystalline on the Si-face and mostly polycrystalline on the C-face. A speculation about the mechanism of the initial graphitization of the basal faces of SiC is given.

The Nobel Prize in Physics 2010
Andre Geim, Konstantin Novoselov

The Nobel Prize in Physics 2010

Andre Geim

Konstantin Novoselov

Photo: Sergeom, Wikimedia Commons

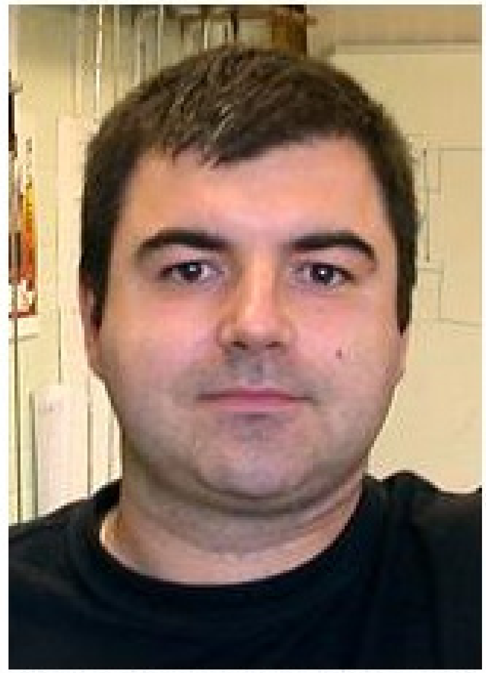


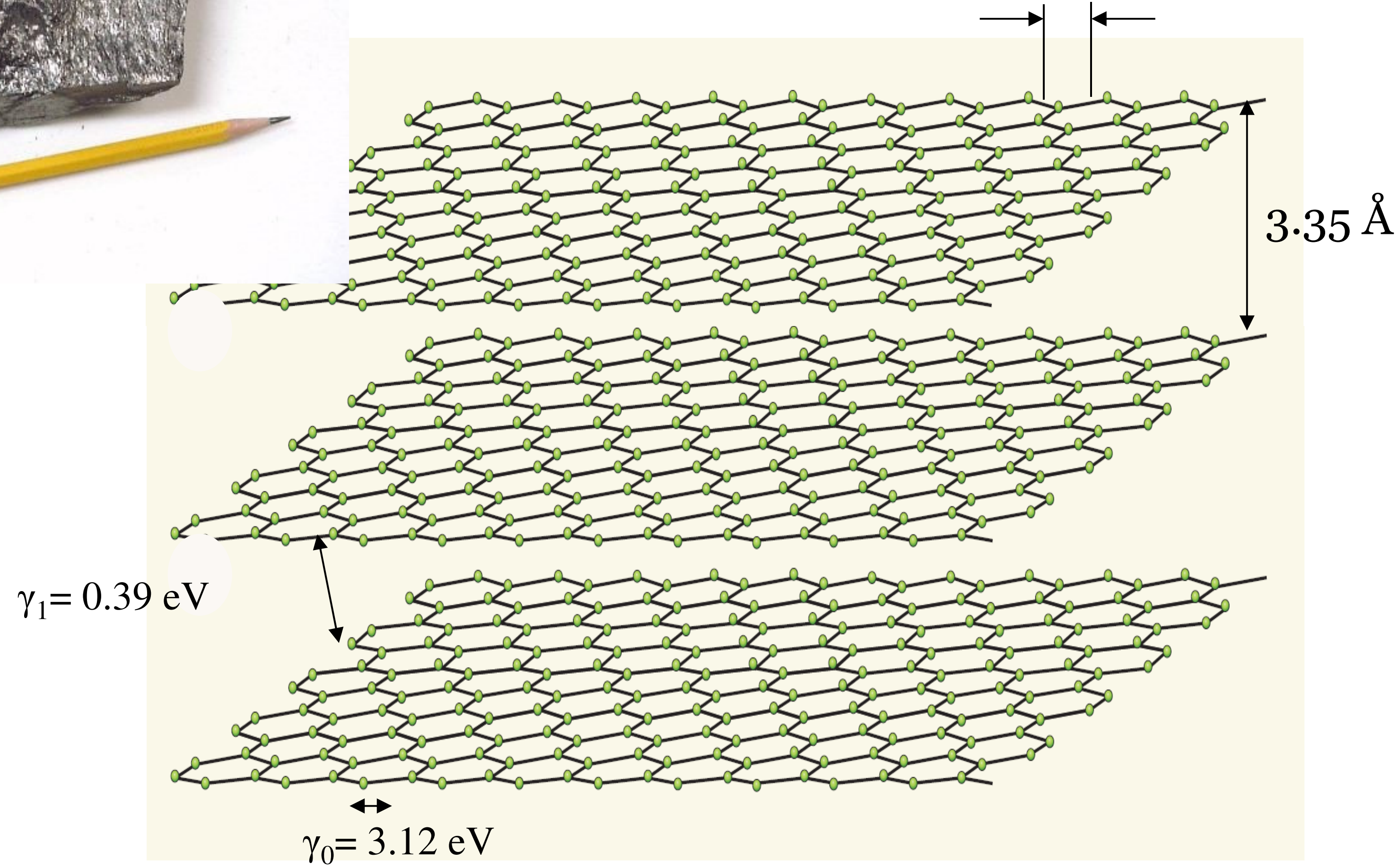
Photo: University of Manchester, UK

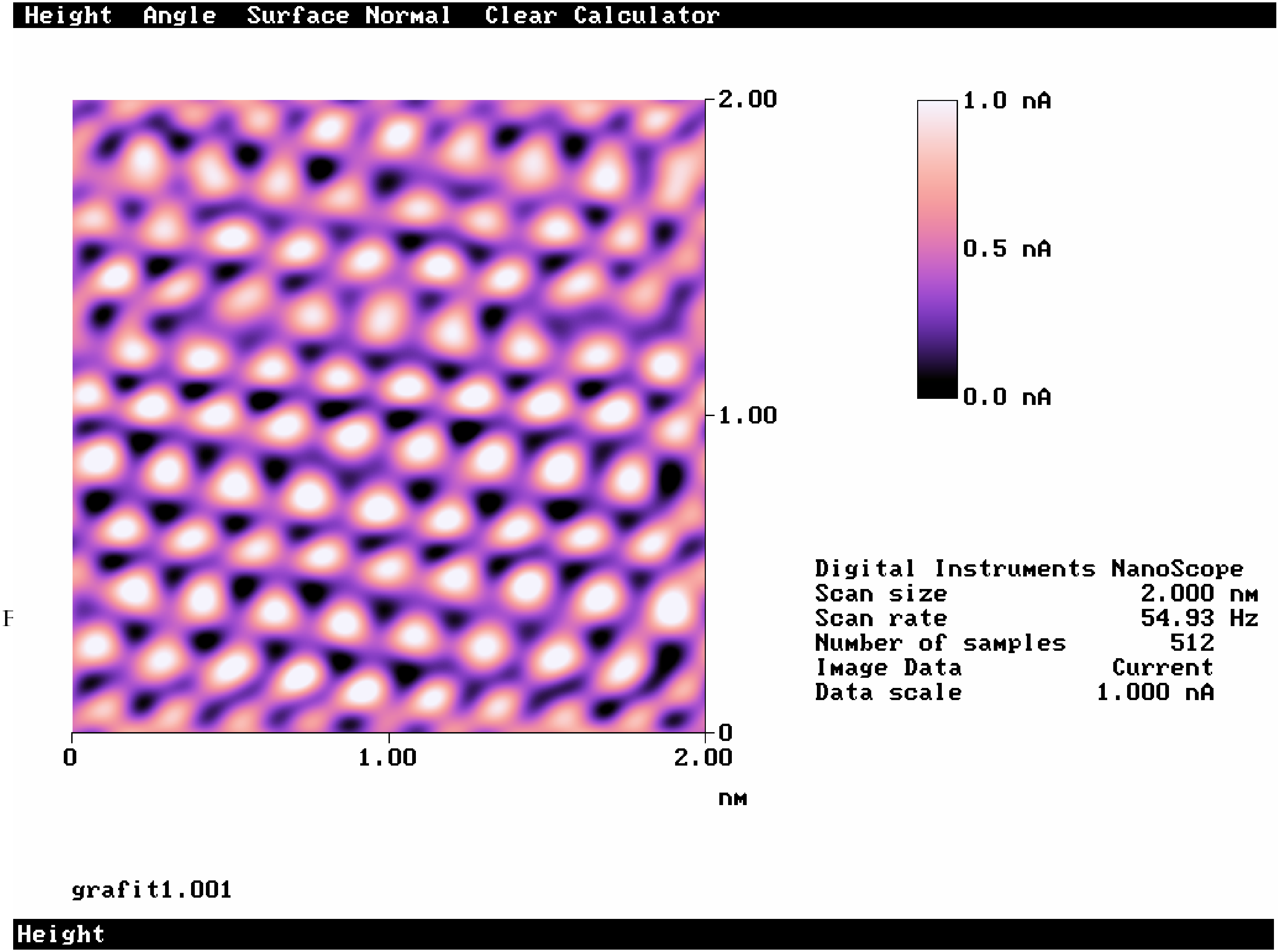
Andre Geim

Konstantin Novoselov

The Nobel Prize in Physics 2010 was awarded jointly to Andre Geim and Konstantin Novoselov *"for groundbreaking experiments regarding the two-dimensional material graphene"*

Grafit




Height Angle Surface Normal Clear Calculator
2.00
1.00
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0
1.00
2.00
nm
1.0 nA
0.5 nA
0.0 nA
Digital Instruments NanoScope
Scan size 2.000 nm
Scan rate 54.93 Hz
Number of samples 512
Image Data Current
Data scale 1.000 nA
grafit1.001
Height

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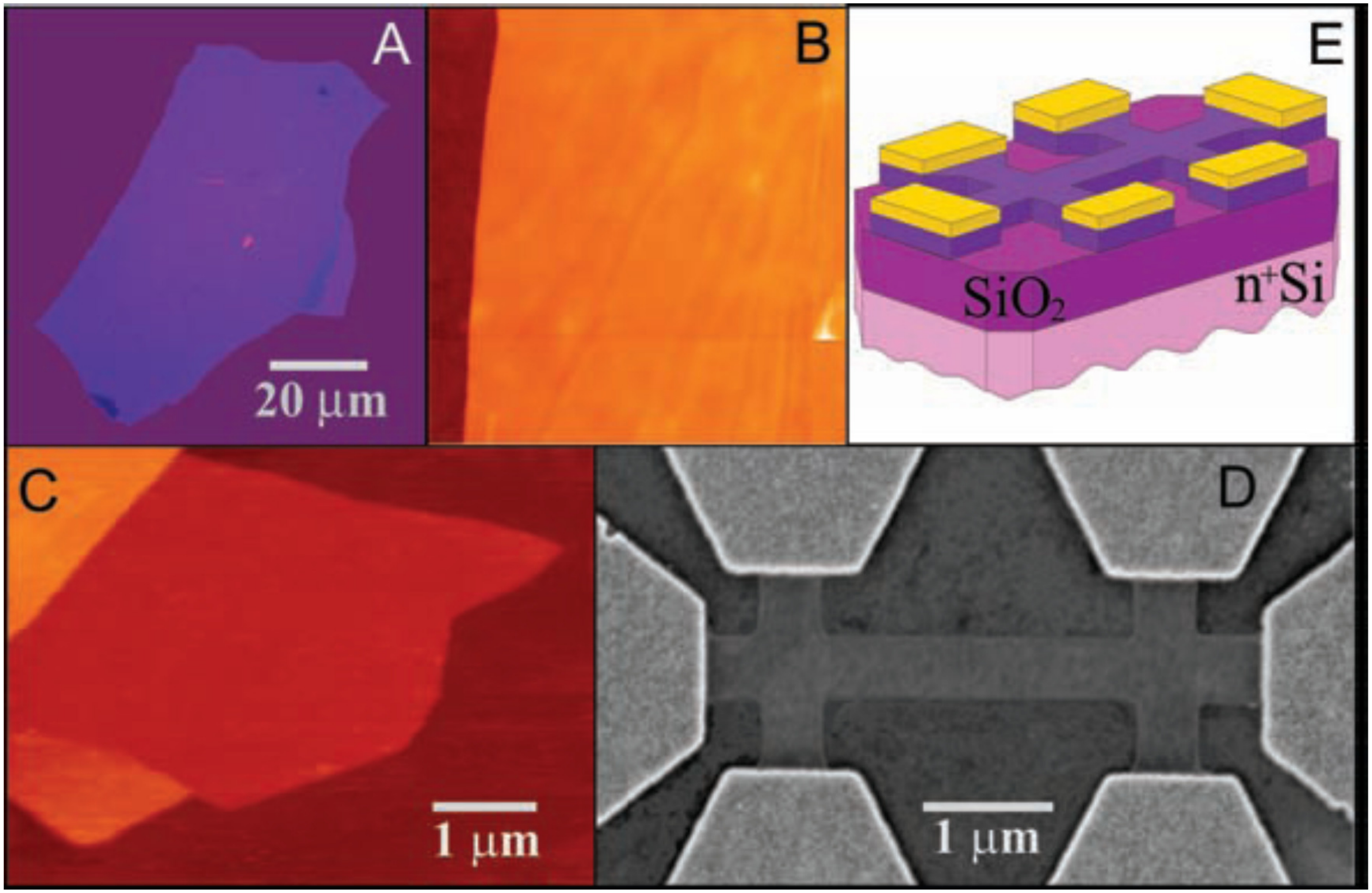
Metoda taśmy klejącej -
badanie tego co zwykle lądowało w koszu…

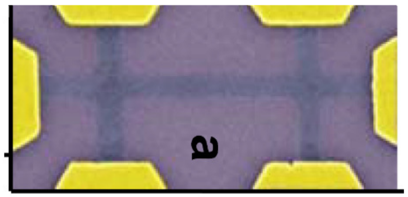


K. Novoselov, A. Geim *et al.* Science (2004)

płatki z kilku warstw,
rozmiary ~10 μm

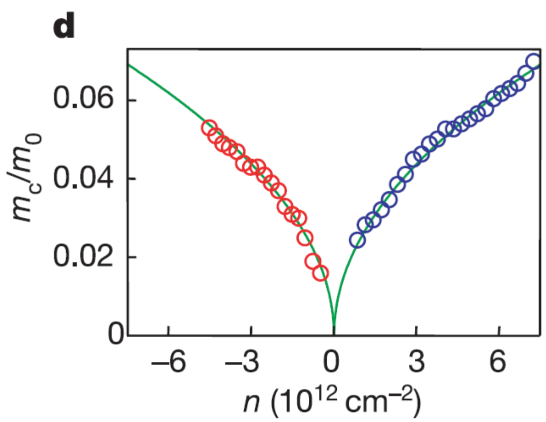
Two-dimensional gas of massless Dirac fermions in graphene

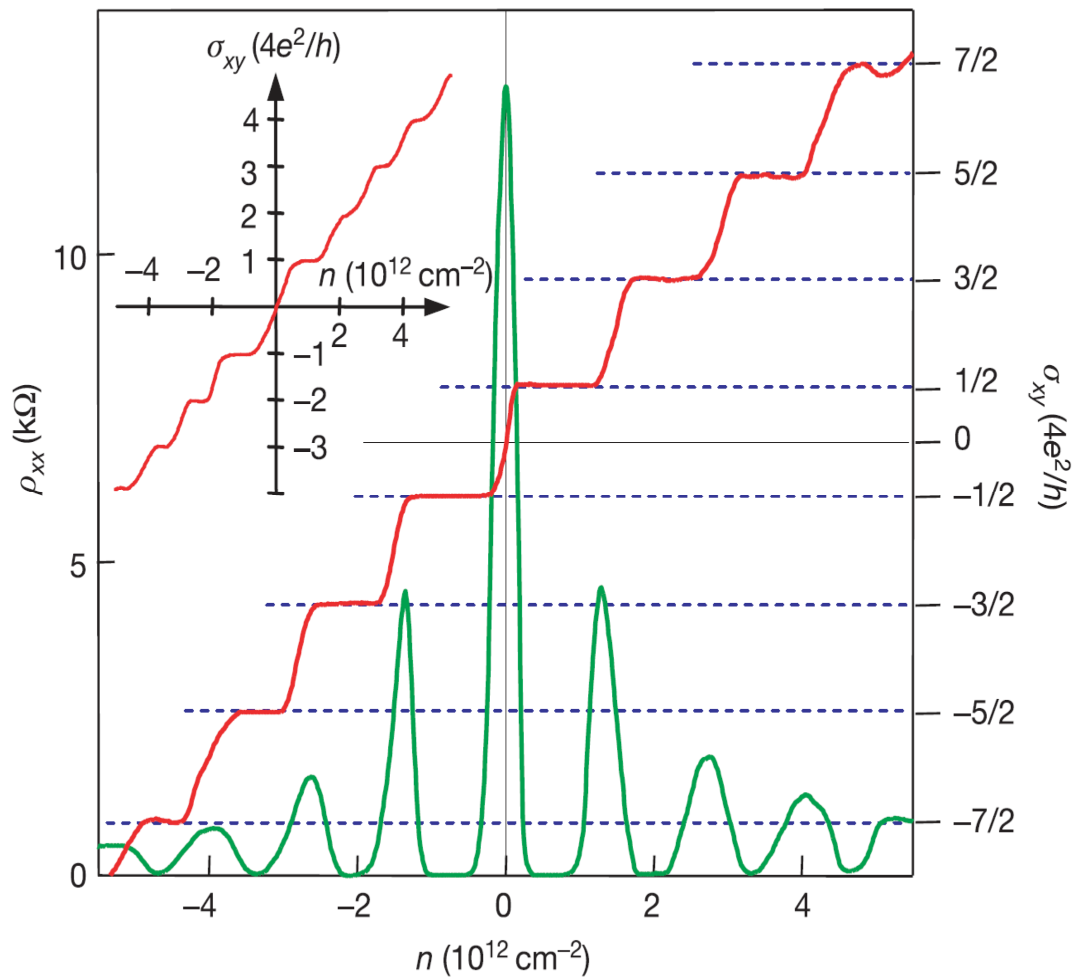
K. S. Novoselov[1], A. K. Geim[1], S. V. Morozov[2], D. Jiang[1], M. I. Katsnelson[3], I. V. Grigorieva[1], S. V. Dubonos[2] & A. A. Firsov[2]



Anomalny kwantowy efekt Halla

Pierwiastkowa zależność energii od pola magnetycznego!



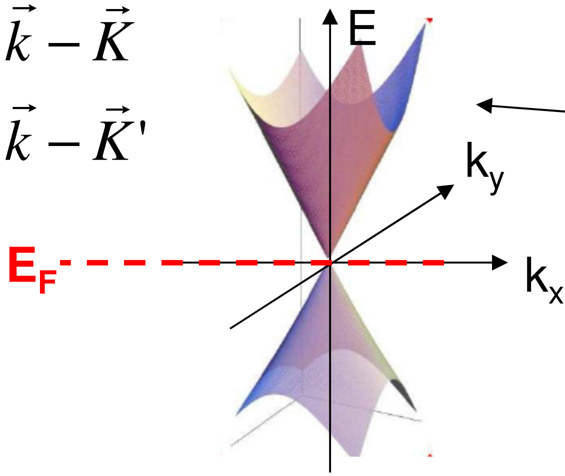


K. Novoselov *et al.*, Nature (2005)

Bezmasowe fermiony Diraca w pobliżu punktów *K, K'*

$$\vec{k} \to \vec{k} - \vec{K}$$

$$\vec{k} \to \vec{k} - \vec{K}'$$



$$\varepsilon = \pm \tilde{c} \cdot \left| \vec{p} \right|$$

Relacja dyspersyjna jak dla fotonu

$$c \to \tilde{c} \approx c / 300$$

$$\frac{3}{2} t \cdot a$$

$$\hat{\sigma} = (\hat{\sigma}_x, \hat{\sigma}_y, \hat{\sigma}_z)$$

$$\hat{H} = \tilde{c}\,\hat{\sigma} \cdot \vec{p} = \hbar \tilde{c}\,\hat{\sigma} \cdot \vec{k} = \gamma \hat{\sigma} \cdot \vec{k}$$

$$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$\sigma_x = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

$$\sigma_x = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$$\begin{pmatrix} 0 & \gamma(\hat{k}_x - i\hat{k}_y) \\ \gamma(\hat{k}_x + i\hat{k}_y) & 0 \end{pmatrix} \begin{pmatrix} F^A(\boldsymbol{r}) \\ F^B(\boldsymbol{r}) \end{pmatrix} = \varepsilon \begin{pmatrix} F^A(\boldsymbol{r}) \\ F^B(\boldsymbol{r}) \end{pmatrix}$$

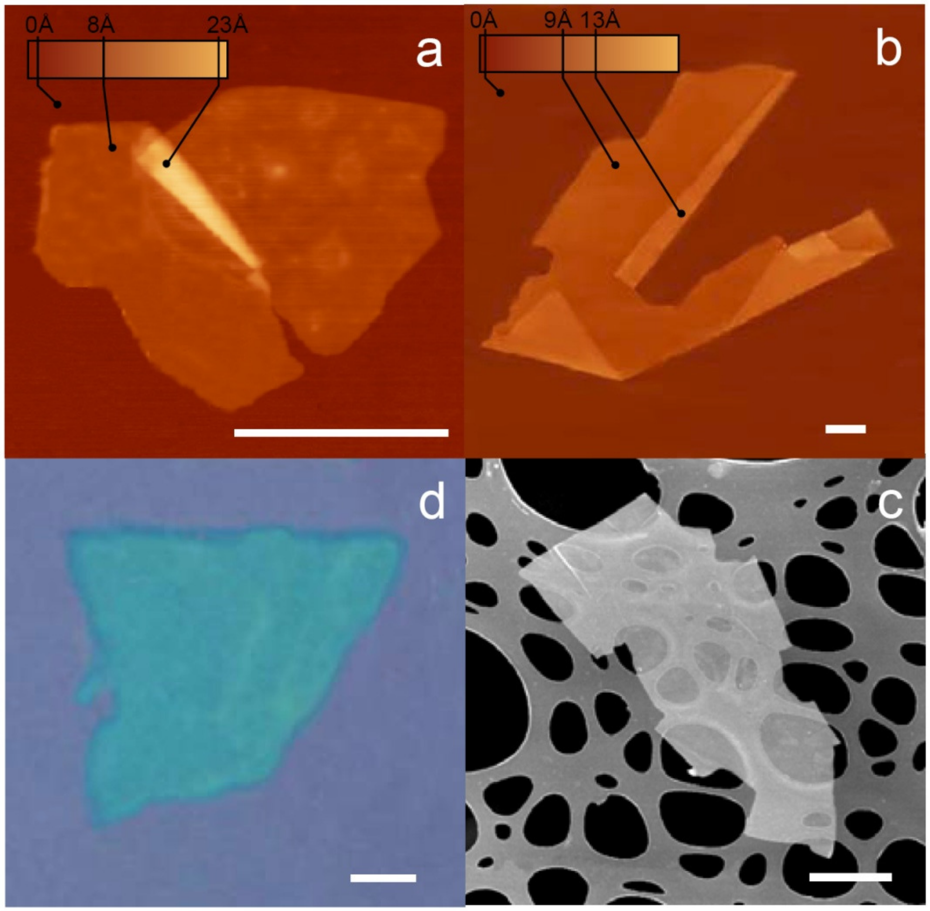
Równianie Diraca dla bezmasowych fermionów!

A.H. Castro Neto et al., Rev. Mod. Phys. (2009)

Inne kryształy dwuwymiarowe

Pojedyncze warstwy

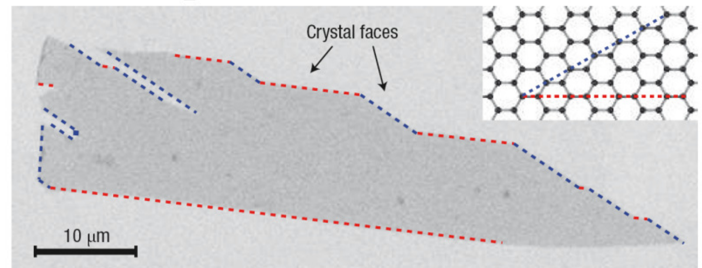
$NbSe_2$
na Si/SiO_2



MoS_2
na Si/SiO_2

grafit
on Si/SiO_2

grafen „duży płatek"



$Bi_2Sr_2CaCu_2O_x$
on carbon

K.S. Novoselov, *et al., Two-dimensional atomic crystals*, *Proc. Natl Acad. Sci. USA,* **102,** 10451–10453 (2005)
K.S. Novoselov and A.K. Geim, *The rise of graphene*, Nature Materials, **6**, 183, (2007)

Kryształy 2D

Graphene family	Graphene	hBN 'white graphene'	BCN	Fluorographene	Graphene oxide
2D chalcogenides	MoS_2, WS_2, $MoSe_2$, WSe_2	Semiconducting dichalcogenides: $MoTe_2$, WTe_2, ZrS_2, $ZrSe_2$ and so on	Metallic dichalcogenides: $NbSe_2$, NbS_2, TaS_2, TiS_2, $NiSe_2$ and so on		
			Layered semiconductors: GaSe, GaTe, InSe, Bi_2Se_3 and so on		
2D oxides	Micas, BSCCO	MoO_3, WO_3	Perovskite-type: $LaNb_2O_7$, $(Ca,Sr)_2Nb_3O_{10}$, $Bi_4Ti_3O_{12}$, $Ca_2Ta_2TiO_{10}$ and so on	Hydroxides: $Ni(OH)_2$, $Eu(OH)_2$ and so on	
	Layered Cu oxides	TiO_2, MnO_2, V_2O_5, TaO_3, RuO_2 and so on		Others	

A. K. Geim & I. V. Grigorieva, Nature 499, 419 (2013)

Jak badać grubość warstw?

Interferencja

Szkolny konkurs fotograficzny „Ciekawe zjawisko fizyczne, reakcja chemiczna”

hasłem „Chemia jest ny wszędzie”

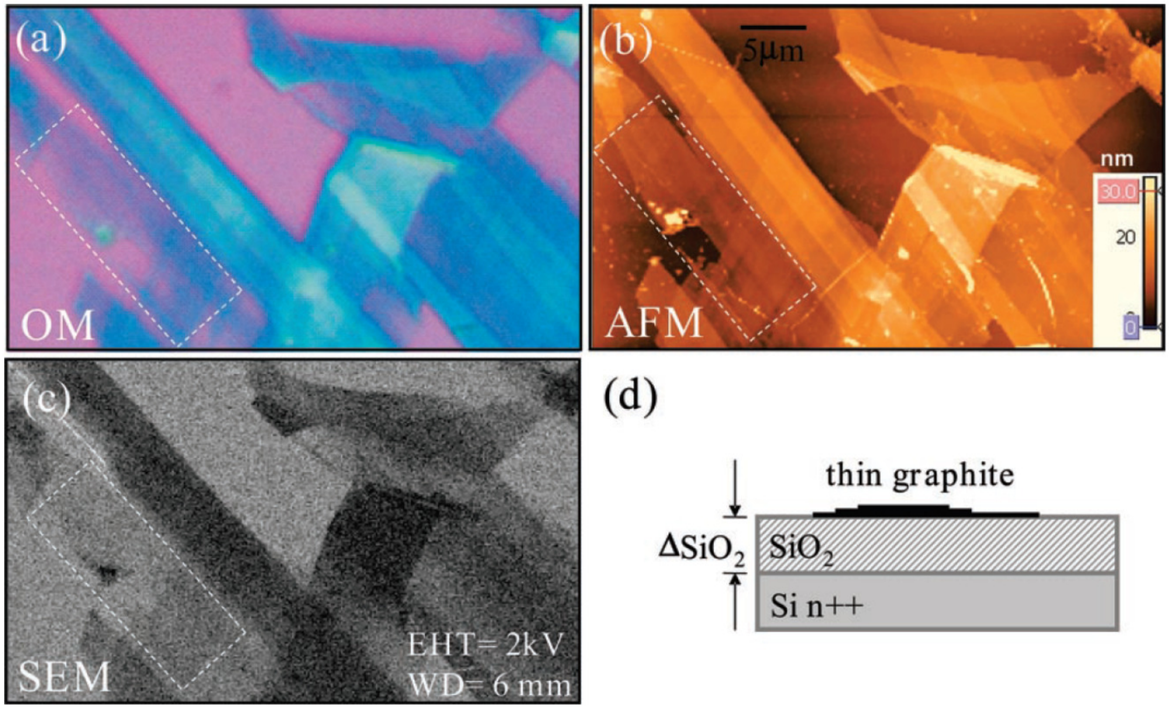
I miejsce

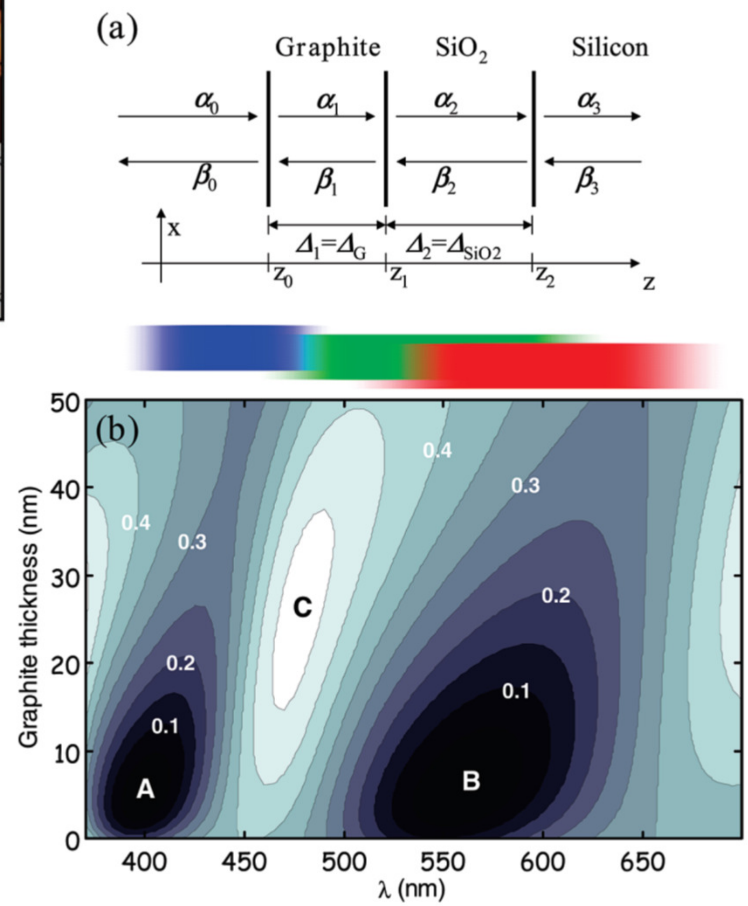
Jacek Płonka

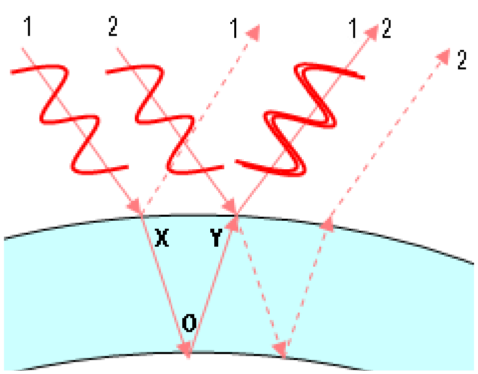
klasa Ia gimnazjum

Szkoła Podstawowa Nr 20 w Jastrzębiu Zdroju z oddziałami gimnazjum (Gimnazjum Nr 9)

Obecność grafenu modyfikuje interferencję!



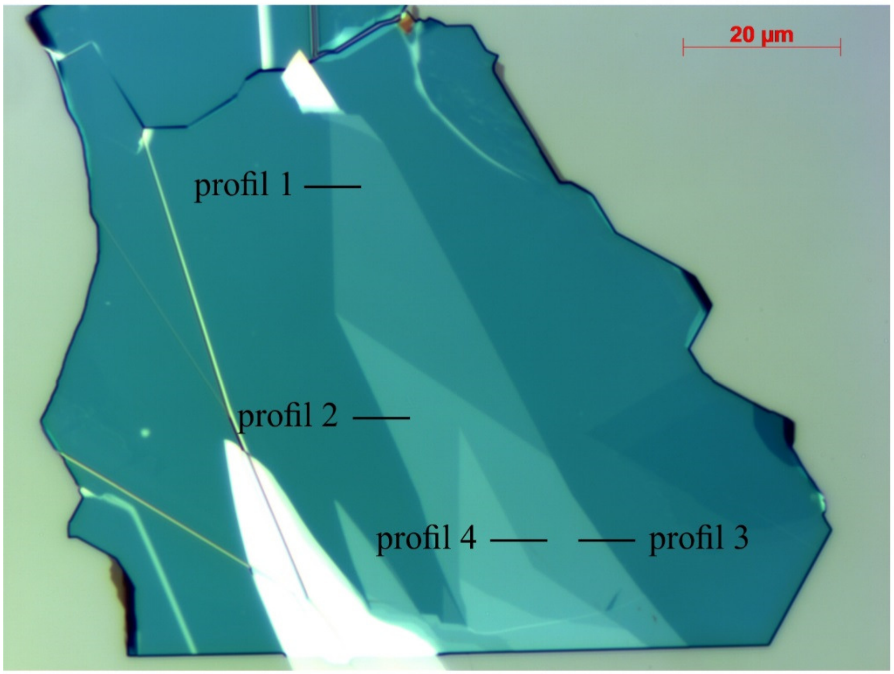


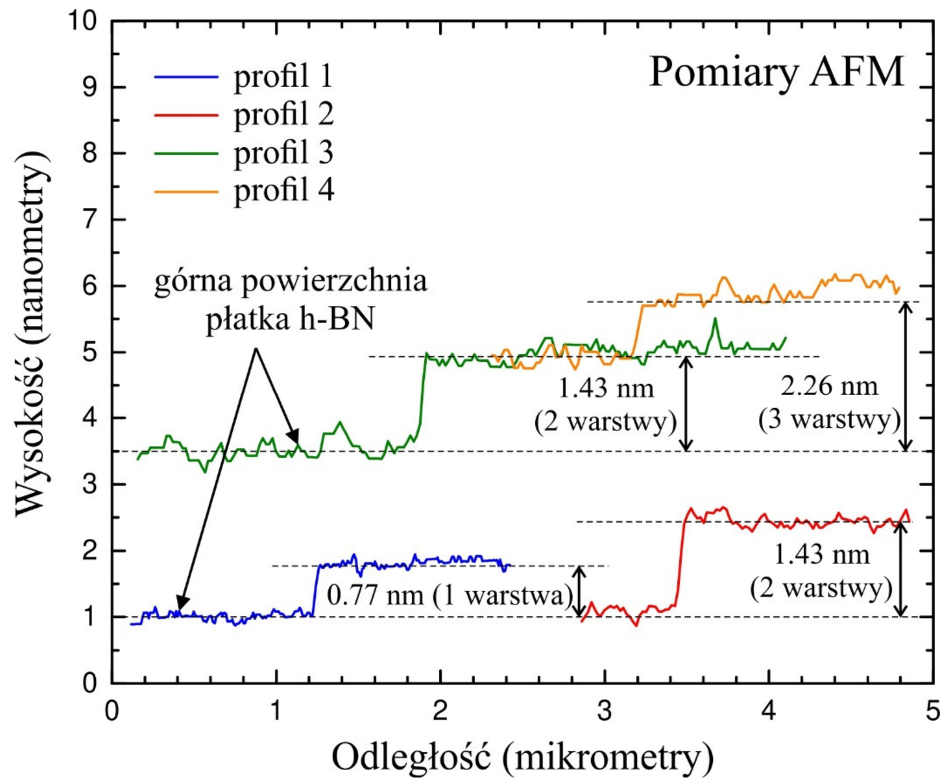


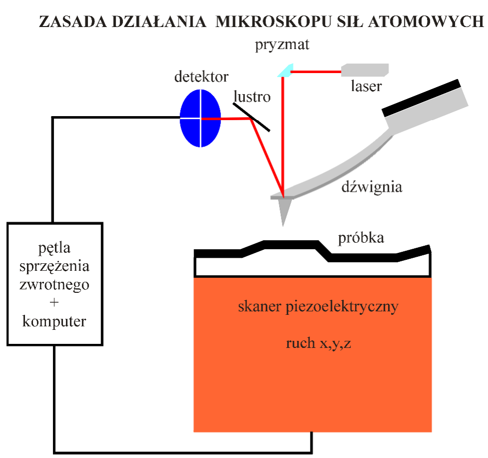
wikimedia.org

S. Roddaro et al. Nano Lett., 7, 2707 (2007)

Porównanie: mikroskop optyczny - mikroskop sił atomowych (AFM)



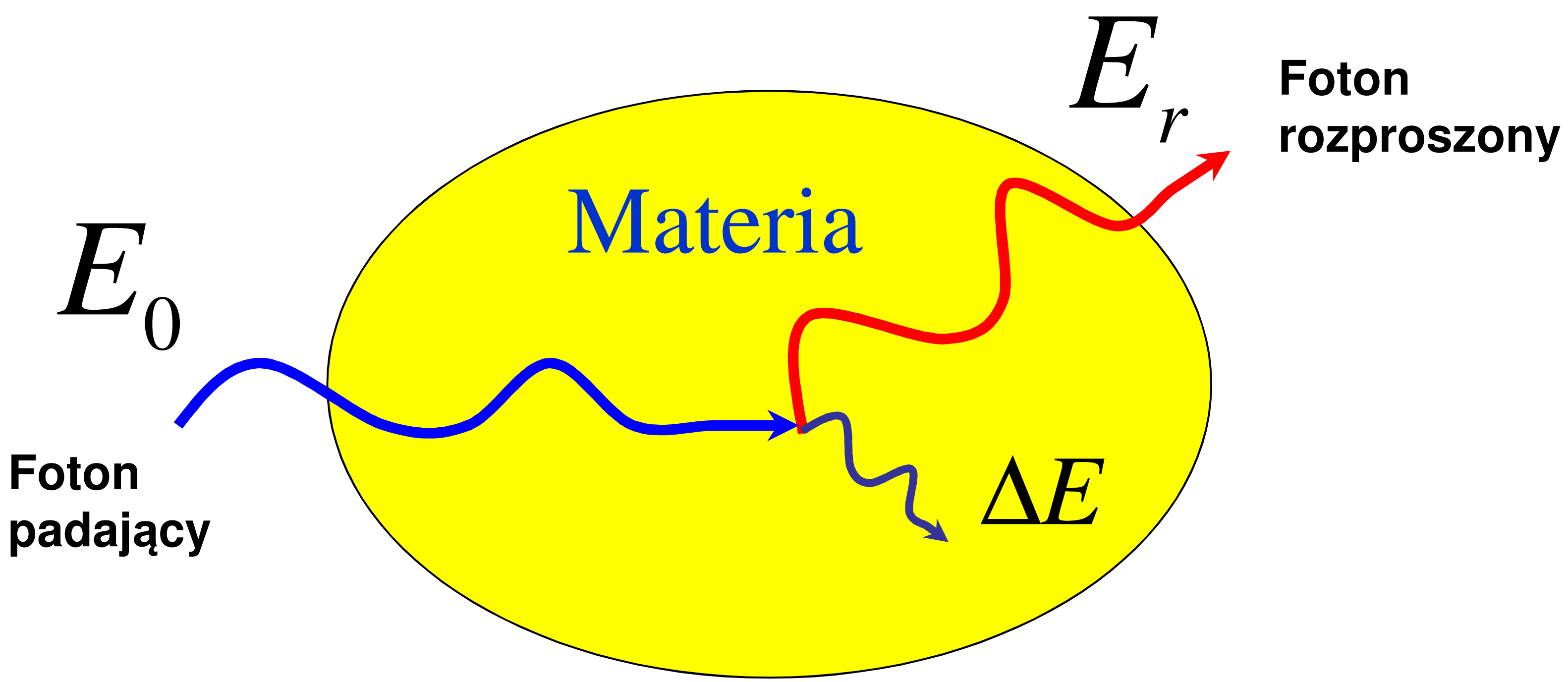




Płatki disiarczku molibdenu (MoS_2) na azotku boru (BN)

K. Nogajewski (2018)
Wydział Fizyki, NHMF Grenoble

Efekt Ramana

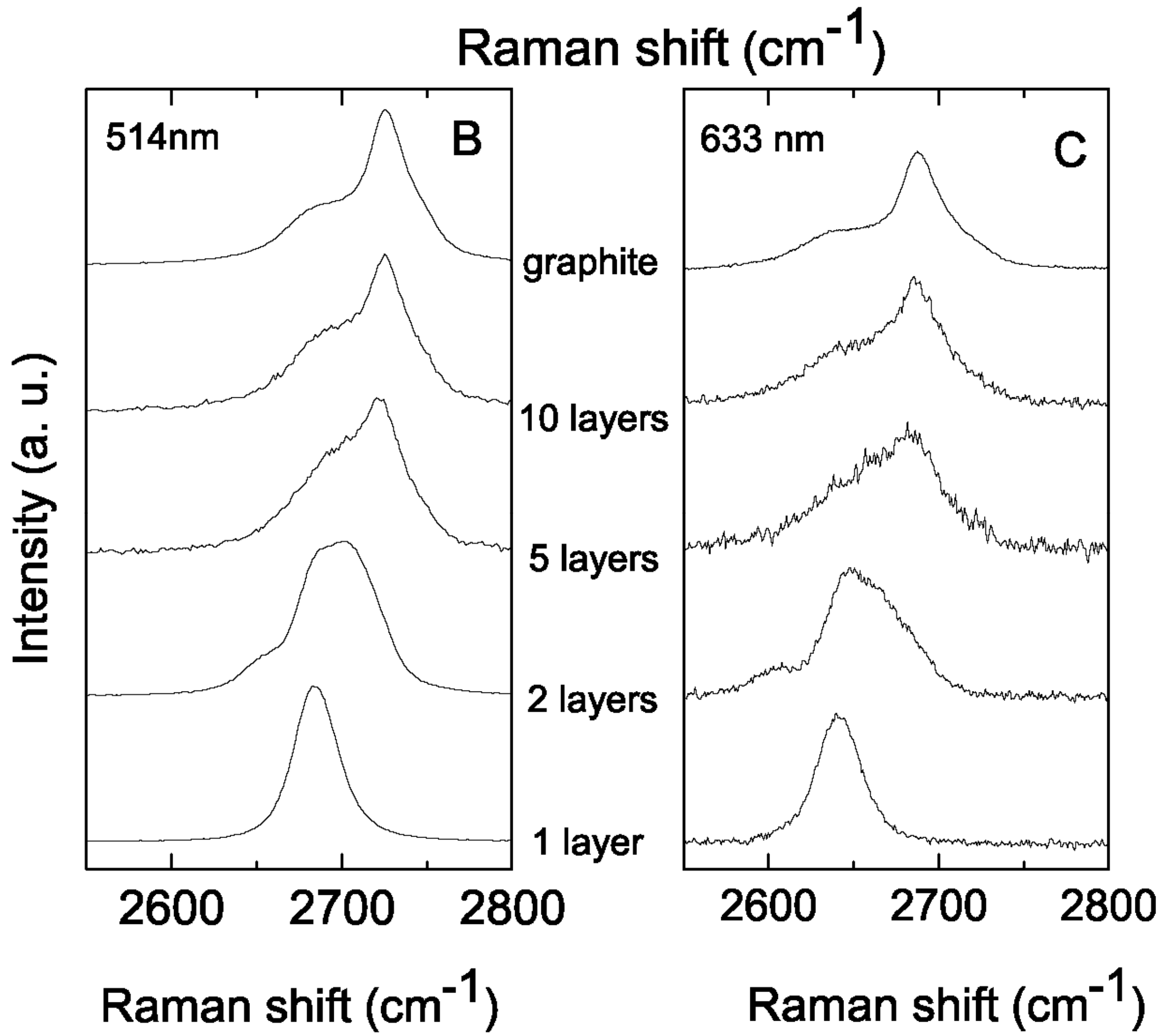


$$\Delta E = E_0 - E_r$$

Nieelastyczne rozpraszanie światła

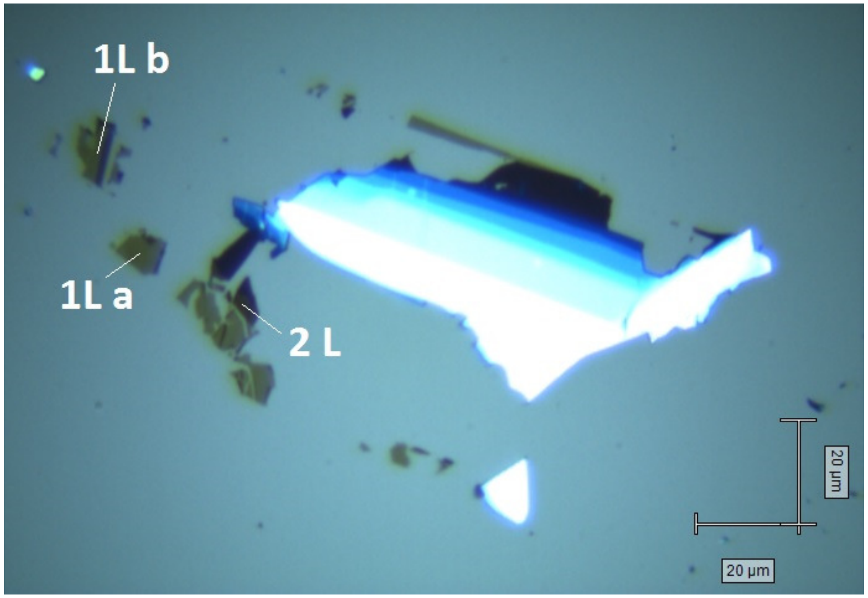
Energia pozostawiona przez foton w materii równa jest różnicy energii fotonu padającego i rozproszonego

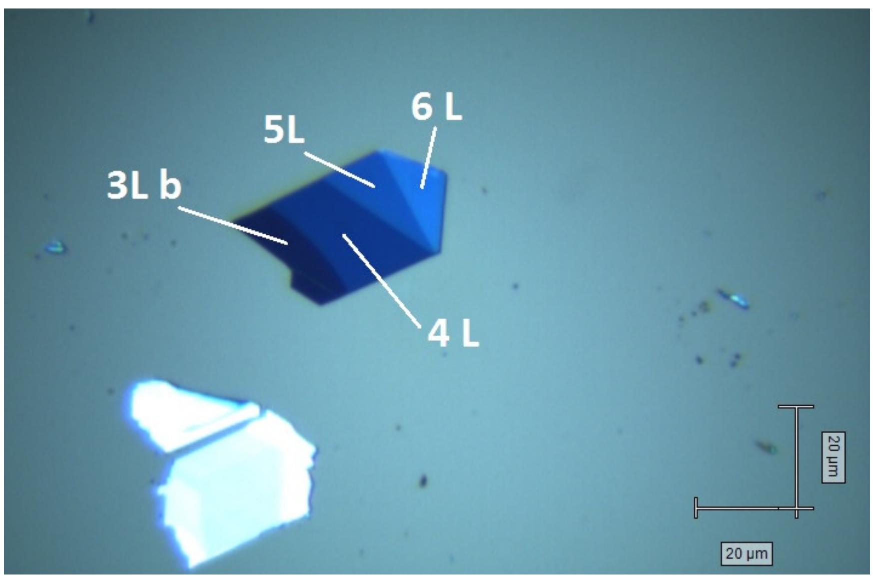
Od grafitu do grafenu

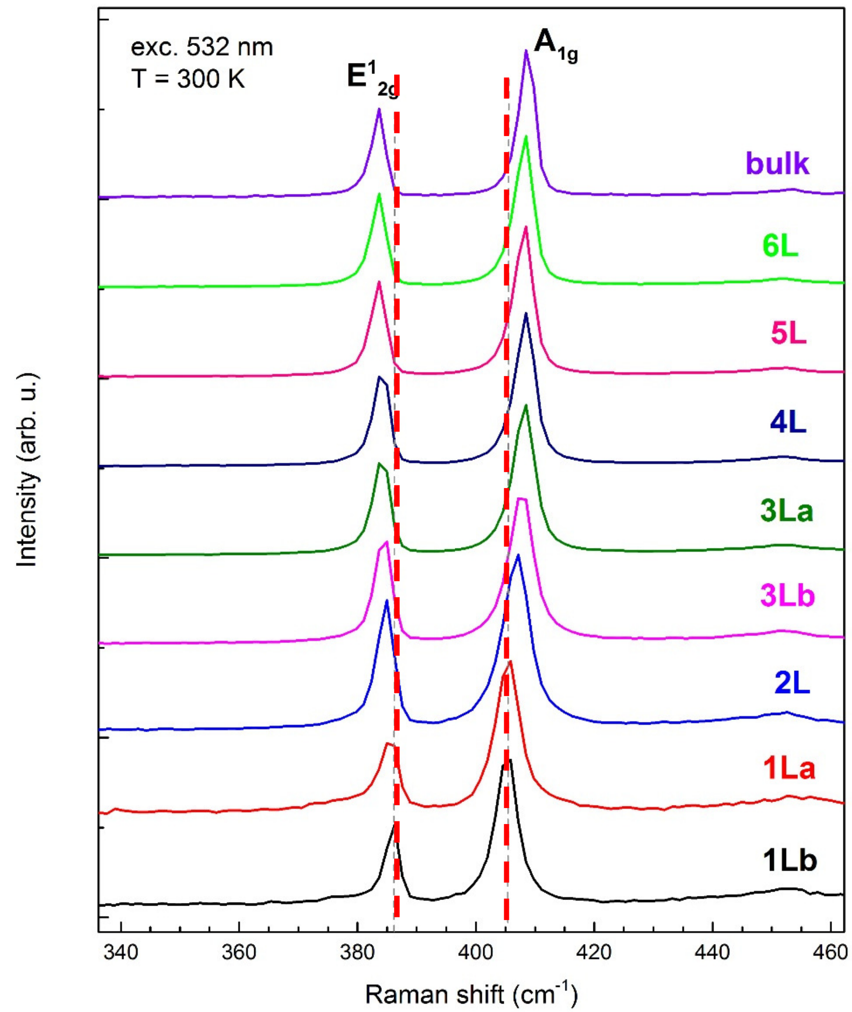


A.C. Ferrari et al.Phys. Rev. Lett. 97, 187401 (2006)

Liczenie warstw MoS_2







Ewa Łacińska (2017)
Wydział Fizyki UW

Wróćmy do grafenu…

- wysoka ruchliwość elektronów (200000 cm^2/Vs)
- duża gęstość krytyczna prądu ~10^8 A/cm^2
- bardzo wysokie przewodnictwo cieplne
- bardzo duża wytrzymałość mechaniczna
- przezroczystość…
- …

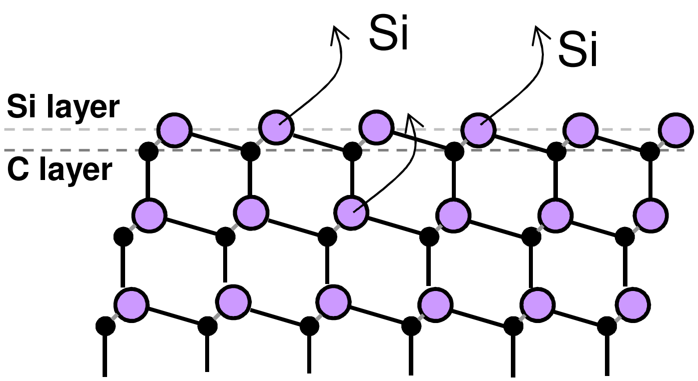
Wspaniały materiał!

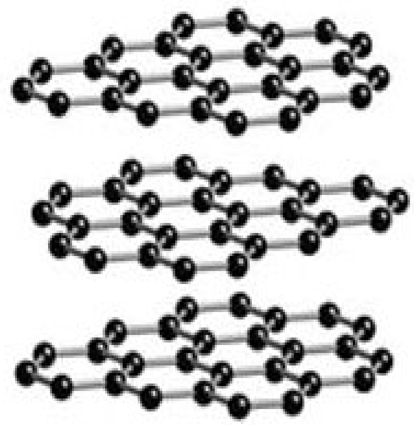
„Tradycyjna” metoda otrzymywania grafenu…

Wygrzewanie SiC

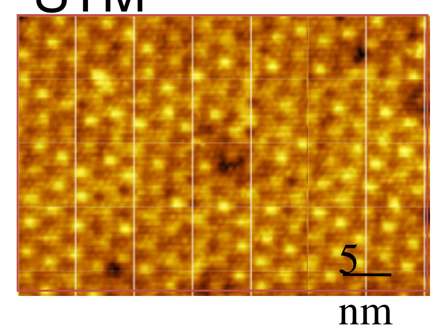
T (>1400°C); wysoka próżnia

SiC → **Kilka, kilkadziesiąt warstw węglowych**





STM



van Bommel *et al.*, Surface Science 1975
Oshima *et al.*, J. Phys. Cond. Matt. 1997
Forbeaux *et al.*, PRB 1998
Berger *et al.*, J. Phys. Chem. 2004, Science 2006

WYDZIAŁ FIZYKI UNIWERSYTET WARSZAWSKI

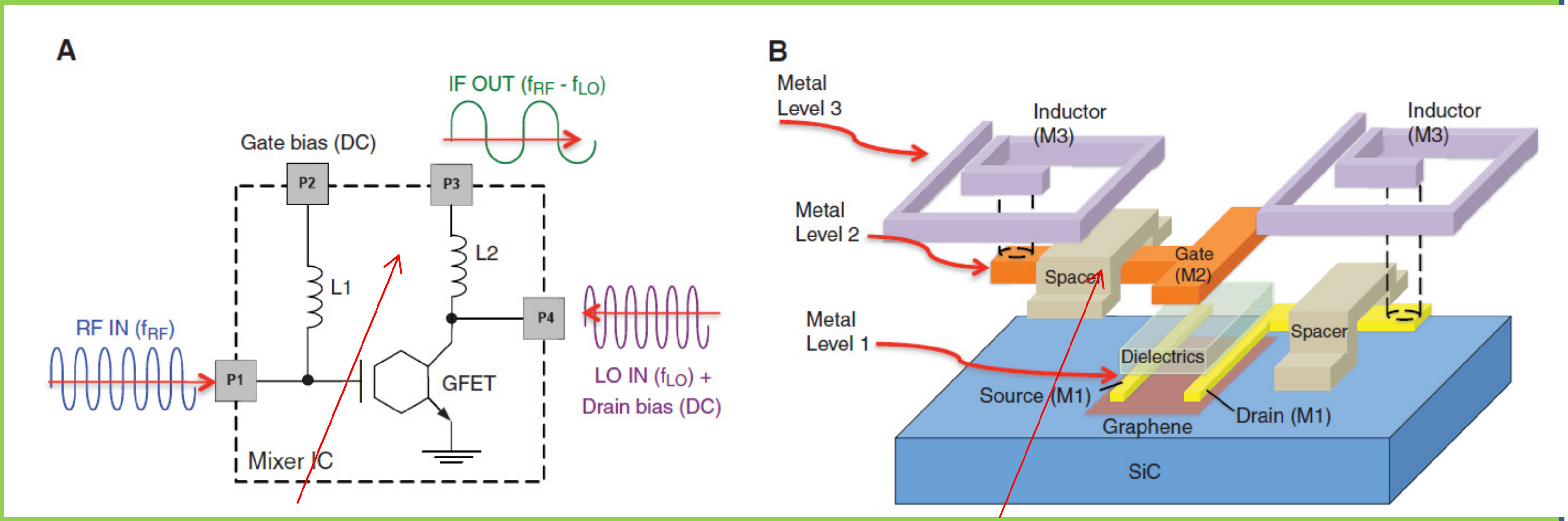
ITME

2006/2007

Układ scalony z tranzystorem z grafenu…

A) Schemat ideowy układu – mieszacza częstotliwości radiowej 10 GHz

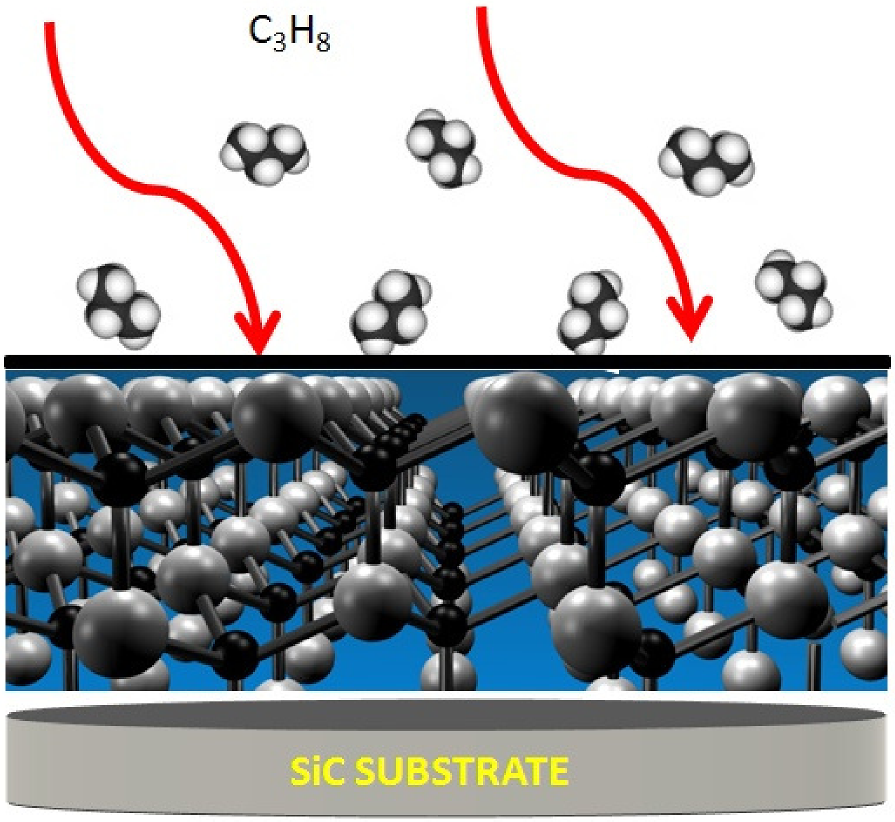
B) Schemat montażowy



Yu-Ming Lin et al., *Wafer-Scale Graphene Integrated Circuit*

10 JUNE 2011 VOL 332 SCIENCE

Brak przerwy energetycznej – problem dla grafenowej elektroniki cyfrowej…



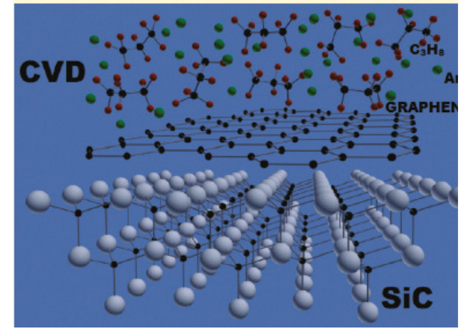
„Prawdziwa epitaksja" – polski pomysł na grafen (dr W. Strupiński, ITME)

Zalety
- **kontrola transportu masy**
- **mniejsze naprężenia warstw**
- **mniejsza wrażliwość na stopnie na podłożach**
- **lepsza kontrola grubości**
- **kompatybilność z technologią SiC**

NANO LETTERS

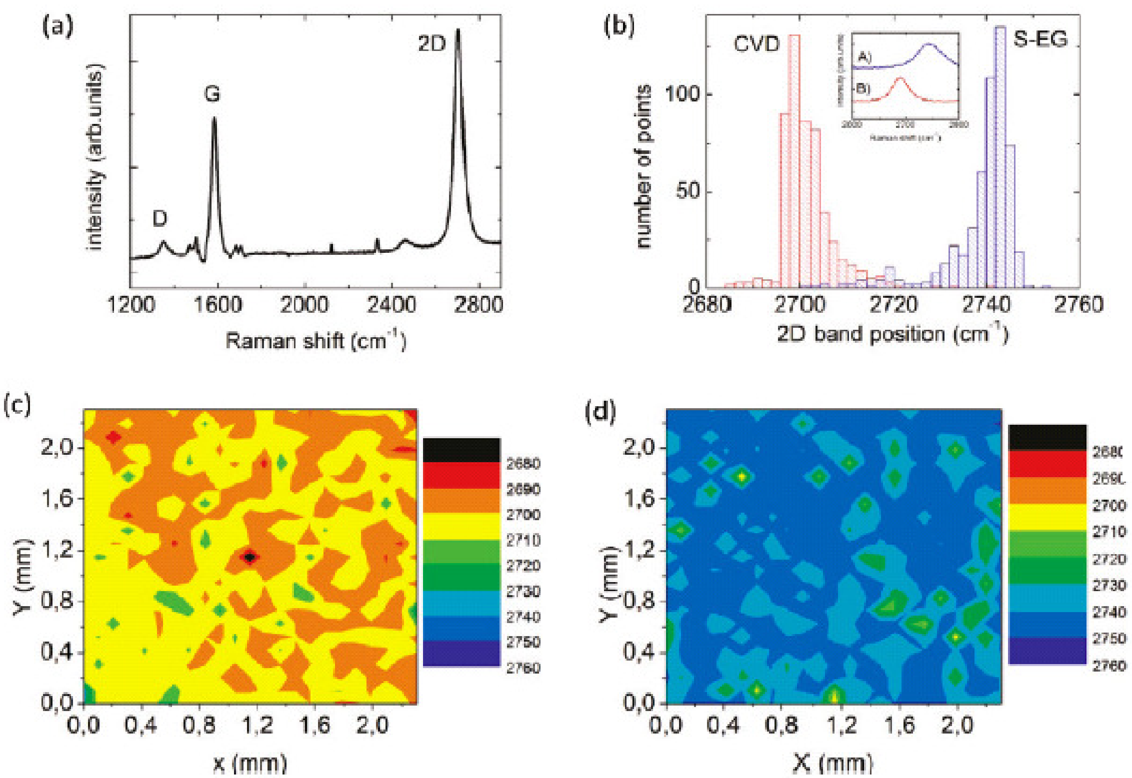
LETTER

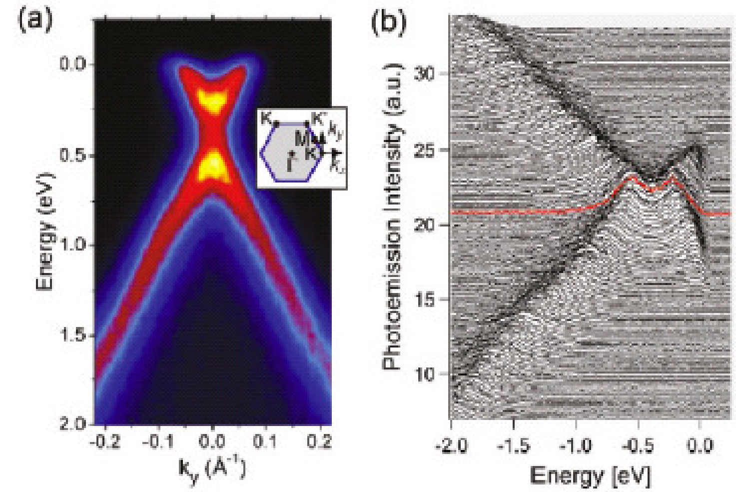
pubs.acs.org/NanoLett

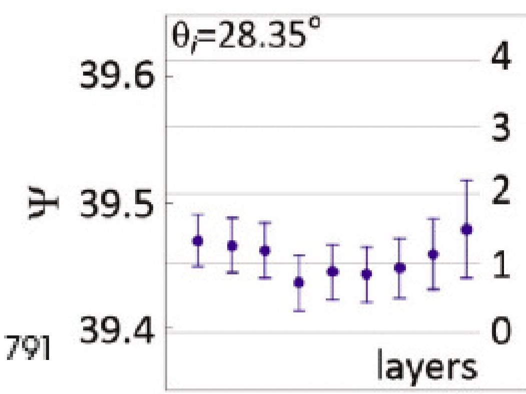


Graphene Epitaxy by Chemical Vapor Deposition on SiC

W. Strupinski,*[1] K. Grodecki,[1,2] A. Wysmolek,[2] R. Stepniewski,[2] T. Szkopek,[3] P. E. Gaskell,[3] A. Grüneis,[4,5] D. Haberer,[4] R. Bozek,[2] J. Krupka,[6] and J. M. Baranowski[1,2]

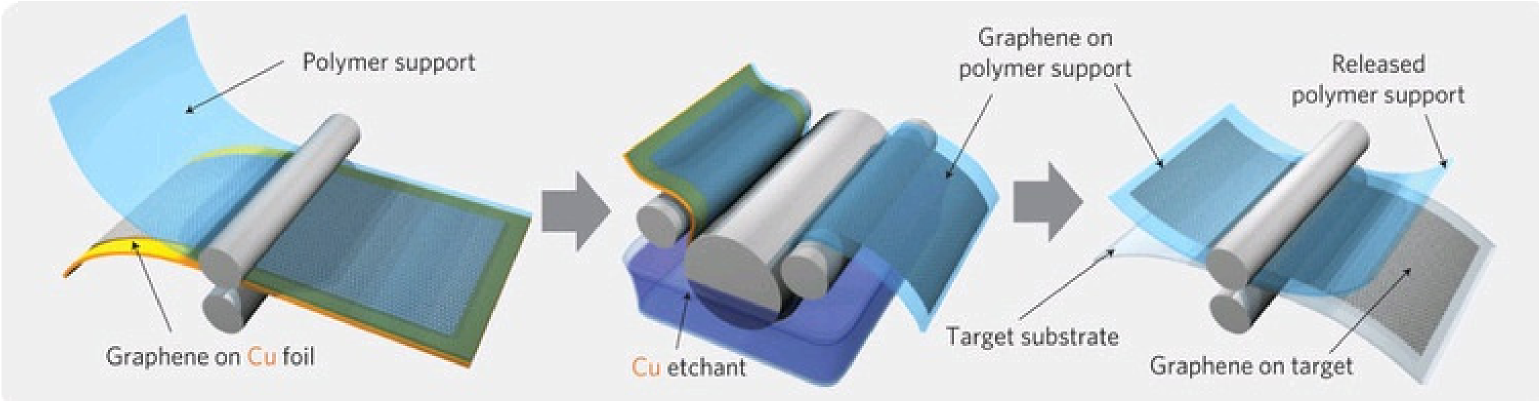


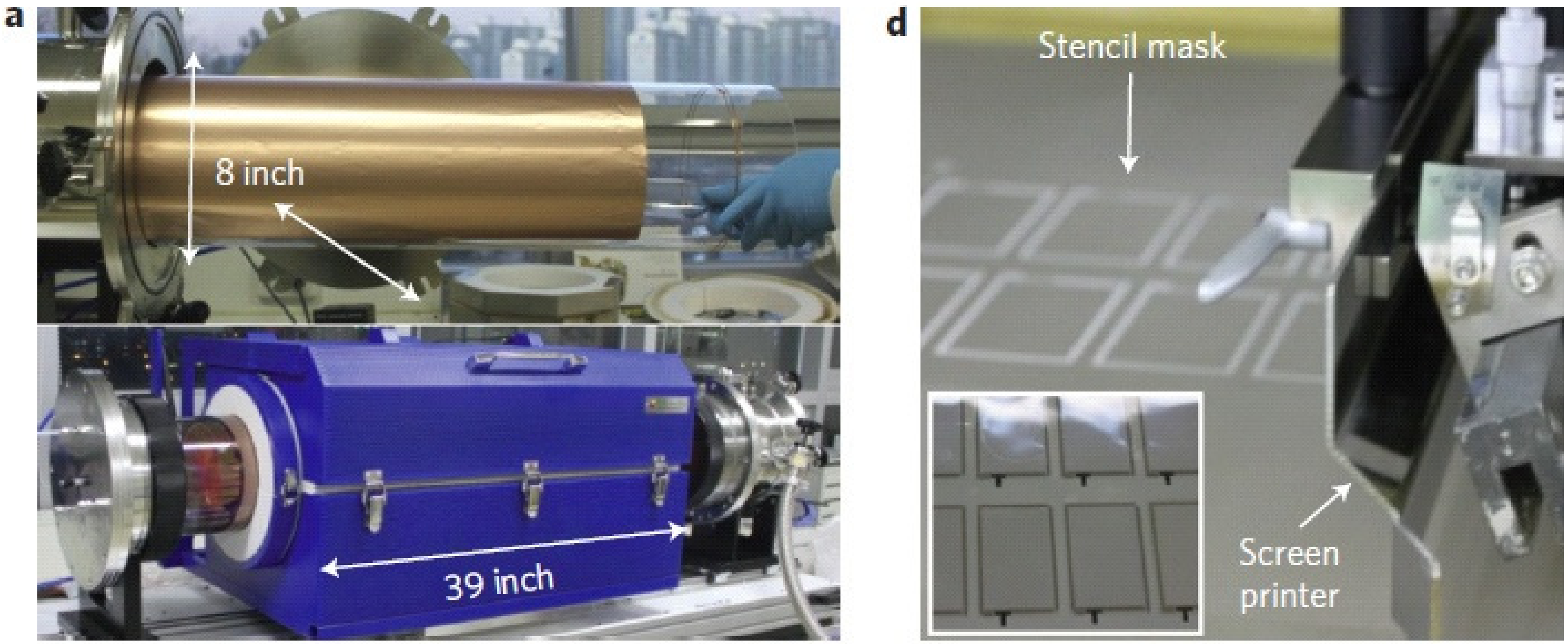




|Nano Lett. 2011, 11, 1786–1791

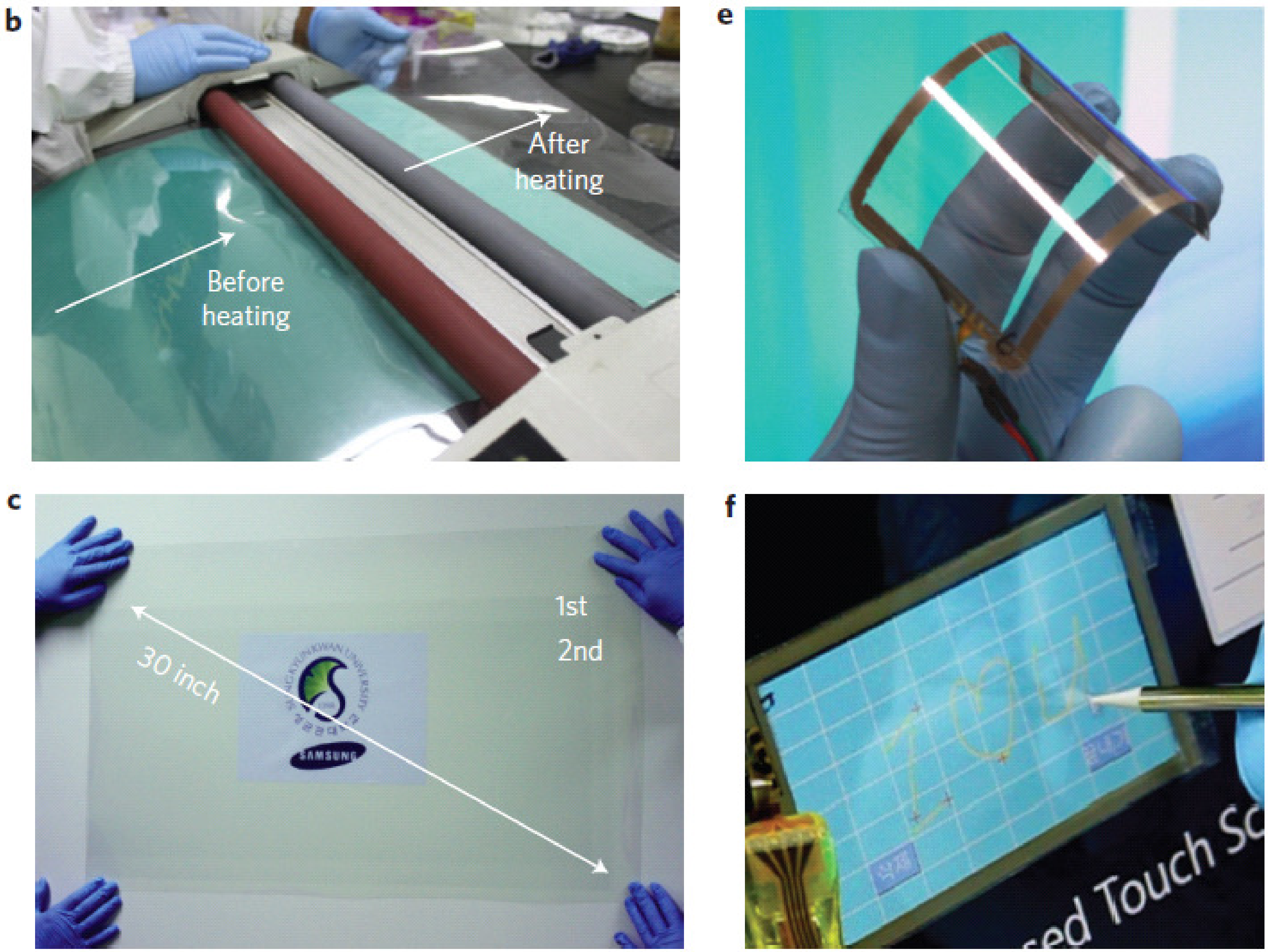
Grafen „roll-to-roll”





Bae et al. NATURE NANOTECHNOLOGY 5,574 (2010)

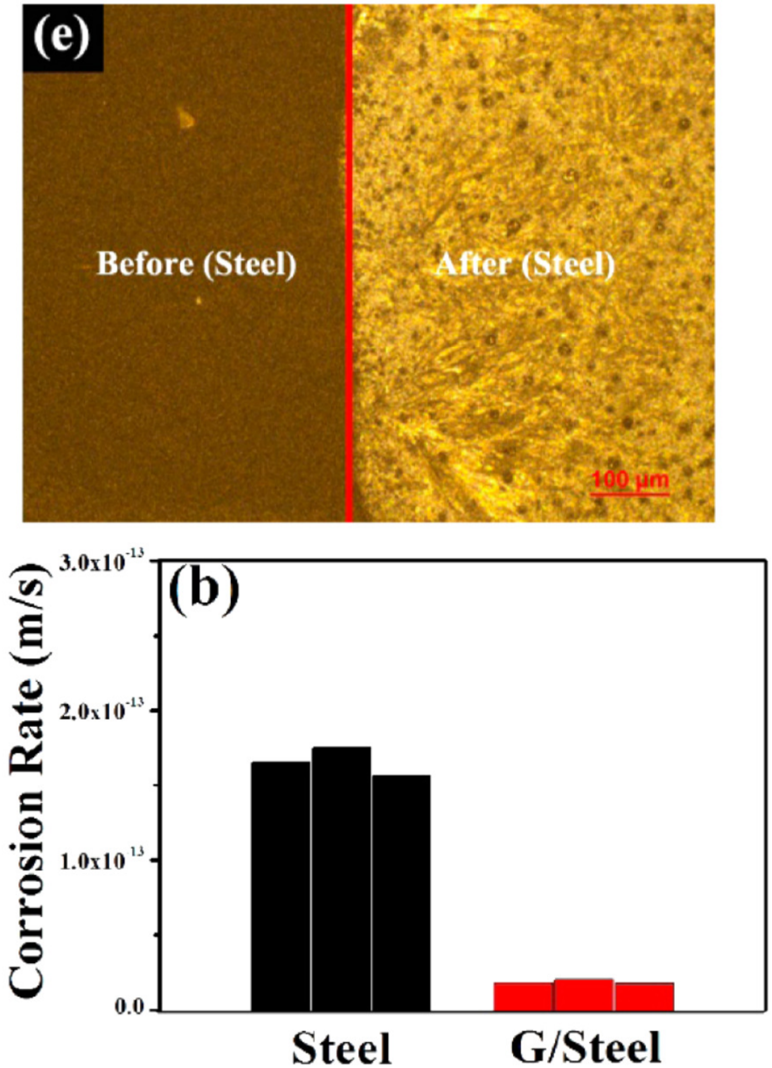
NATURE NANOTECHNOLOGY



Bae et al. NATURE NANOTECHNOLOGY 5,574 (2010)

Pokrycia antykorozyjne

Korozja - USA – straty 1000 Miliardów $ rocznie !!!



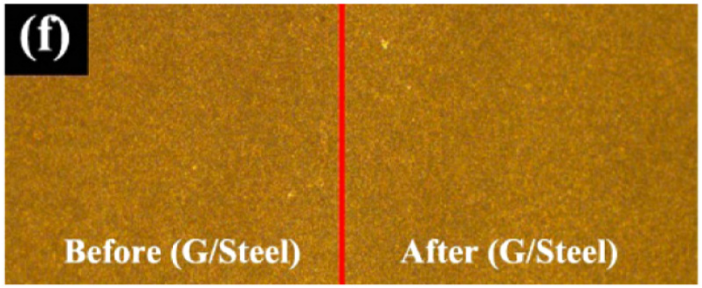


Table 1. Corrosion Current (I_{corr}), Corrosion Potential (E_{corr}), Corrosion Rate (R_{corr}), and Corrosion Reduction Times[a]

	I_{corr} (A/cm^2)	E_{corr} (V)	R_{corr} (m/s)	reduction times
steel	5.41×10^{-5}	0.188	1.75×10^{-13}	
G/steel	6.25×10^{-5}	0.167	2.02×10^{-14}	8.6
Cu	5.61×10^{-5}	0.210	3.75×10^{-13}	
G/Cu	6.64×10^{-5}	0.176	2.42×10^{-14}	15.4
Ni	5.78×10^{-6}	0.215	6.65×10^{-14}	
G/Ni	6.95×10^{-7}	0.191	3.22×10^{-15}	20.6
Ni NF	5.88×10^{-6}	0.211	6.22×10^{-14}	
G/Ni NF	6.86×10^{-7}	0.187	3.35×10^{-15}	18.6
CuNi NF	5.01×10^{-5}	0.193	4.85×10^{-13}	
G/CuNi NF	6.15×10^{-5}	0.179	2.92×10^{-14}	16.6
Cu NF	5.11×10^{-5}	0.185	4.15×10^{-13}	
G/Cu NF	6.35×10^{-5}	0.173	2.98×10^{-14}	13.9

[a]Deduced by extrapolating the Tafel anodic and cathodic linear parts until they intersect as straight lines.

M. Zhu et al. ACS Appl. Mater. Interfaces, **2016**, *8* (1), pp 502–510

Efektywność powłok grafenowych

	I_{corr} (A/cm^2)	E_{corr} (V)	R_{corr} (m/s)	reduction times
steel	5.41×10^{-5}	0.188	1.75×10^{-13}	
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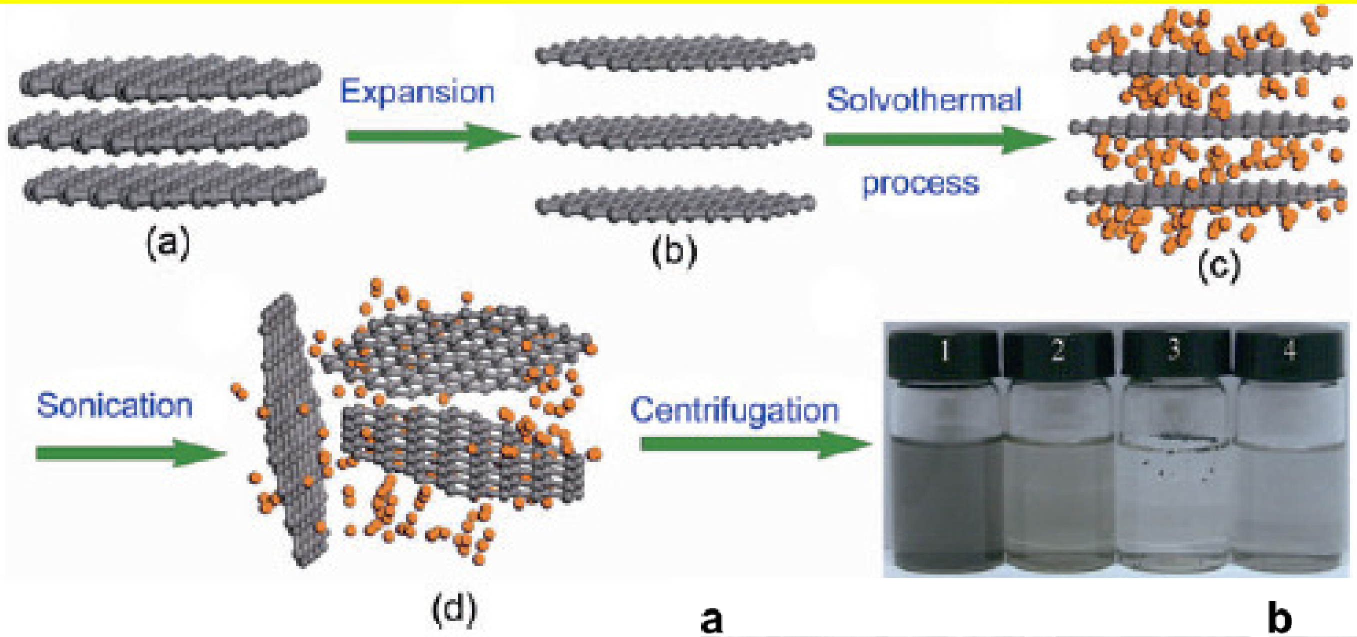
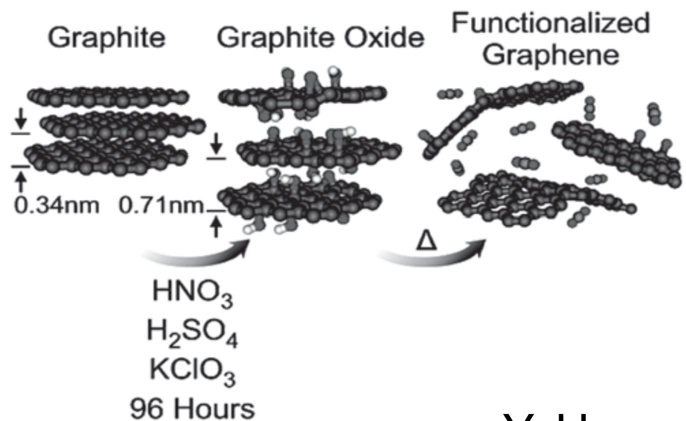
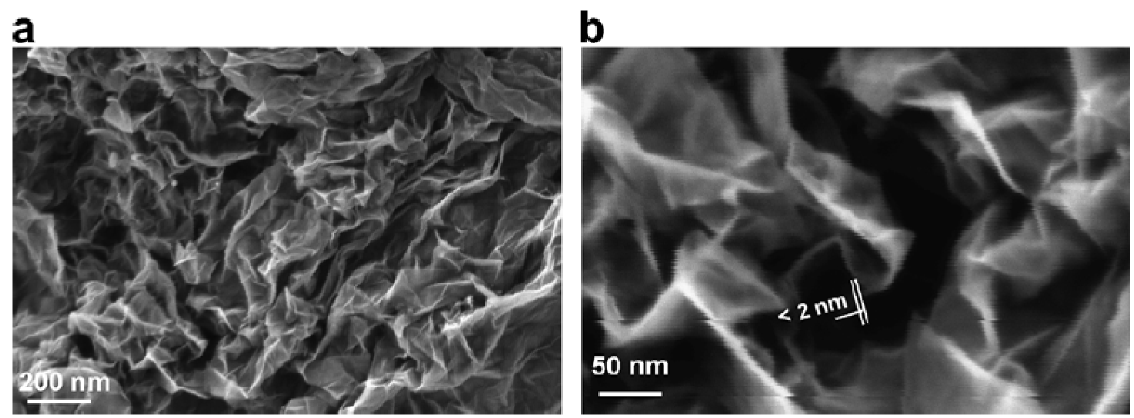
M. Zhu et al. ACS Appl. Mater. Interfaces, **2016**, *8* (1), pp 502–510

Rozwarstwianie grafitu…

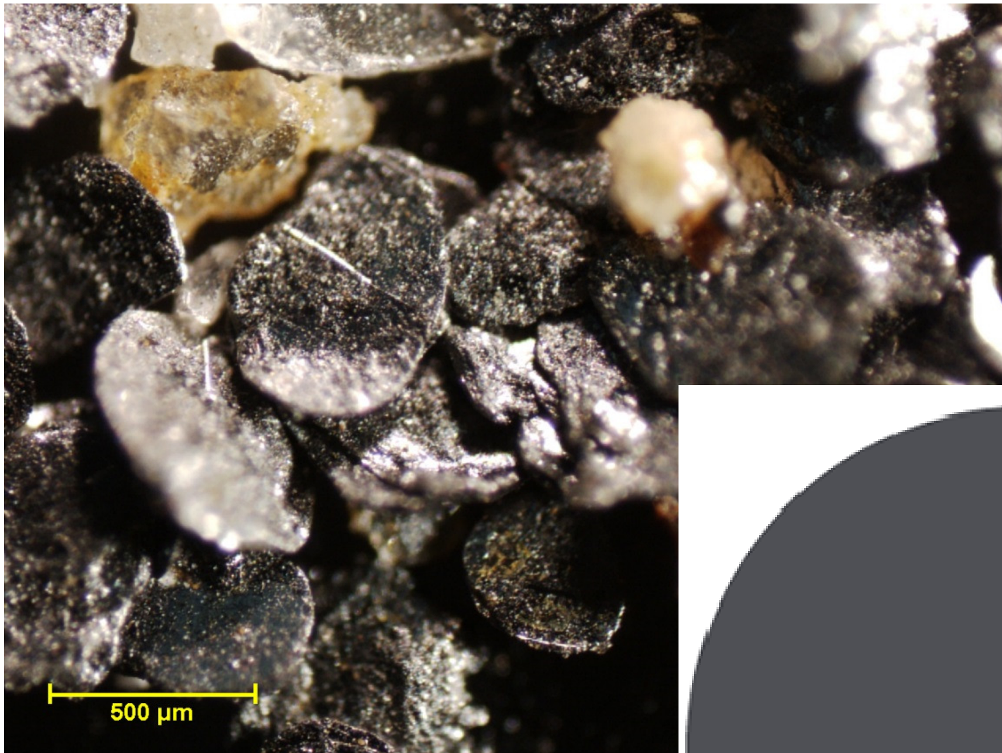


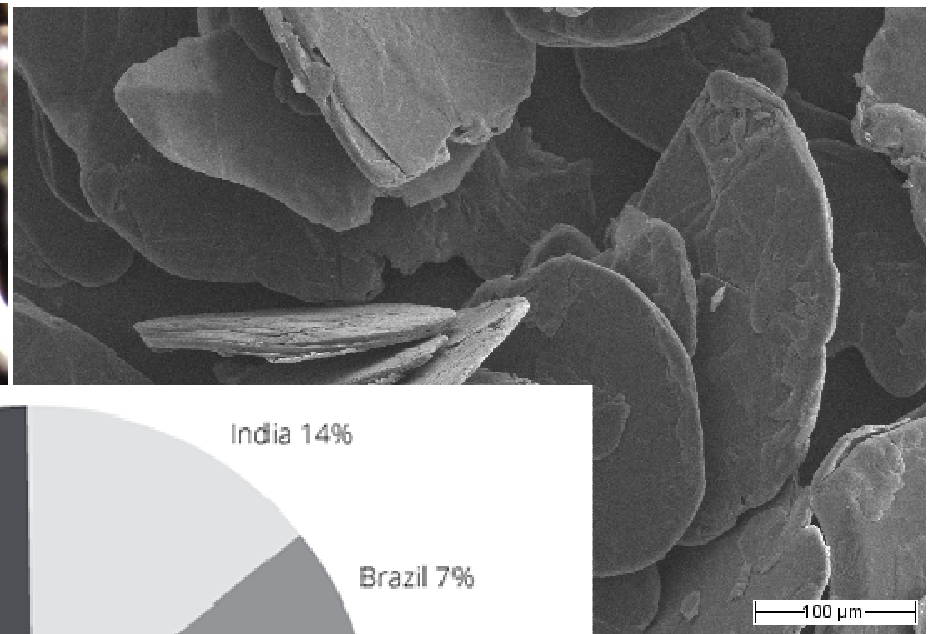


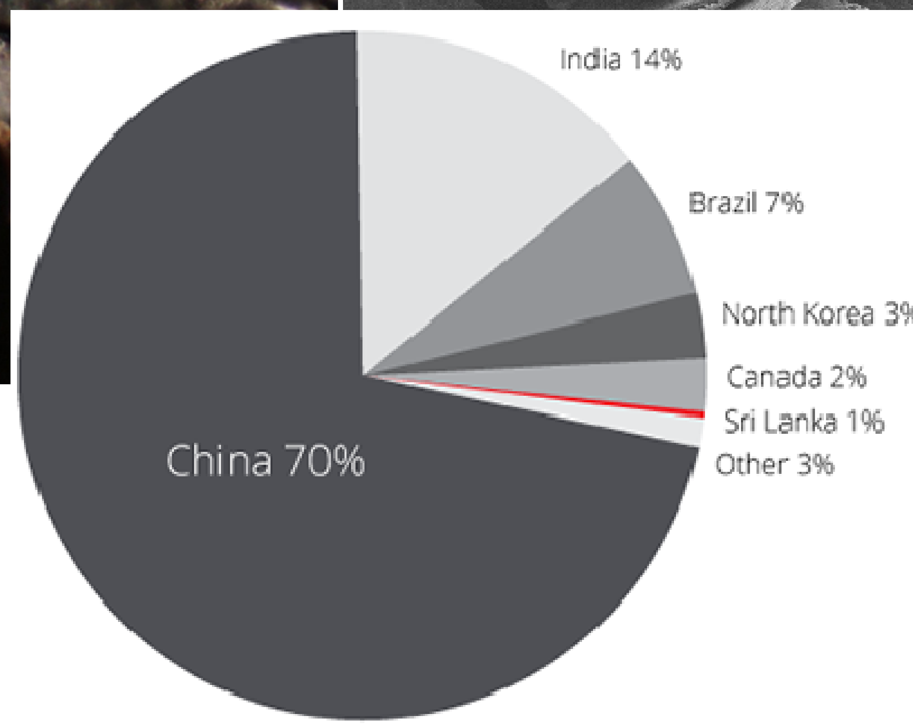


S. Stankovich et al., Carbon **45** 1558(2007)
Y. Hernandez et al., Nature nanotechnology 3, 563 (2008)
W. Quian et al., Nano Res **2**, 706 (2009)
A. Ciesielski and P. Samori, Chem. Soc. Rev. **43**, 381 (2014)

Grafit z kopalni…





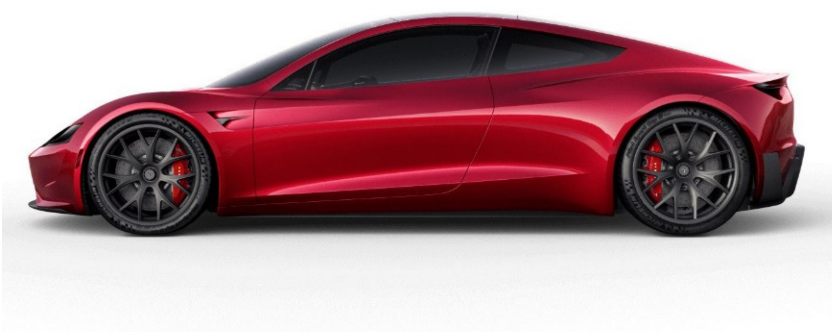


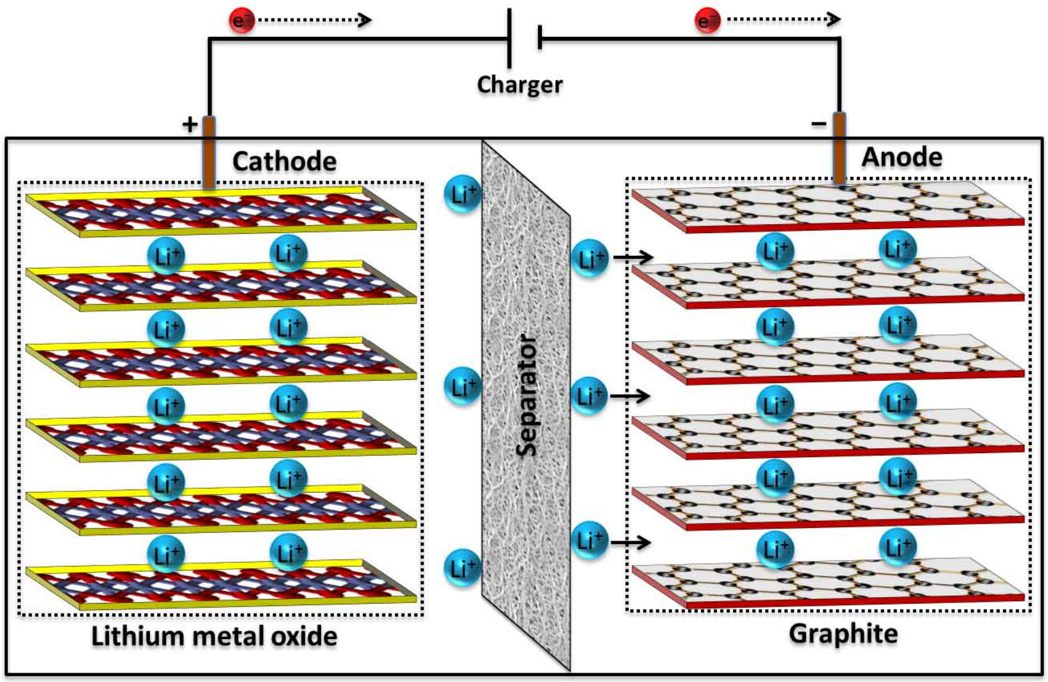
Światowe wydobycie
1,1 mln ton rocznie (2012)
Największe złoża – Turcja

http://www.eaglegraphite.com

Anoda w bateriach litowo-jonowych

BASF
DIMLER

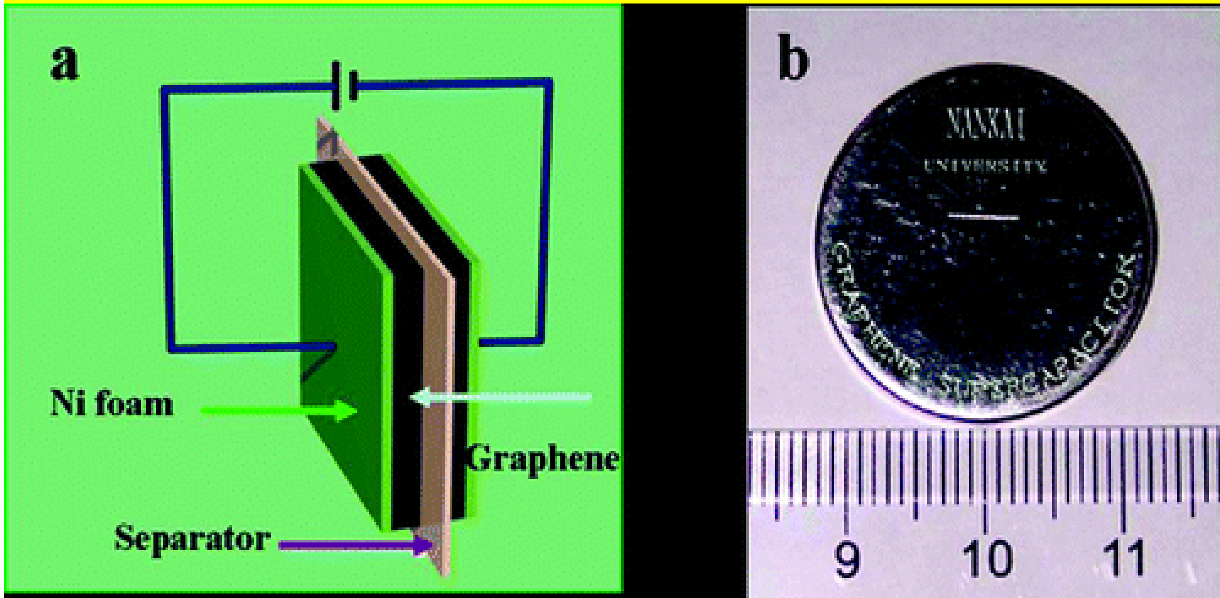




https://electrek.co/2017/11/17/new-tesla-roadster-halo/

https://engineering.purdue.edu/ViPER/research.html

Szybkie ładowanie – rozładownie



Superkondensatory

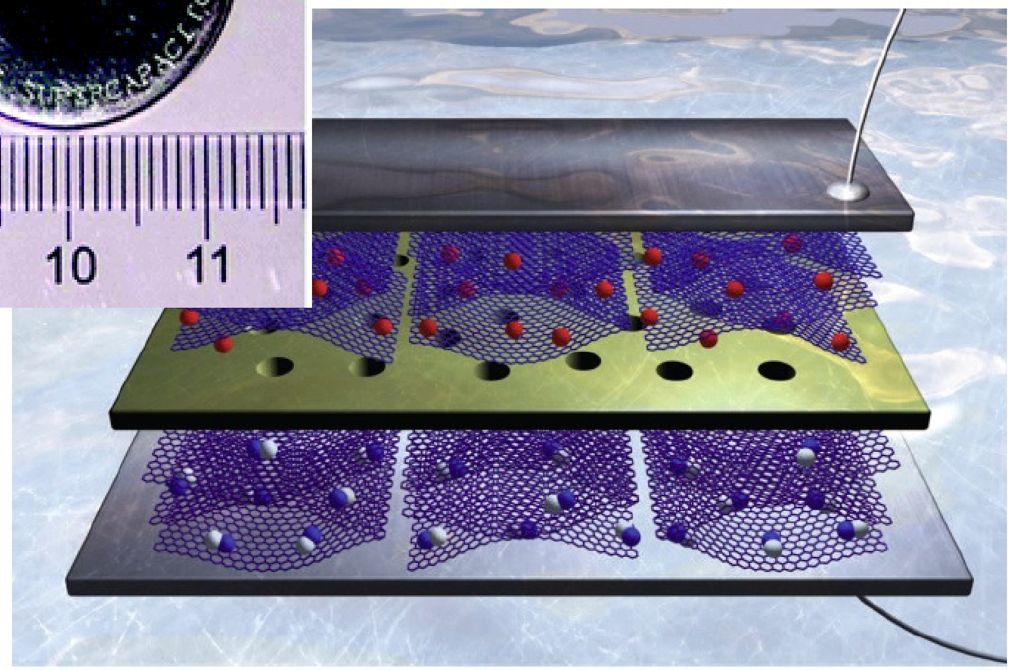


Figure 4 | In a supercapacitor device two high-surface-area graphene-base electrodes (blue and purple hexagonal planes) are separated by a membran (yellow). Upon charging, anions (white and blue merged spheres) and cation (red spheres) of the electrolyte accumulate at the vicinity of the graphene surface. The ions are electrically isolated from the carbon material by the electrochemical double layer that is serving as a molecular dielectric.

Pojemność kondensatora płaskiego:

$$C=\varepsilon\varepsilon_0 S/d$$

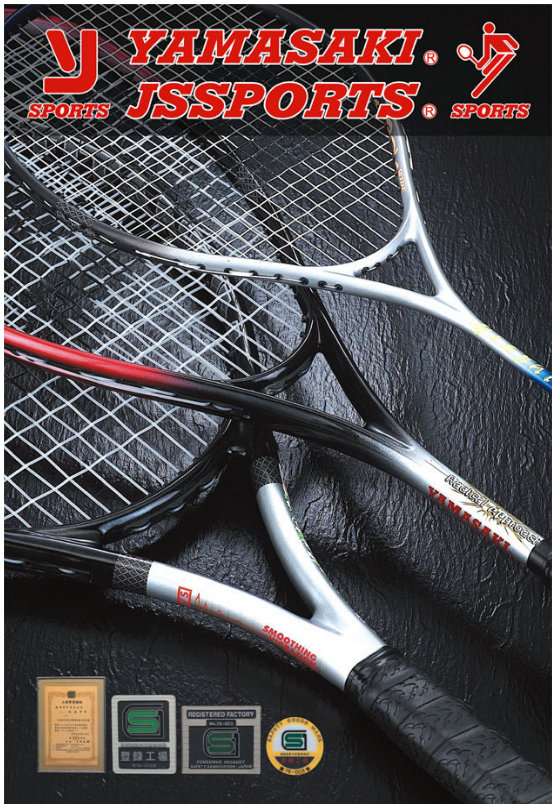
bardzo małe d (izolująca elektryczna warstwa podwójna), duża efektywna powierzchnia S grafenu

Yan Wang et al. J. Phys.Chem. C 113, 13103 (2009)

K. Novoselov et al. Nature 490, 193 (2012)

Kompozyty

Rama waży mniej niż 1 kg! Nanorurki służą do wzmacniania samochodów, kije golfowe, rakiety tenisowe….



Grafenowe gąbki do efektywnego usuwania zanieczyszczeń z wody

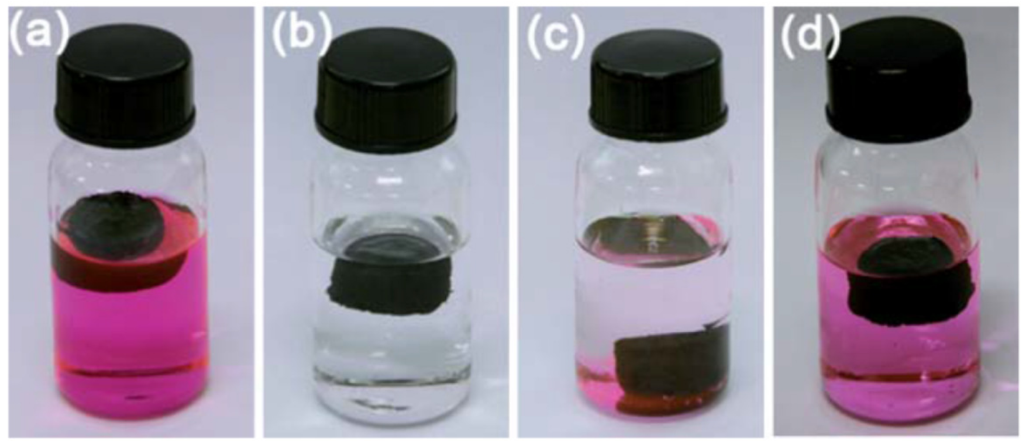
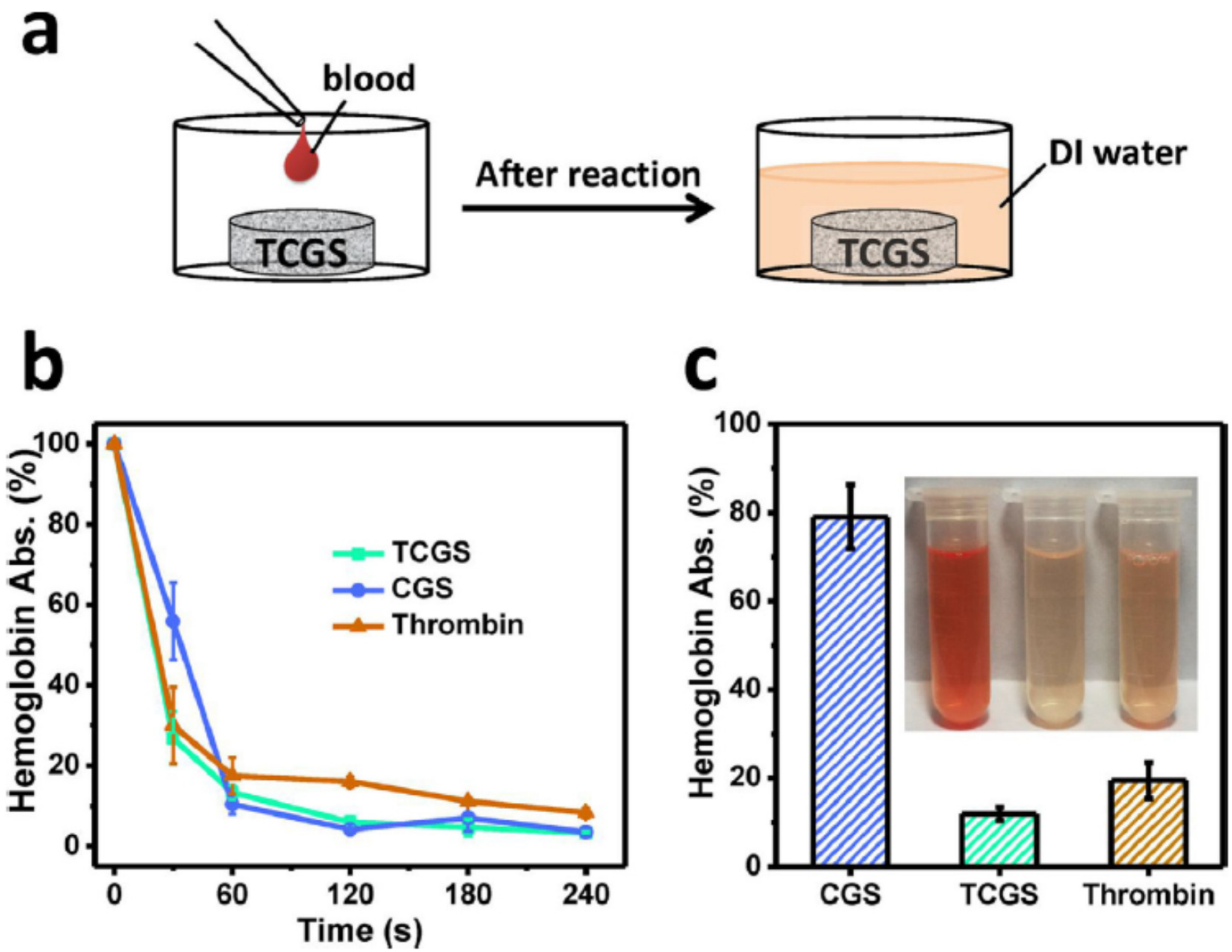


Fig. 3 The adsorption and desorption of rhodamine B in GS. (a) and (b) A GS in rhodamine B solution (a) at the beginning and (b) for 180 min. (c) and (d) The same GS adsorbed with rhodamine B in ethanol for (c) 2 min and (d) 10 min.

Jinping Zhao et al. J. Mater. Chem. **22**, 20197 (2012)

Gąbki grafenowe + funkcjonalizacja



Colloids and Surfaces B: Biointerfaces 161, 27 (2018)

Efekt synergii !

Niedostatek słodkiej wody - problem globalny

Grafen pomoże?

Odwrotna Osmoza (RO- Reverse osmosis)
(RO) obecnie najefektywniejszy sposób odsalania wody morskiej wymaga (dostępne komercyjnie instalacjach)
ok. **1.8 kWh/m³** (w 1990 r ~5 kWh/m³).

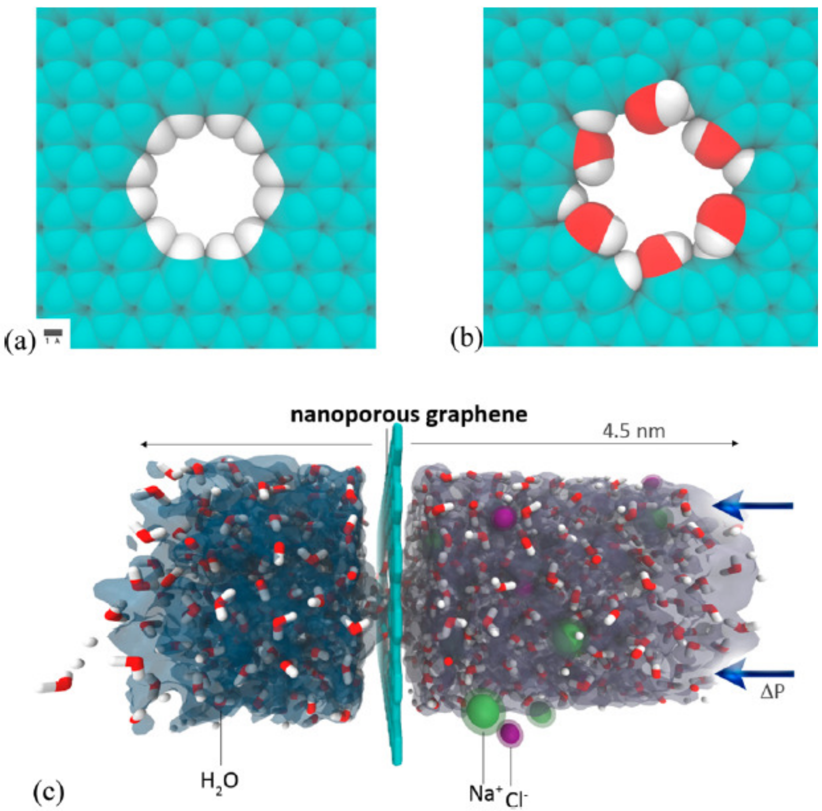


Figure 1. Hydrogenated (a) and hydroxylated (b) graphene pores, and (c) side view of the computational system investigated in this work.

Nano Letters

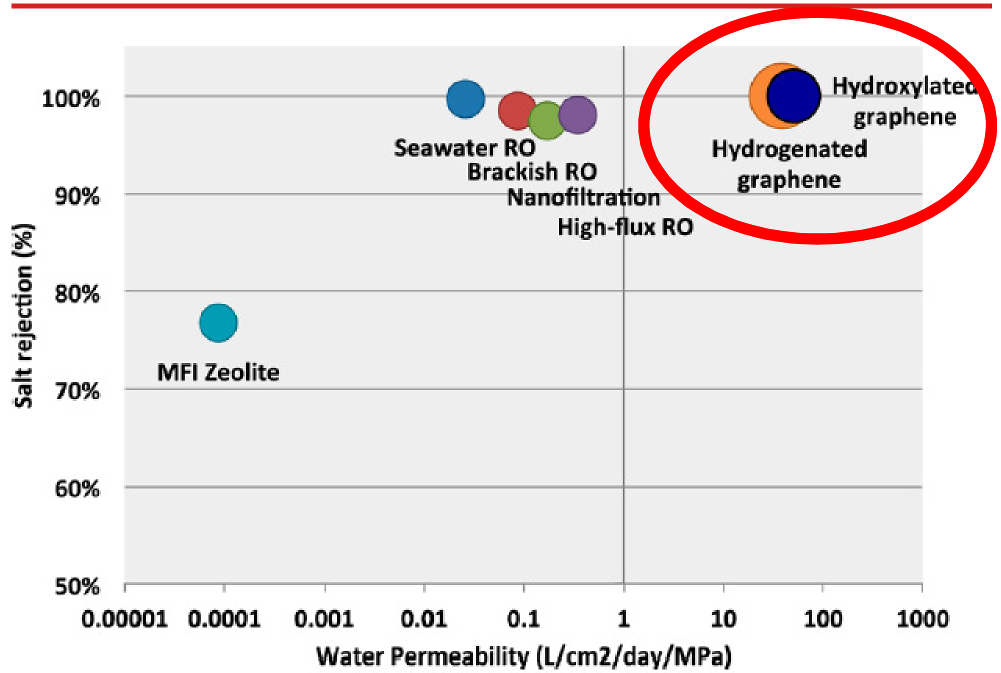
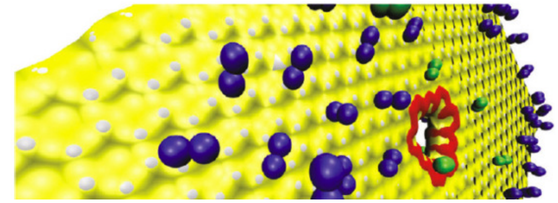


Figure 8. Performance chart for functionalized nanoporous graphene versus existing technologies. The graphene nanopores examined in this work could reject salt ions with a water permeability 2−3 orders of magnitude higher than commercial RO. The data for RO and MFI zeolites is adapted from Pendergast et al.[5]

dx.doi.org/10.1021/nl3012853 | *Nano Lett.* 2012, 12, 3602−3608

Efektywna separacja gazów



Porous Graphene as the Ultimate Membrane for Gas Separation

De-en Jiang,*,† Valentino R. Cooper,*,‡ and Sheng Dai†

NANO LETTERS
2009
Vol. 9, No. 12
4019-4024

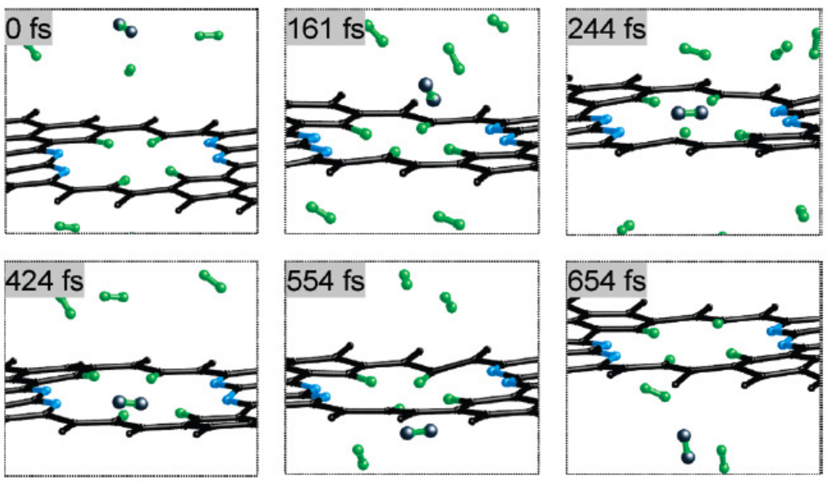


Figure 5. Snapshots of H_2 diffusing through the nitrogen-functionalized pore from first principles molecular dynamics simulations at 600 K. The passing-through H_2 molecule is highlighted in dark gray.

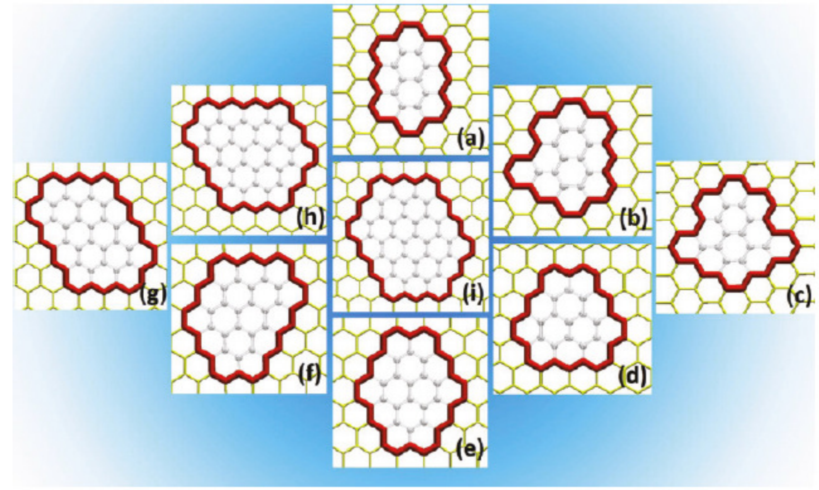
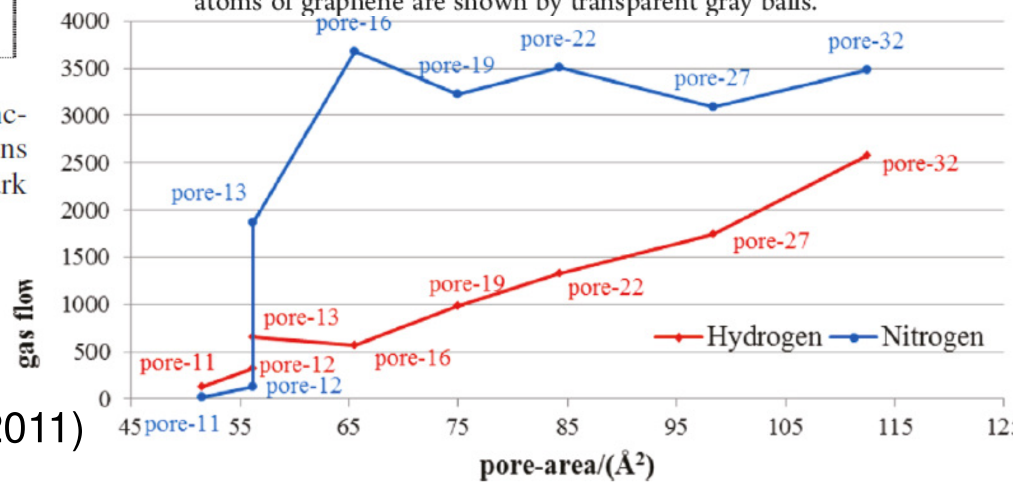
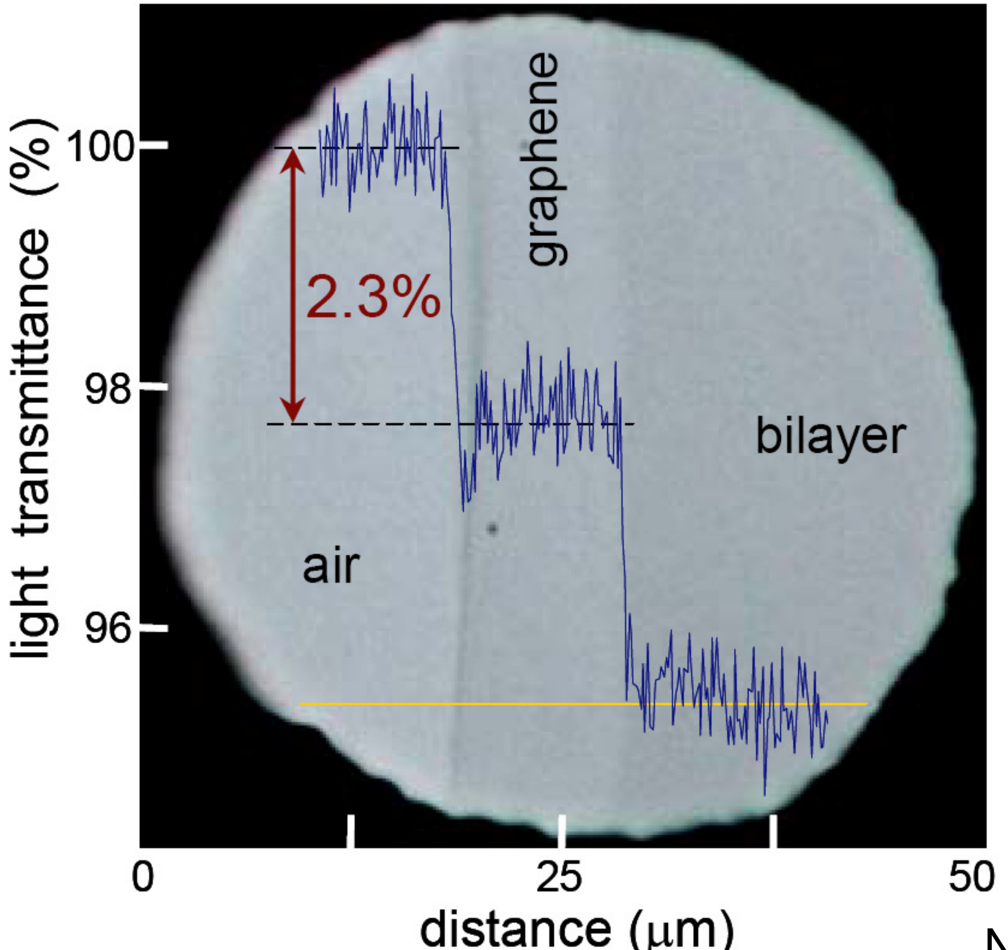


Figure 2. Structure of porous graphene models: (a) pore-10, (b) pore-11, (c) pore-12, (d) pore-13, (e) pore −16, (f) pore-19, (g) pore-22, (h) pore-27, and (i) pore-32; each model is named according to the number of drilled atoms from the graphene sheet. Graphene is represented by yellow hexagons, and the pore shape is colored red; the drilled carbon atoms of graphene are shown by transparent gray balls.



D. Jiang, et al., Nano Letters **9**, 4019 (2009)
H. Du et al. ,J. Phys. Chem. C B**115**, 23261 (2011)

Grafen absorbuje światło i przewodzi prąd !



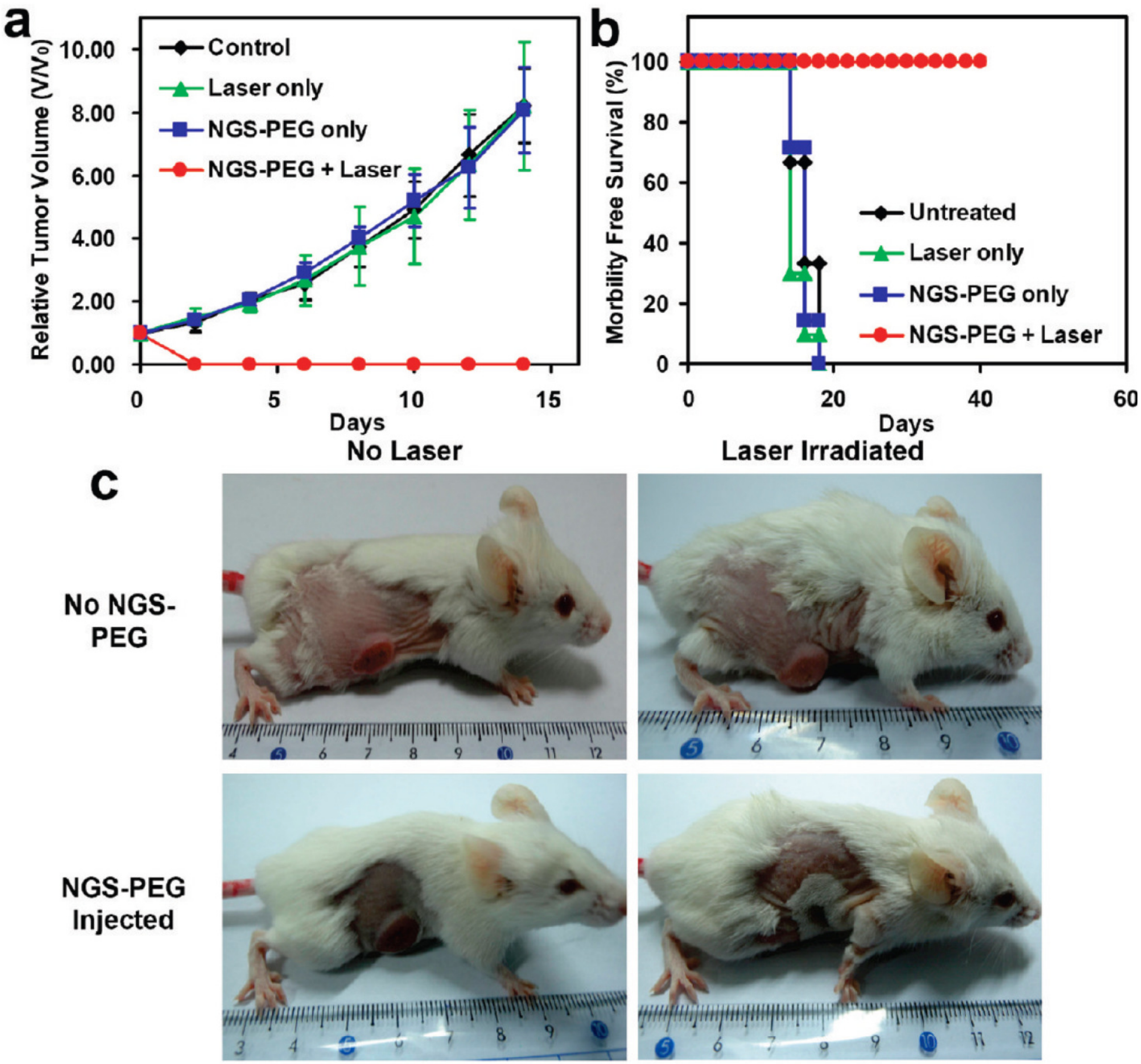
$$T = (1 + \tfrac{1}{2}\pi\alpha)^{-2}$$

$$\alpha = e^2/\hbar c = 1/137{,}036\ !$$

Nair *et al.*, *Science* **320**, 1308 (2008)

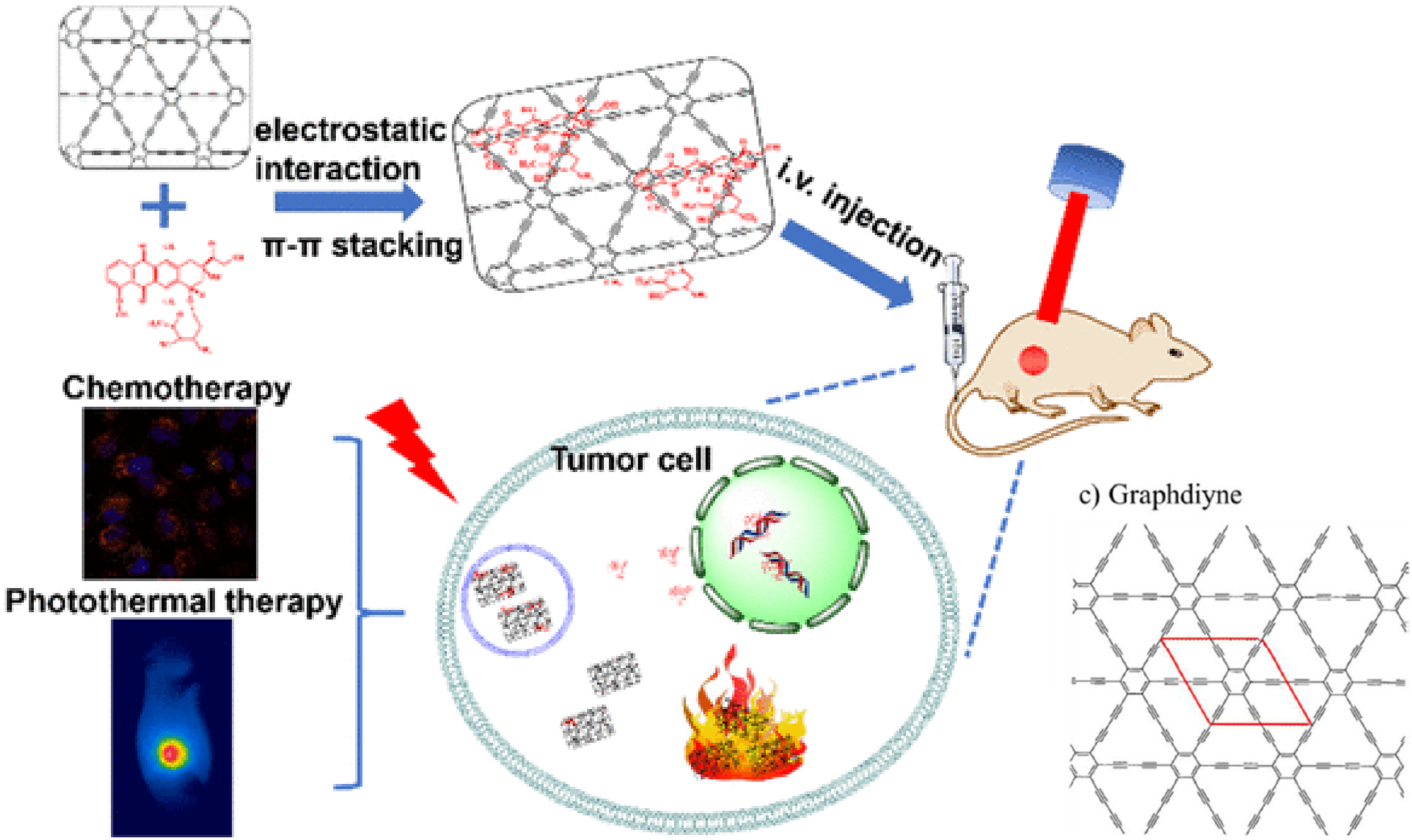
Świetny materiał na przezroczyste elektrody (ekrany dotykowe, wyświetlacze…)

Zwalczanie nowotworów…



DOI: 10.1021/nl100996u | *Nano Lett.* **2010,** *10,* 3318--3323

Nowe materiały 2D w walce z rakiem



ACS Appl. Mater. Interfaces, **2018**, *10* (10), pp 8436–8442

Grafen jako nośnik leków…

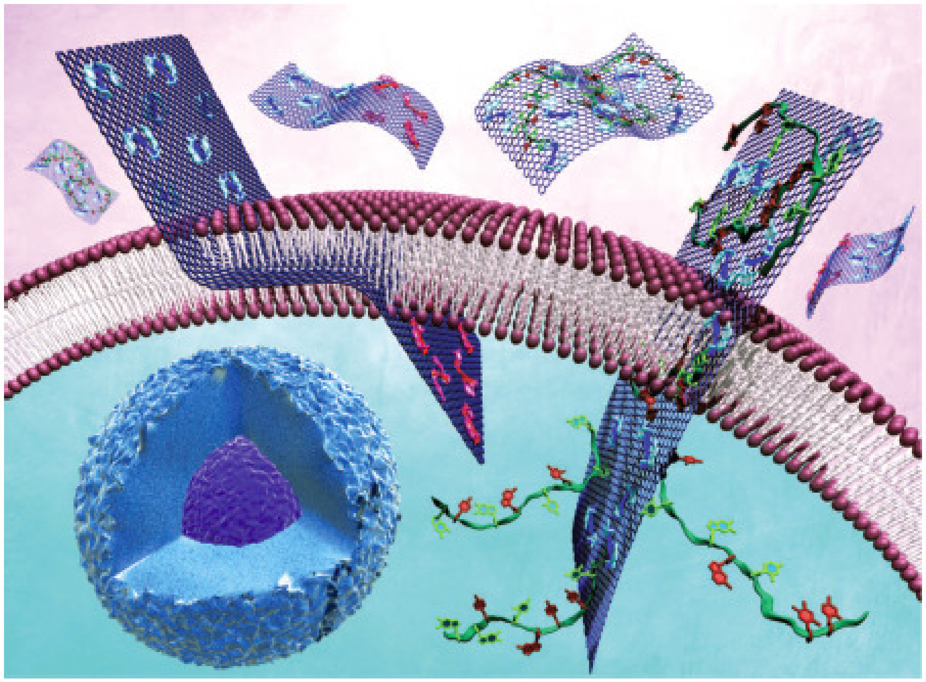
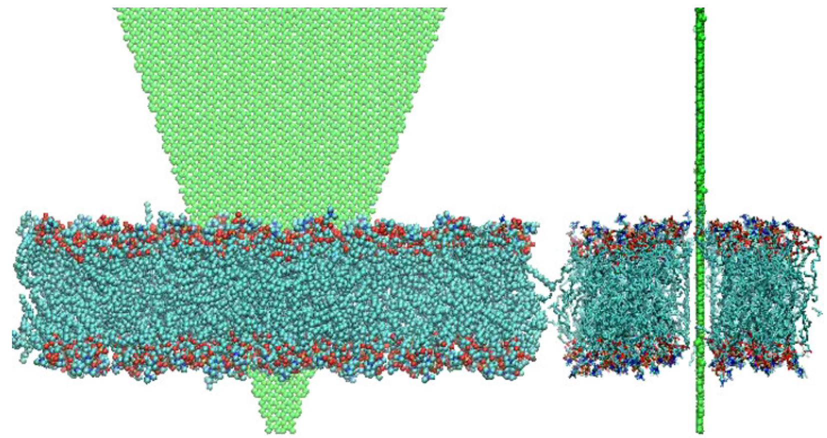
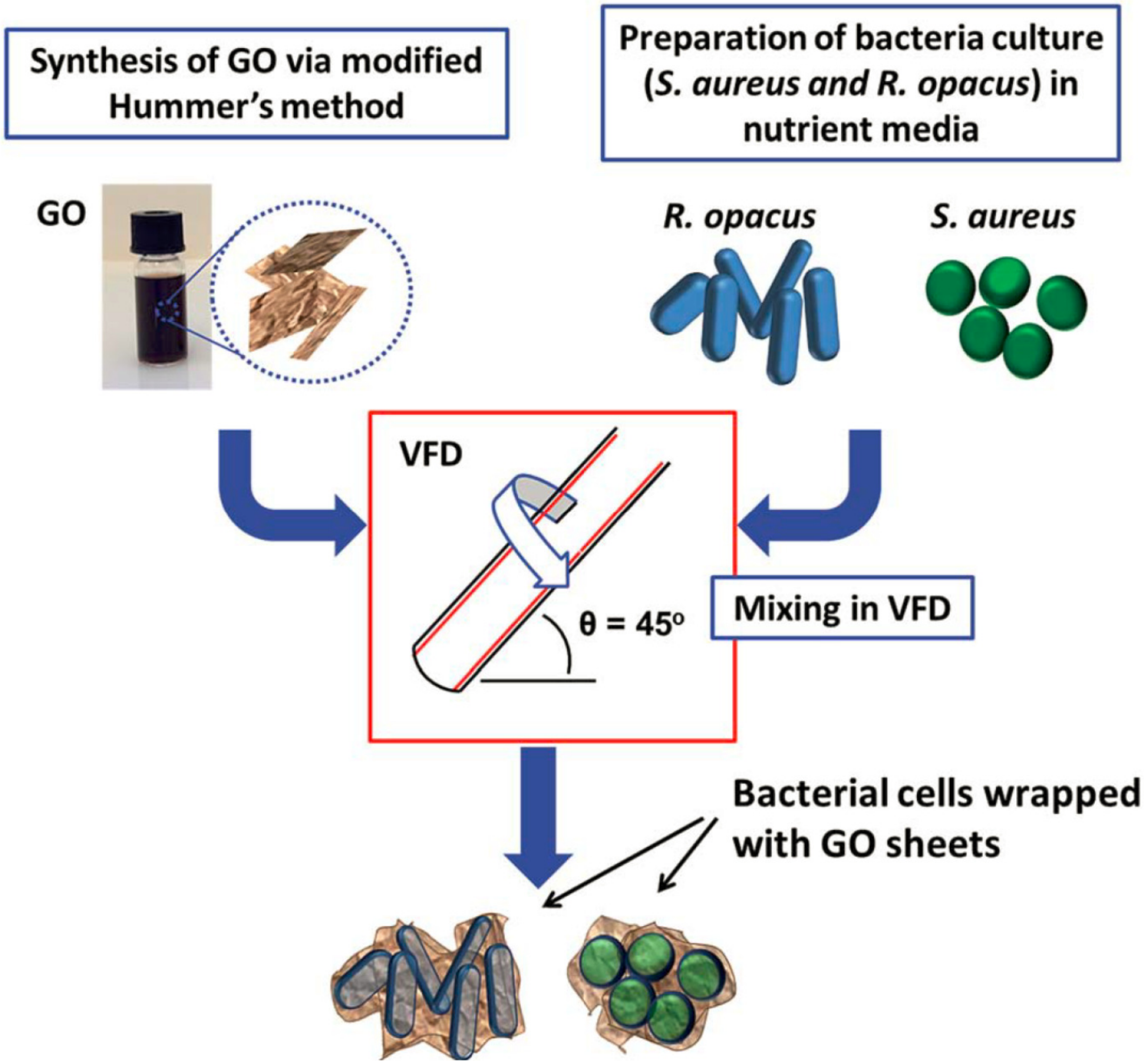


Figure 5 | Manipulating the hydrophilic–lipophilic properties of graphene (blue hexagonal planes) through chemical modification would allow interactions with biological membranes (purple-white double layer), such as drug delivery into the interior of a cell (blue region).



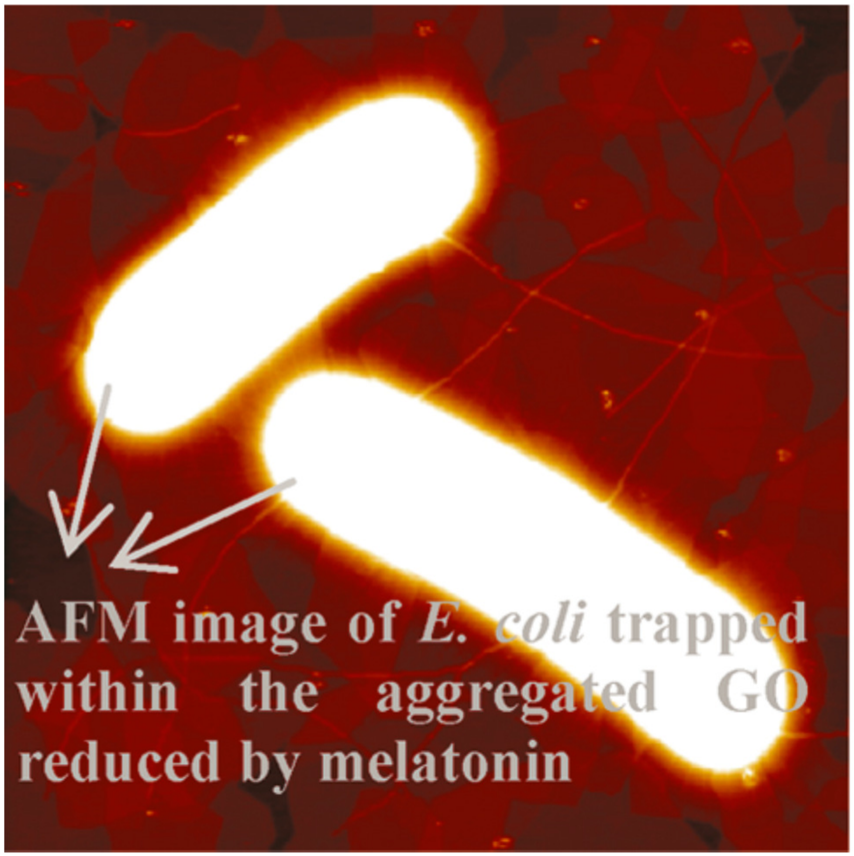
Li et al, PNAS (2013)

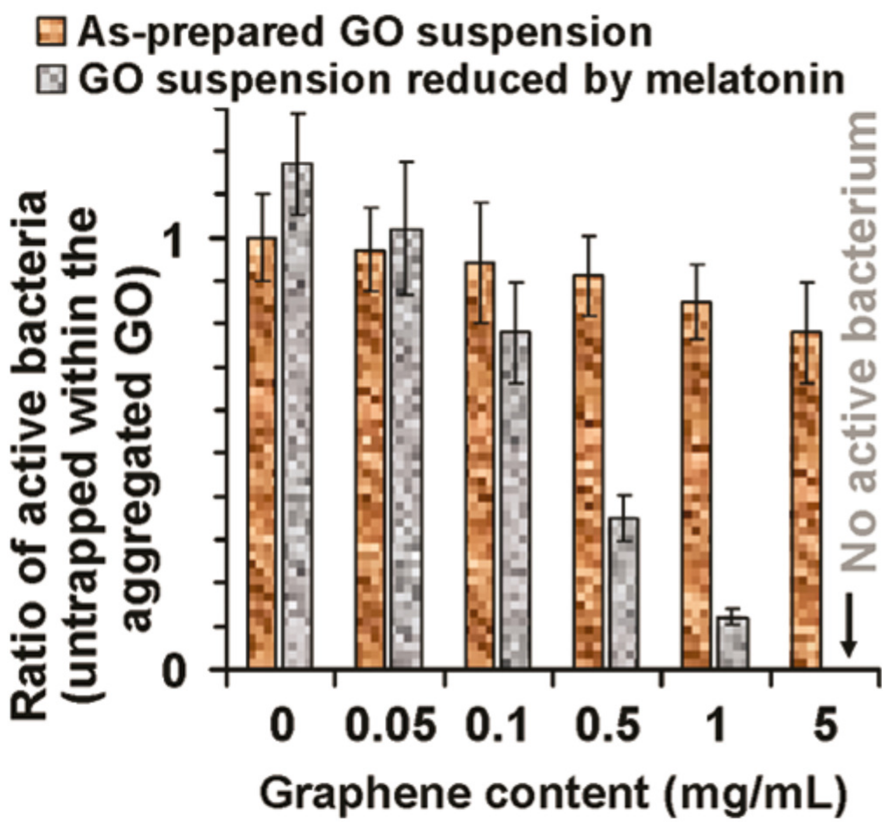
Zawijanie bakterii



M. H. Wahid et al. ***RSC Adv.***, 2015,**5**, 37424-37430

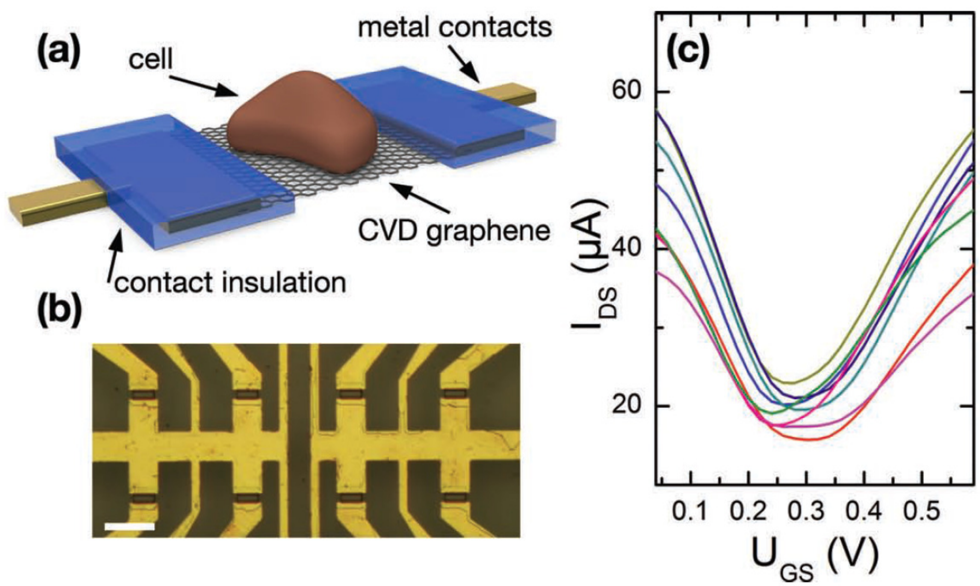
Zawijanie bakterii



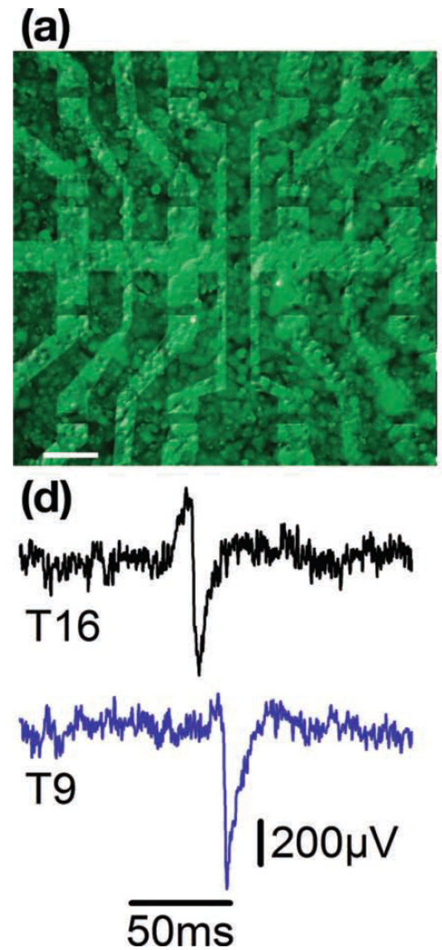


O. Akhavan et al. J. Phys. Chem. B, 2011, 115 (19), pp 6279–6288

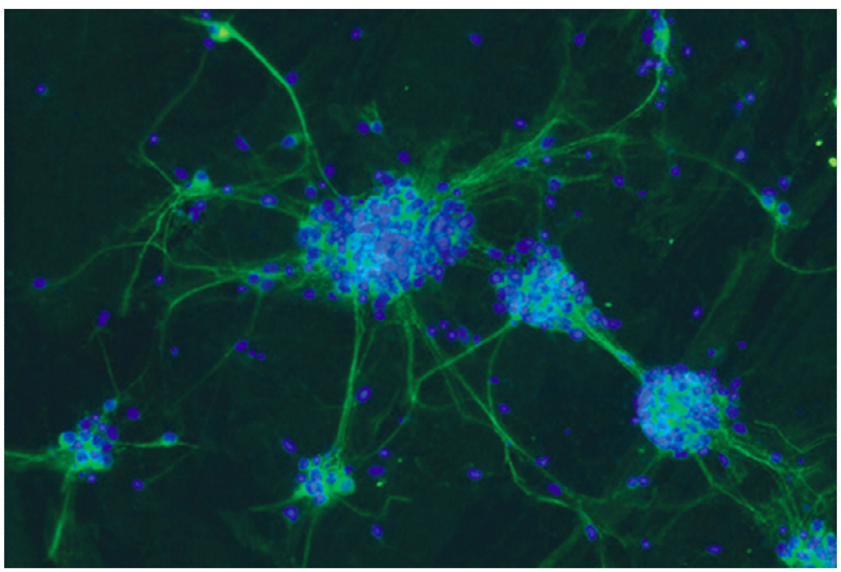
Badanie sygnałów bioelektrycznych



Można śledzić rozchodzenie się sygnałów elektrycznych w komórkach



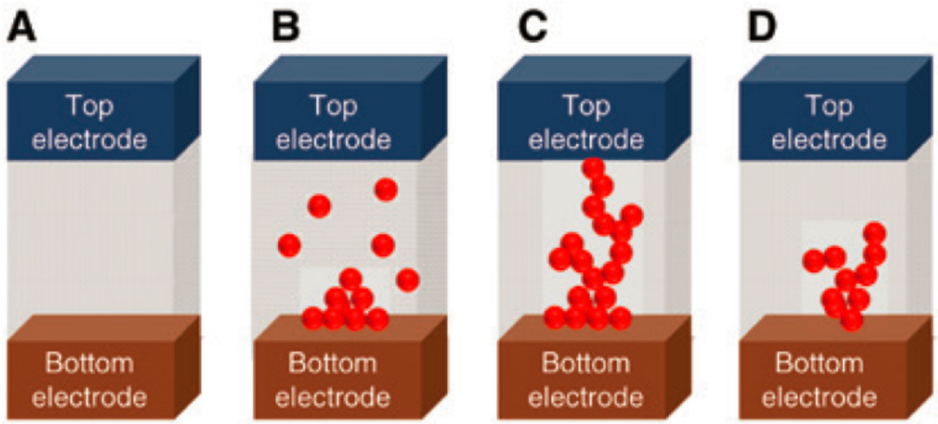
Neurony na grafenie…(biologiczne implanty)

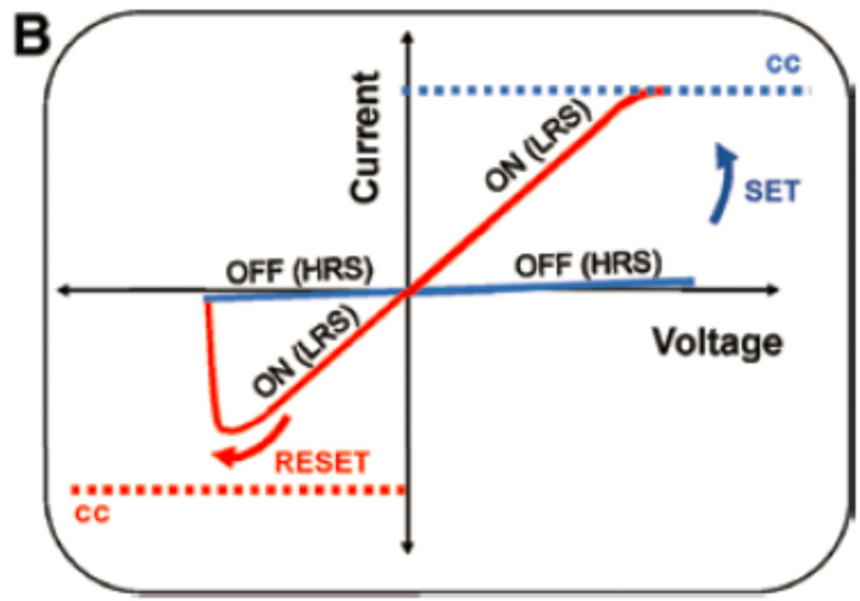


L. Hess et al., Adv. Mater. **23**, 5045 (2011)

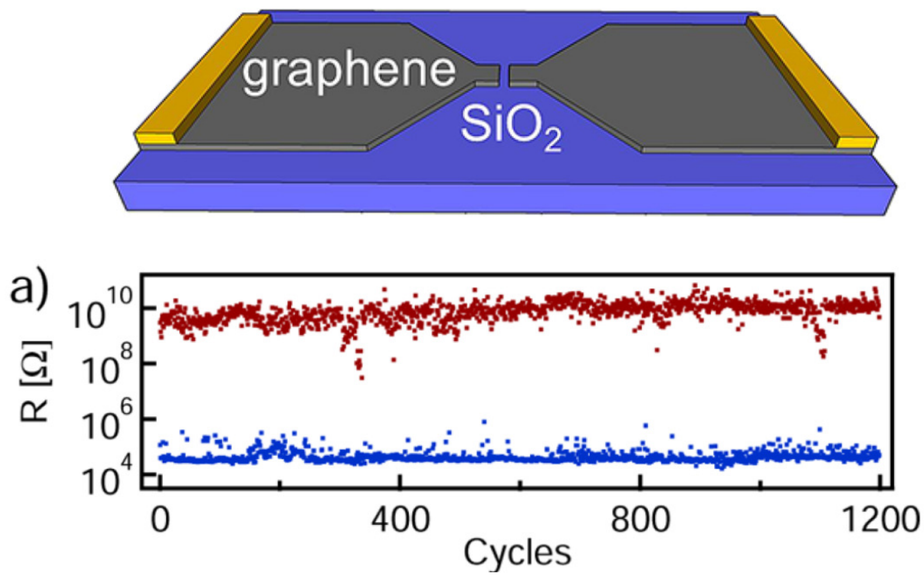
C. Schmidt, Nature, **483**, S37 (2012)

Memrystor – nowy element podstawowy



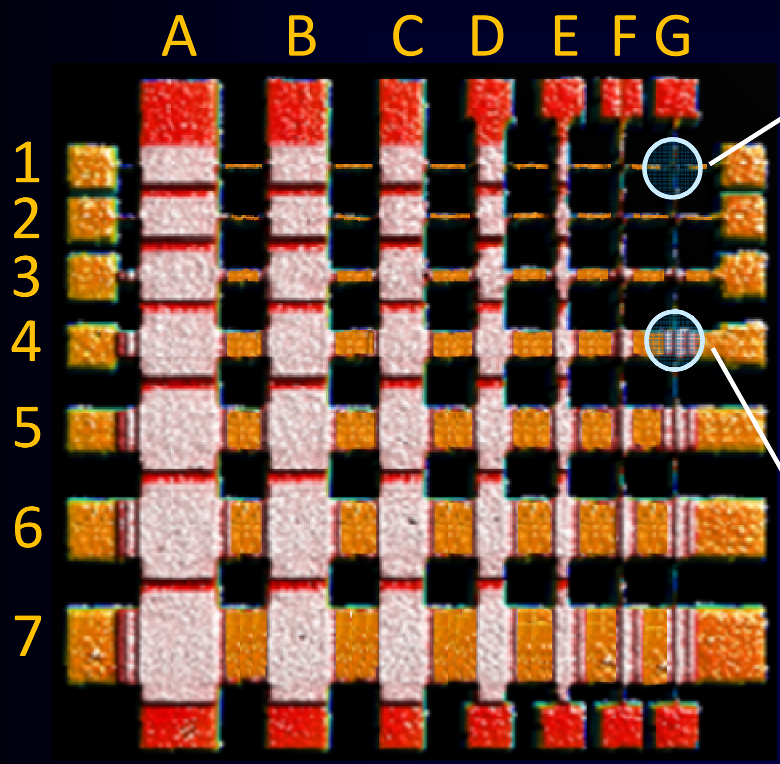


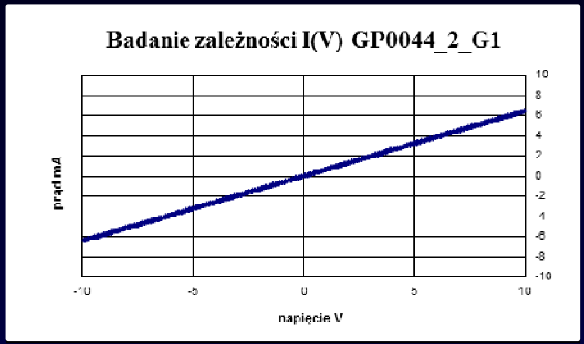
Nanotechnol Rev 2016; 5(3): 311–329

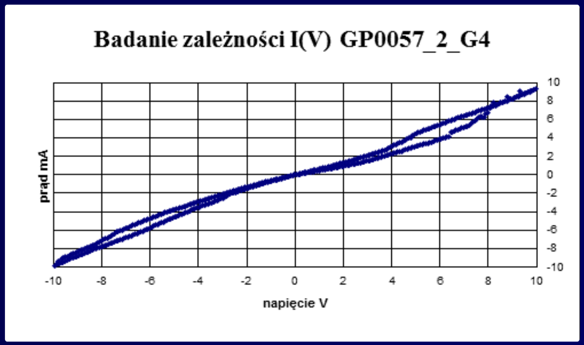


Nano Lett. 2017, 17, 6783-6789

Grafenowe elastyczne układy memrystywne



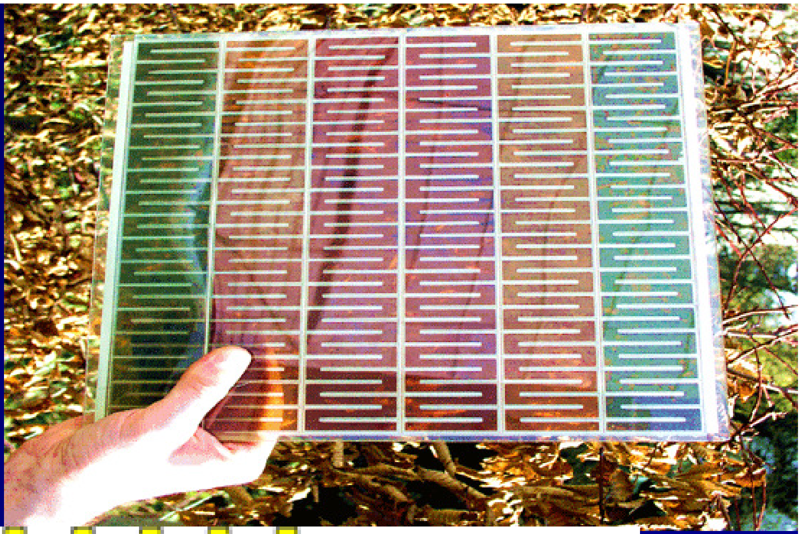


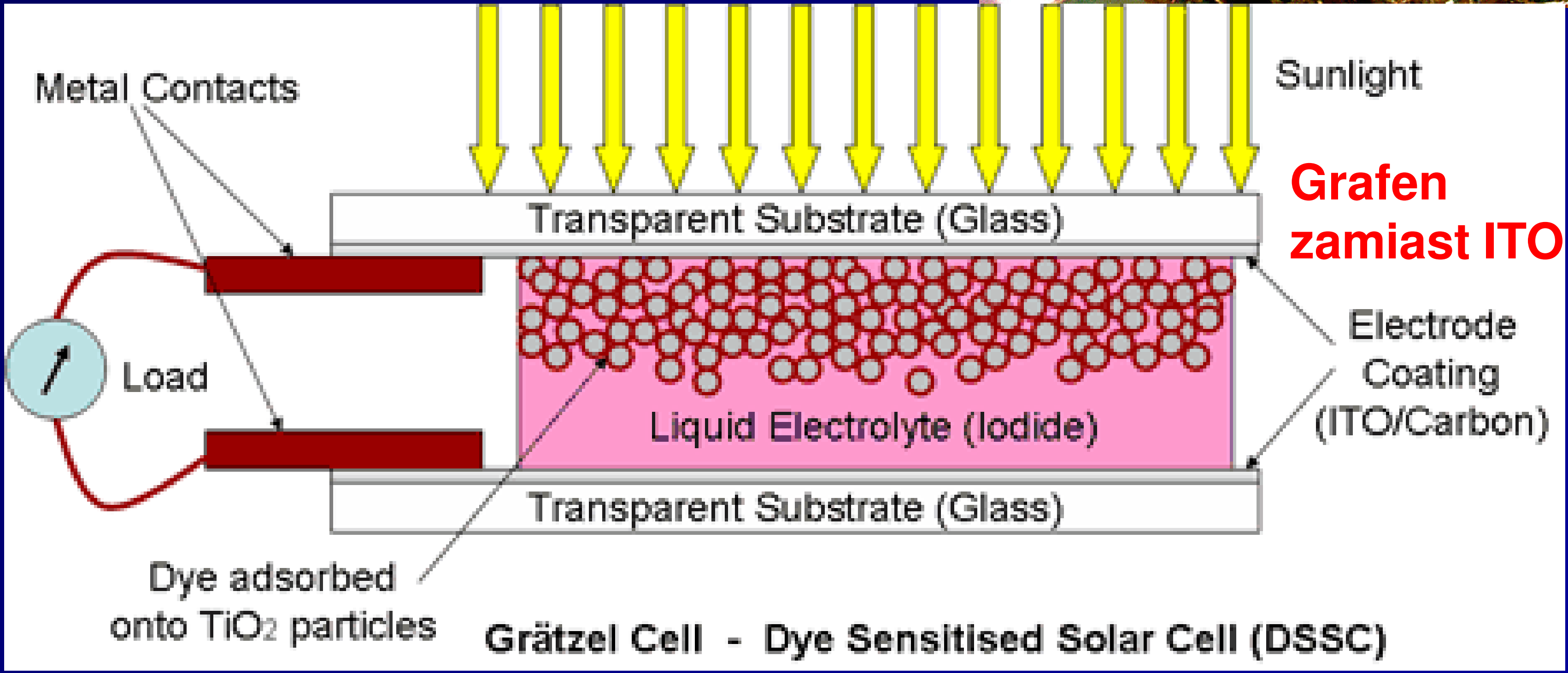


Wydrukowany układ memrystywny typu cross-bar z elementem czynnym z GO

Baterie słoneczne

Ulepszone ogniwa Grätzela…



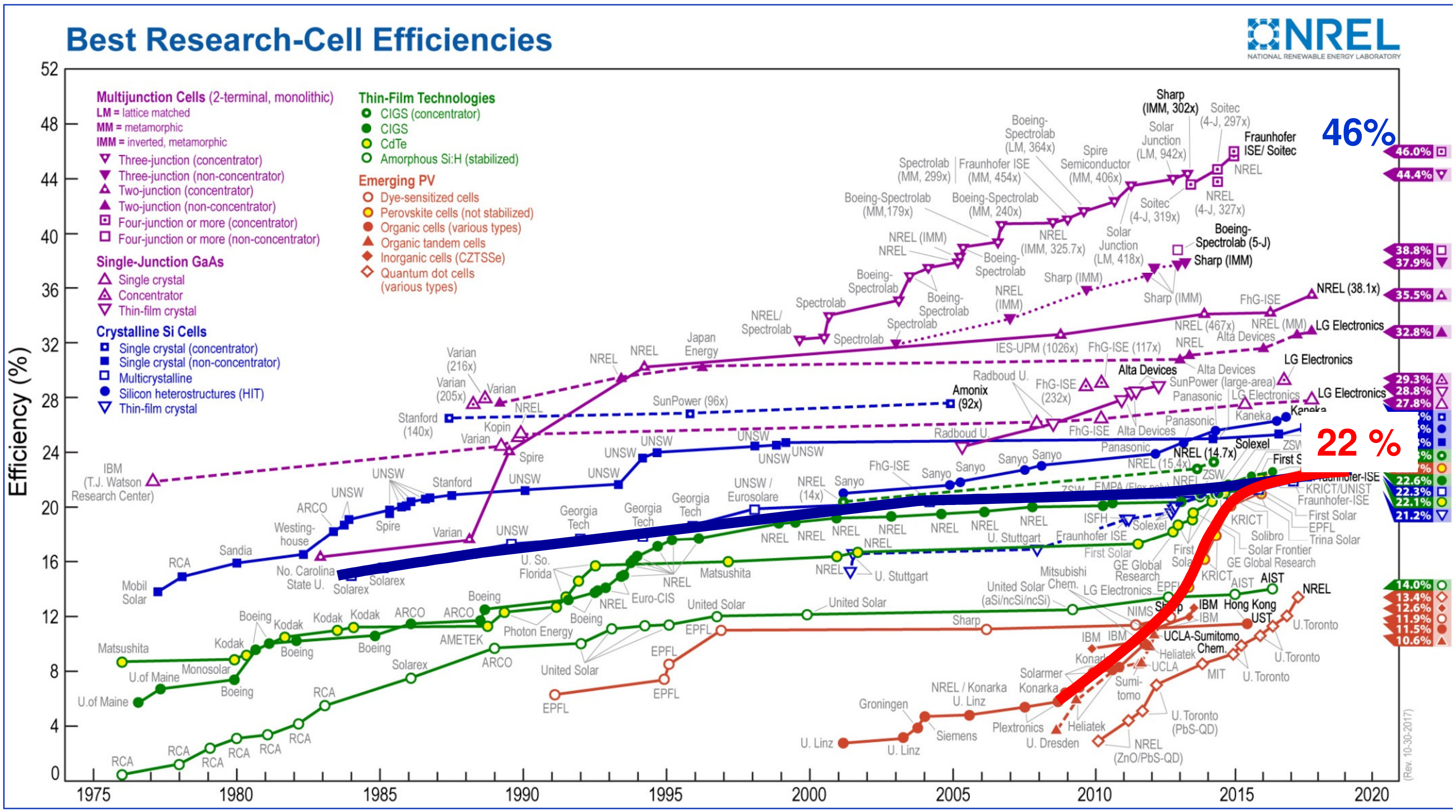


Grafen zamiast ITO

http://www.solarisnano.com/

http://www.mpoweruk.com/semiconductors.htm

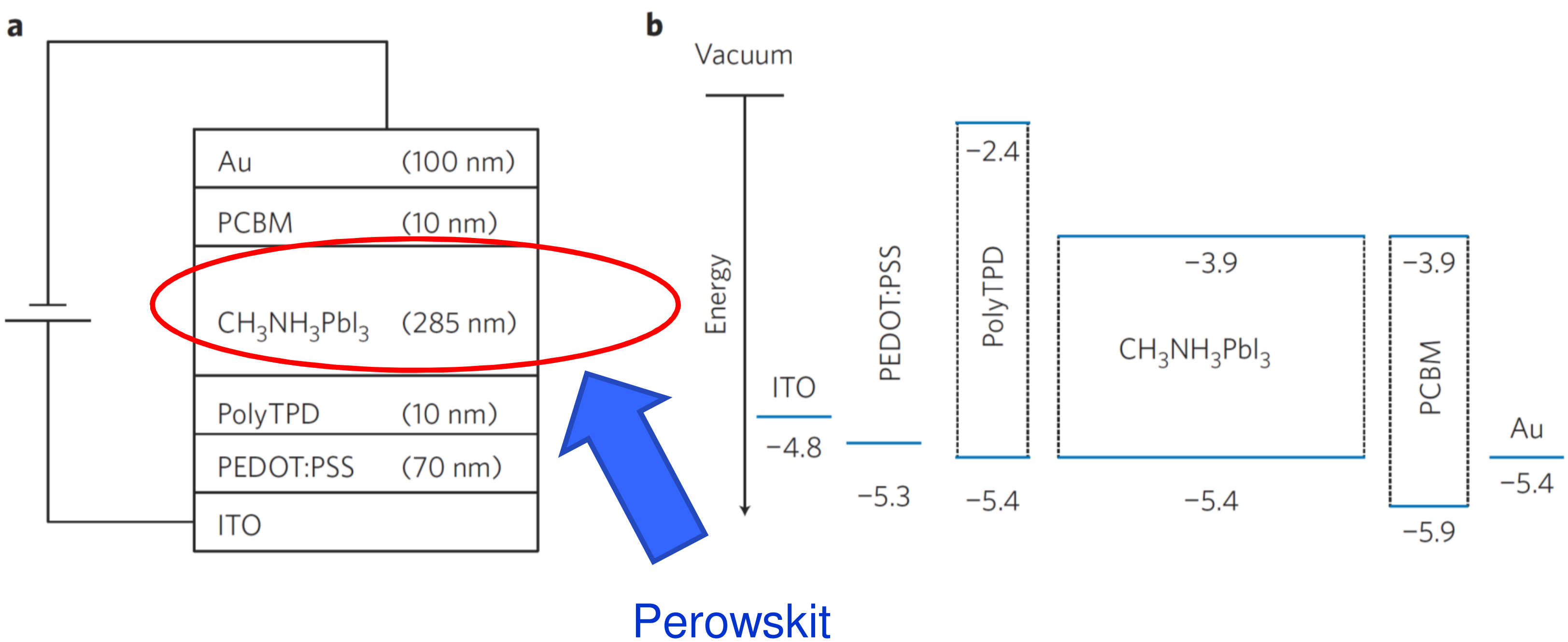
Wydajność ogniw słonecznych



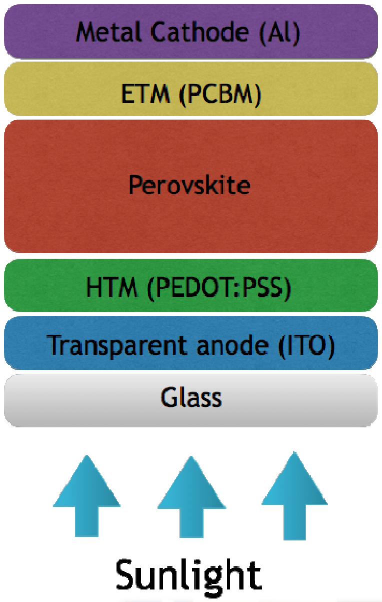
LETTERS
PUBLISHED ONLINE: 22 DECEMBER 2013 | DOI: 10.1038/NPHOTON.2013.341
nature photonics

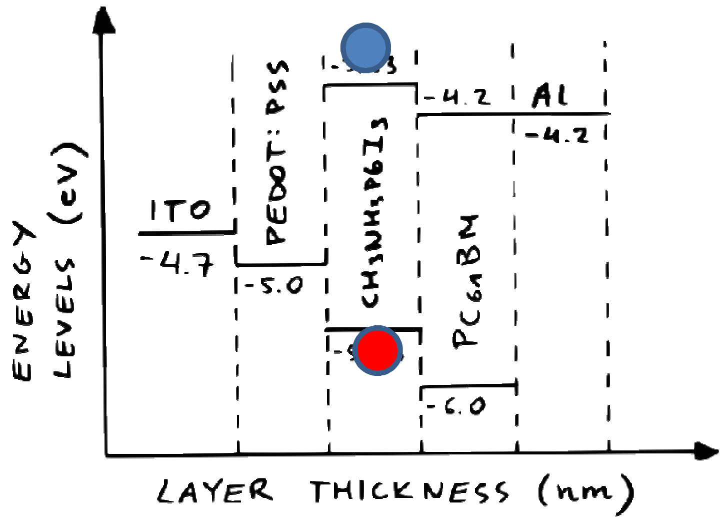
Perovskite solar cells employing organic charge-transport layers

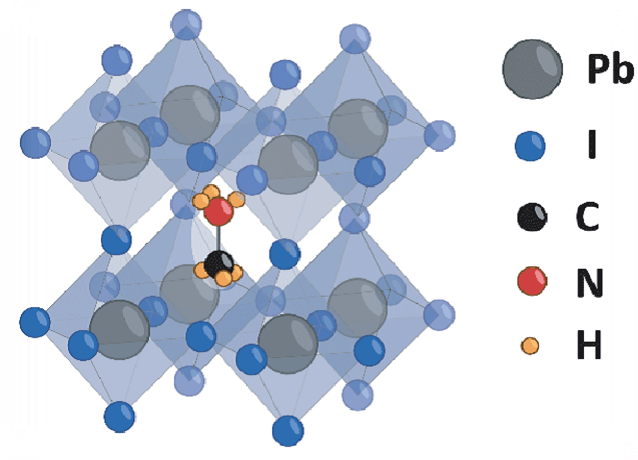
Olga Malinkiewicz[1], Aswani Yella[2], Yong Hui Lee[2], Guillermo Mínguez Espallargas[1], Michael Graetzel[2], Mohammad K. Nazeeruddin[2]* and Henk J. Bolink[1]*



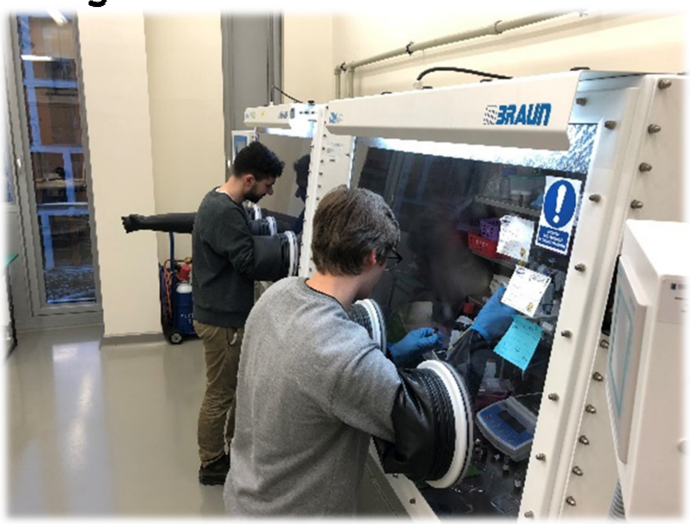
Perowskitowe ogniwa słoneczne

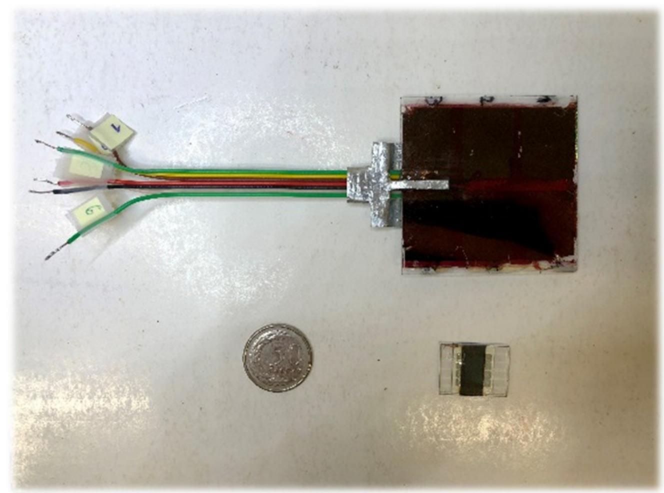






https://www.nrel.gov/pv/assets/images/perovskite-1-model.gif



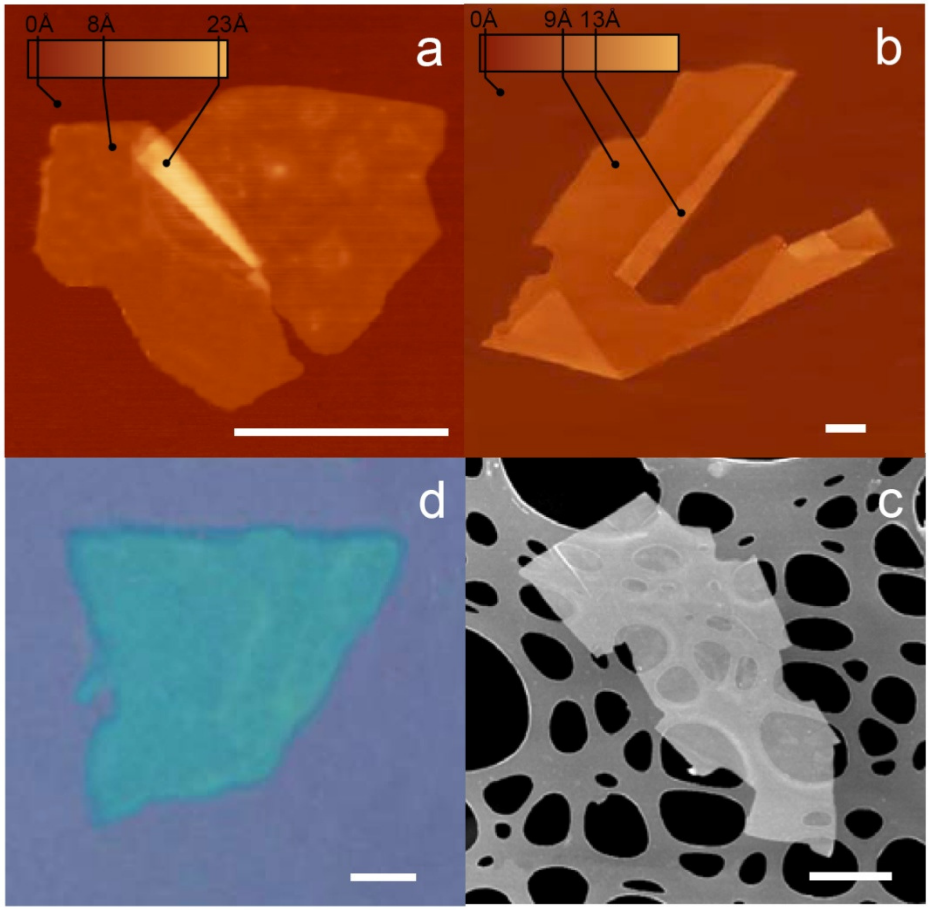


A. Wincukiewicz i inni @ Wydział Fizyki UW
(grupa prof. M. Kamińskiej)

Inne materiały 2D

Pojedyncze warstwy

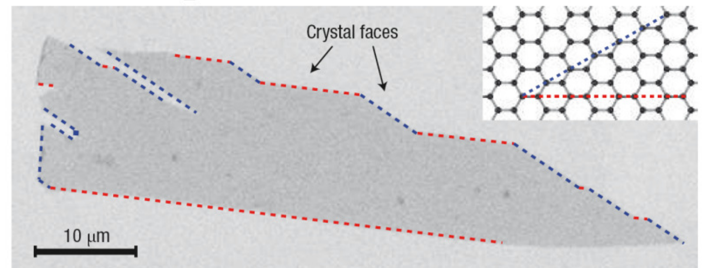
$NbSe_2$
na Si/SiO_2



MoS_2
na Si/SiO_2

grafit
on Si/SiO_2

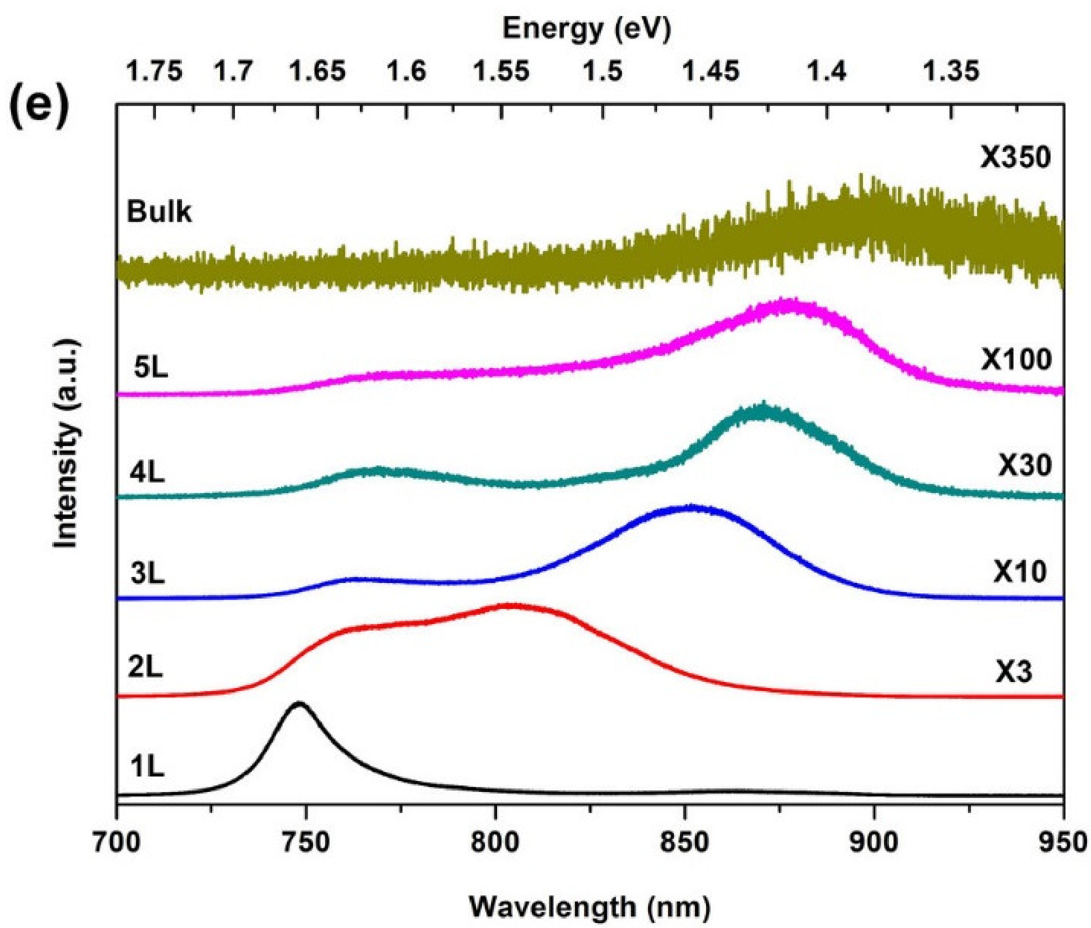
grafen „duży płatek"

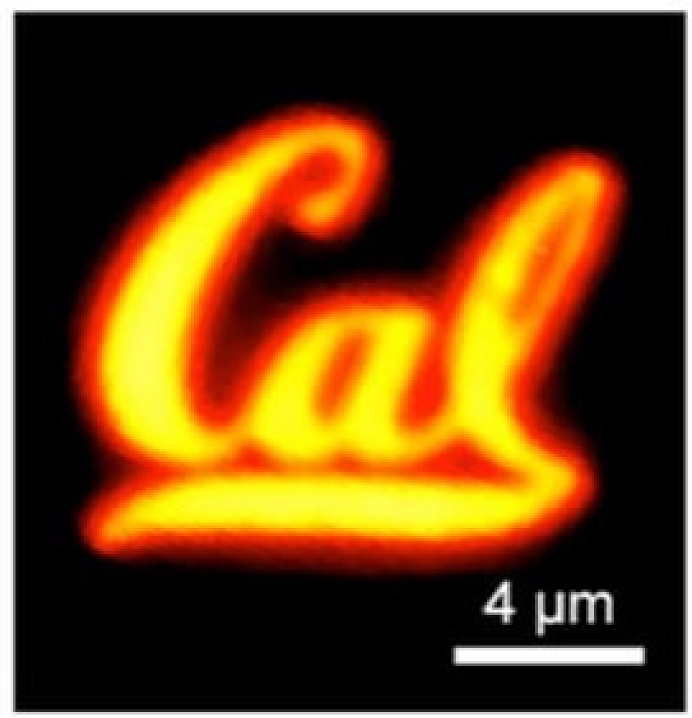


$Bi_2Sr_2CaCu_2O_x$
on carbon

K.S. Novoselov, *et al.*, *Two-dimensional atomic crystals*,
Proc. Natl Acad. Sci. USA, **102,** 10451–10453 (2005)
K.S. Novoselov and A.K. Geim,
The rise of graphene, Nature Materials, **6**, 183, (2007)

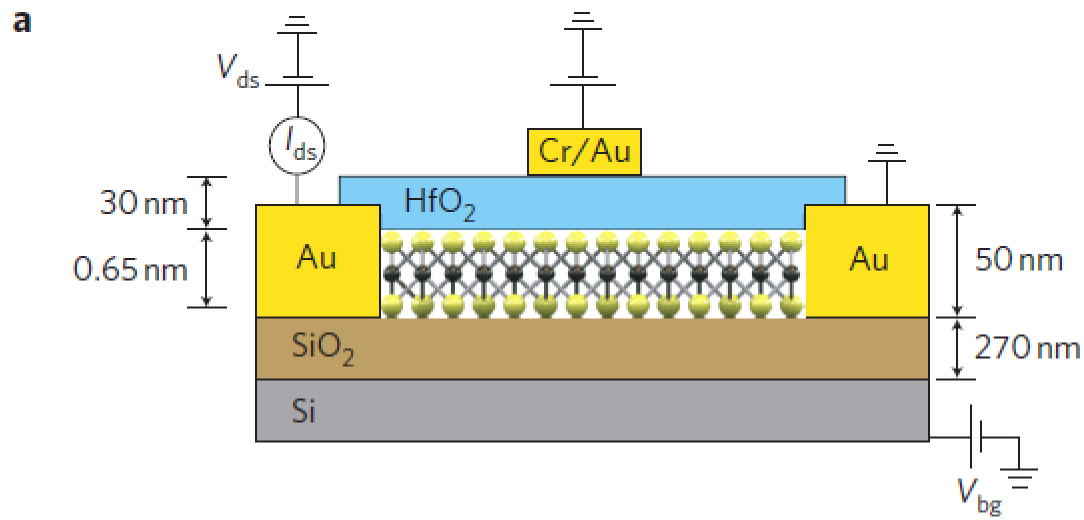
Niezwykłe zachowanie emisji MoS_2



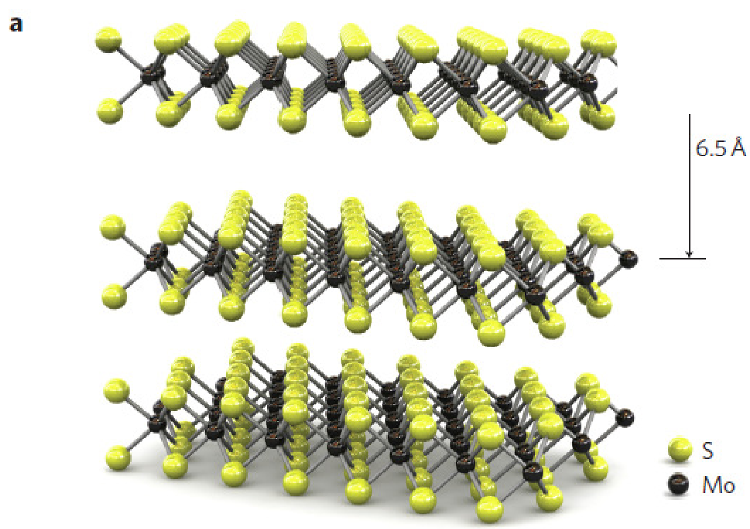


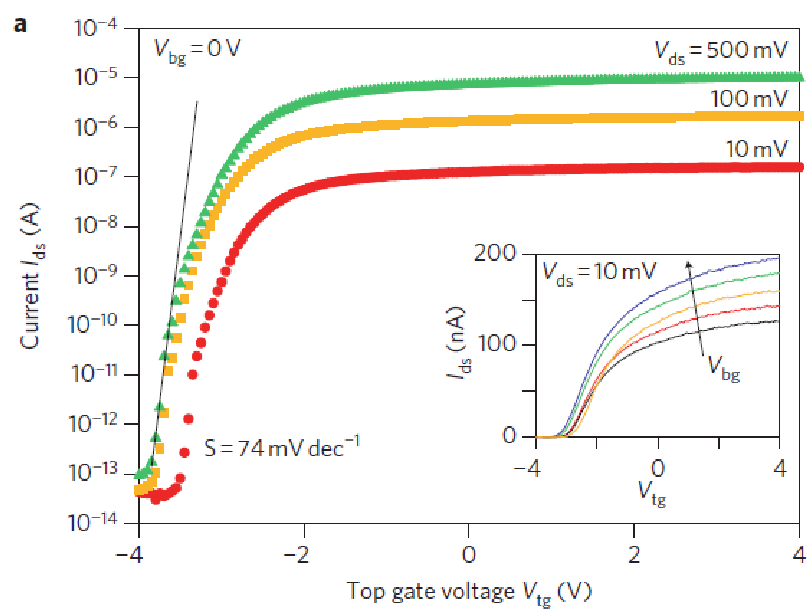
H. Terrones et al. Scientific Reports 4, 4215 (2014)   M. Amani et al. SCIENCE 350, 1065 (2015)

MoS_2 ma przerwę energetyczną!



Scotch tape method works!





New technologies are needed!

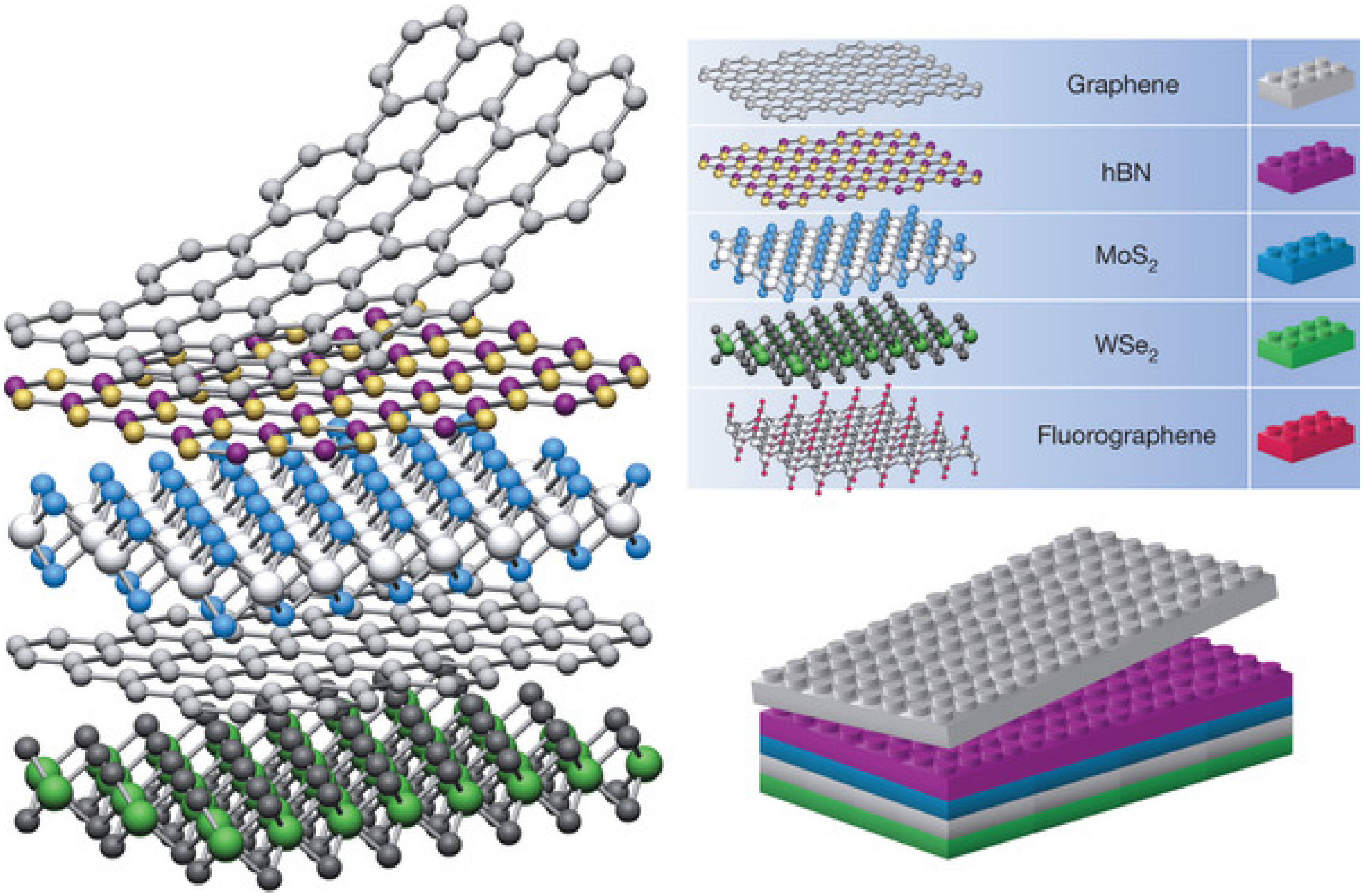
B. Radisavljevic et al., Nature naotechnology (2011)

Nowe struktury Van der Waalsa

<table>
<tr><td>Graphene family</td><td>Graphene</td><td>hBN
'white graphene'</td><td>BCN</td><td>Fluorographene</td><td>Graphene oxide</td></tr>
<tr><td rowspan="2">2D chalcogenides</td><td rowspan="2" colspan="2">MoS_2, WS_2, $MoSe_2$, WSe_2</td><td rowspan="2">Semiconducting dichalcogenides:
$MoTe_2$, WTe_2,
ZrS_2, $ZrSe_2$ and so on</td><td colspan="2">Metallic dichalcogenides:
$NbSe_2$, NbS_2, TaS_2, TiS_2, $NiSe_2$ and so on</td></tr>
<tr><td colspan="2">Layered semiconductors:
GaSe, GaTe, InSe, Bi_2Se_3 and so on</td></tr>
<tr><td rowspan="2">2D oxides</td><td>Micas,
BSCCO</td><td>MoO_3, WO_3</td><td rowspan="2" colspan="2">Perovskite-type:
$LaNb_2O_7$, $(Ca,Sr)_2Nb_3O_{10}$,
$Bi_4Ti_3O_{12}$, $Ca_2Ta_2TiO_{10}$ and so on</td><td>Hydroxides:
$Ni(OH)_2$, $Eu(OH)_2$ and so on</td></tr>
<tr><td>Layered
Cu oxides</td><td>TiO_2, MnO_2, V_2O_5,
TaO_3, RuO_2 and so on</td><td>Others</td></tr>
</table>

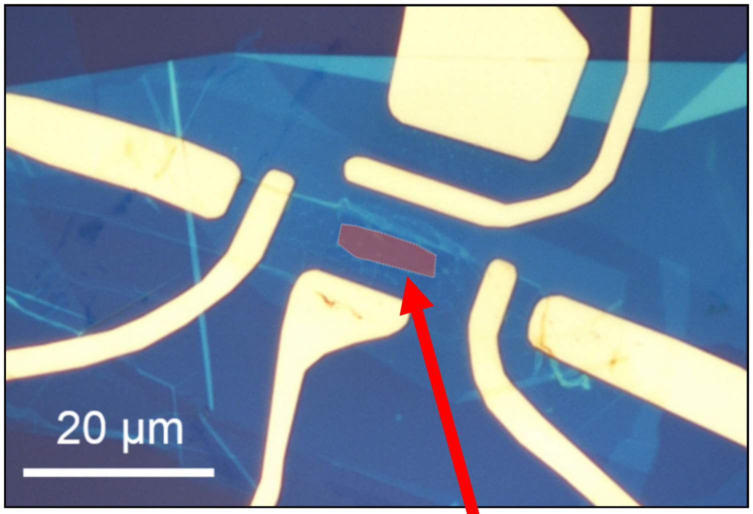
A. K. Geim & I. V. Grigorieva, Nature 499, 419 (2013)

Nano-LEGO



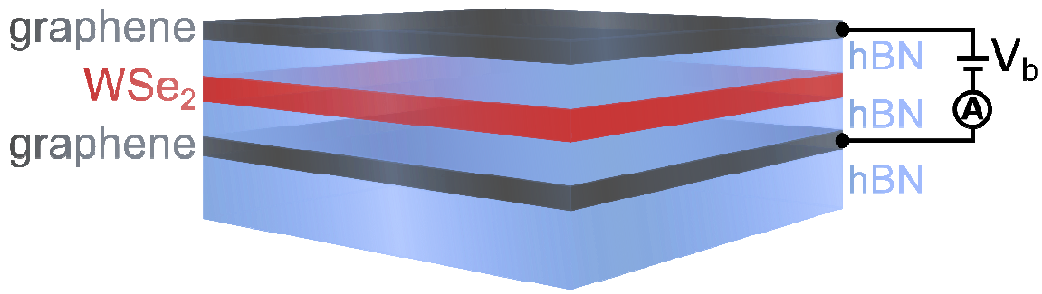
A. K. Geim & I. V. Grigorieva, Nature 499, 419 (2013)

Nano-Lego - przykład

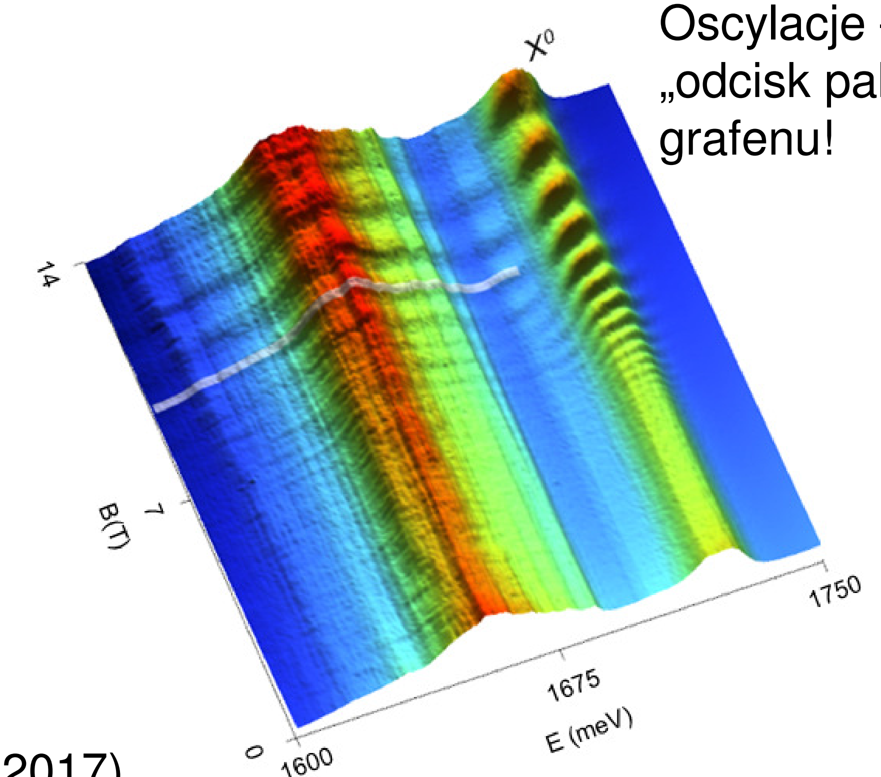


Płatek WSe_2

Struktura przygotowana
w University of Manchester



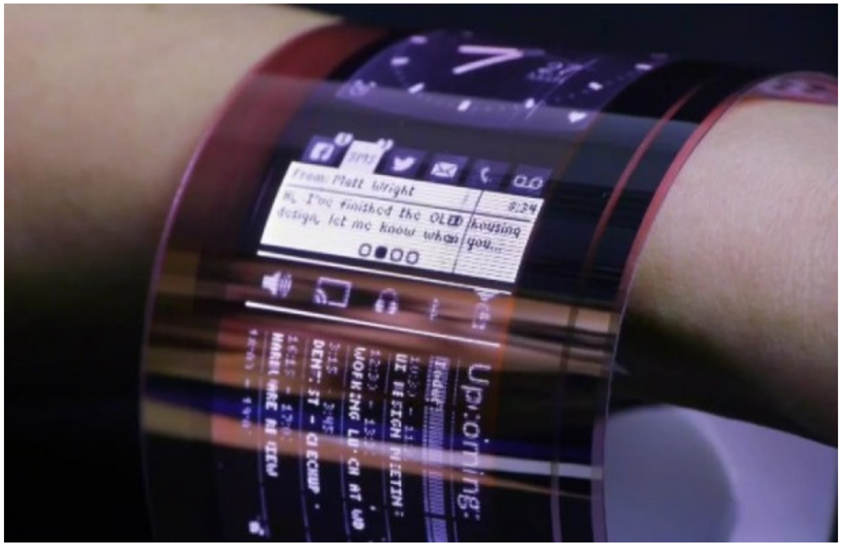
Oscylacje –
„odcisk palca”
grafenu!



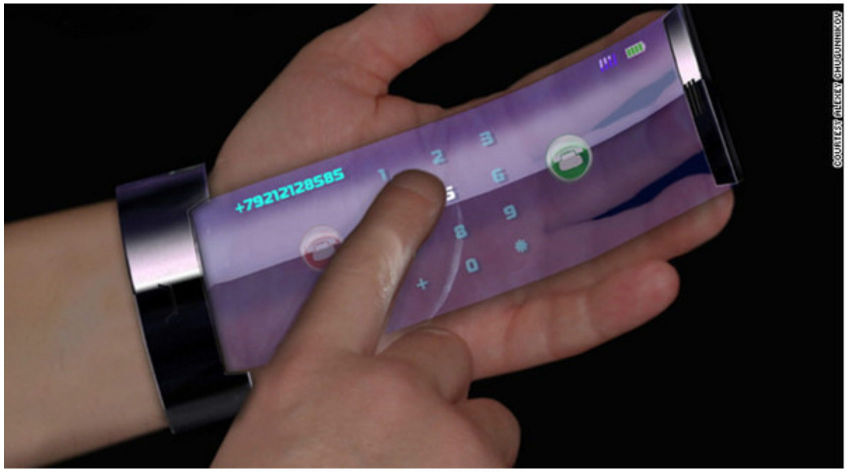
J. Binder et al., Nano Letters 17, 1425 (2017)

Grafen i inne materiały 2D – nowe możliwości!

http://www.ibtimes.co.uk/

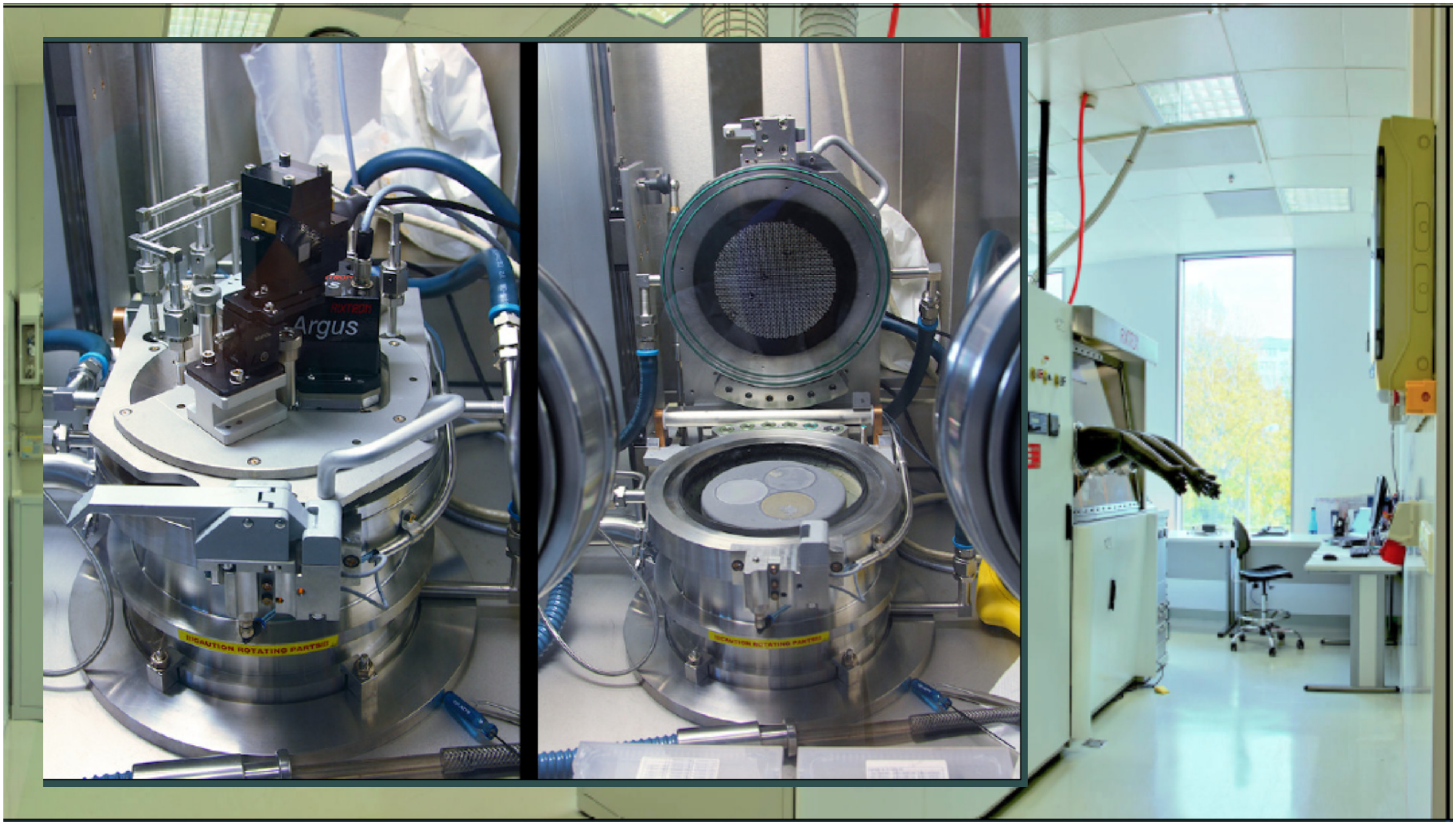


http://www.2dmaterialsmag.com
/flexible-graphene/

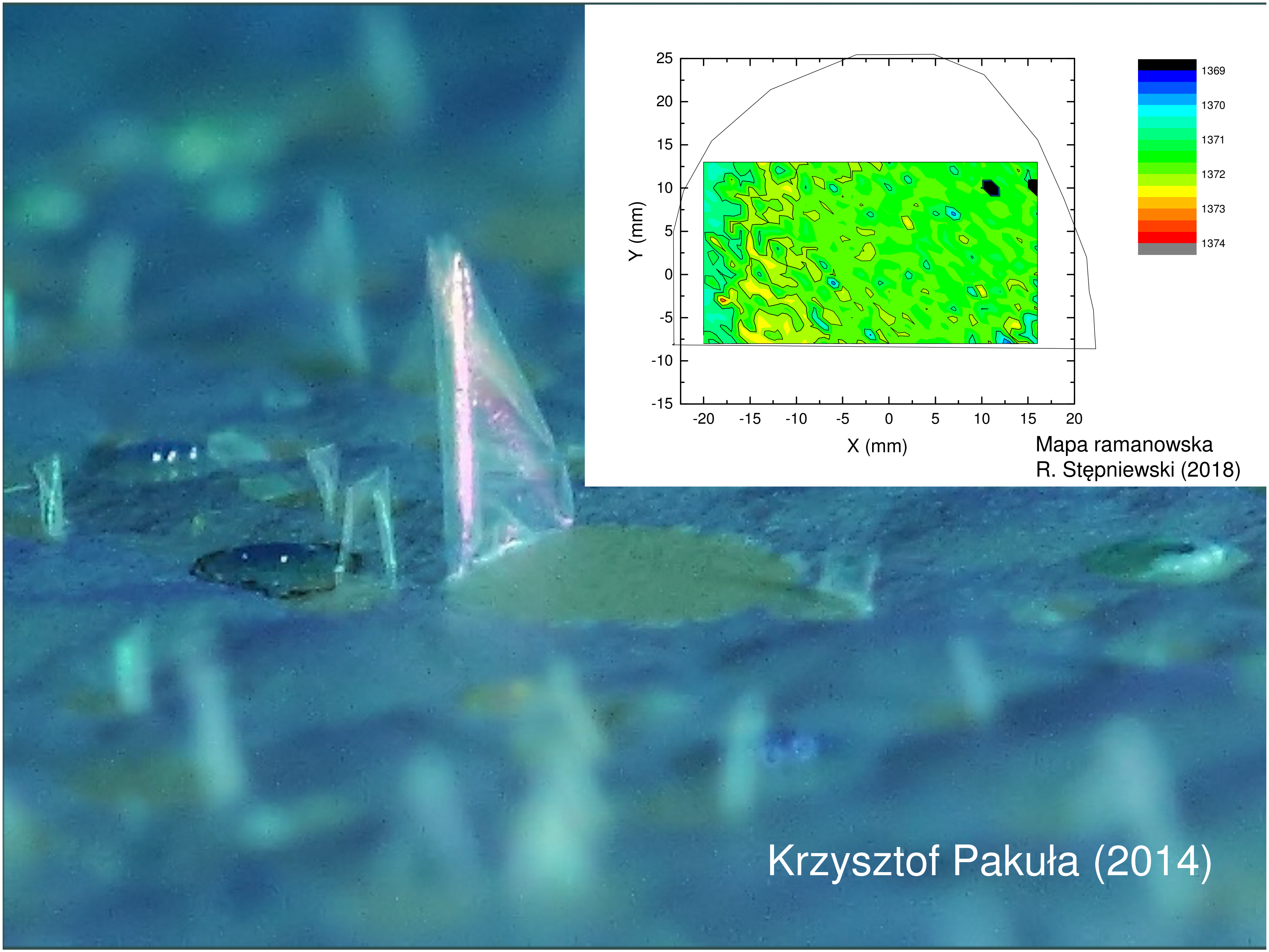


http://blog.idroidusa.com/

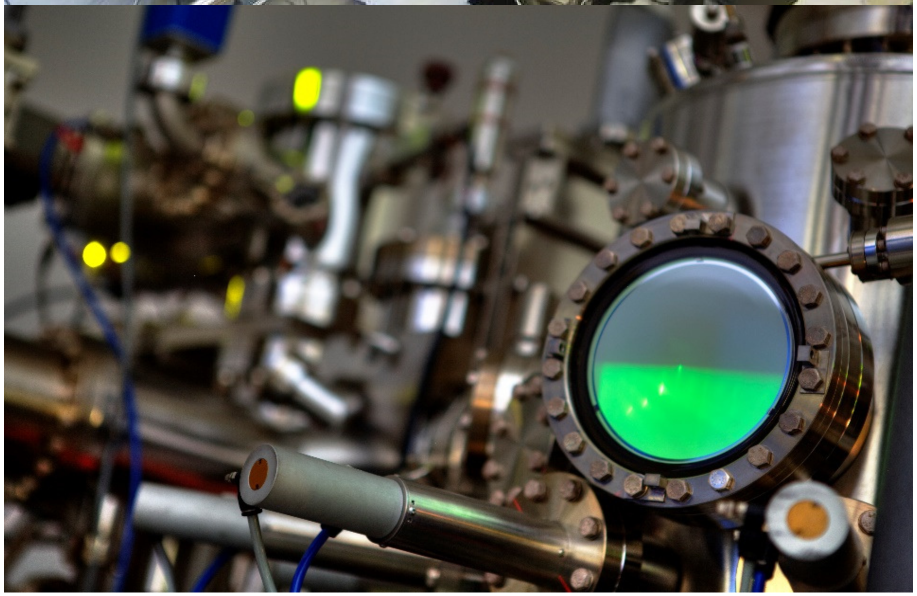
Epitaksja: Pracownia MOVPE (Wydział Fizyki UW)

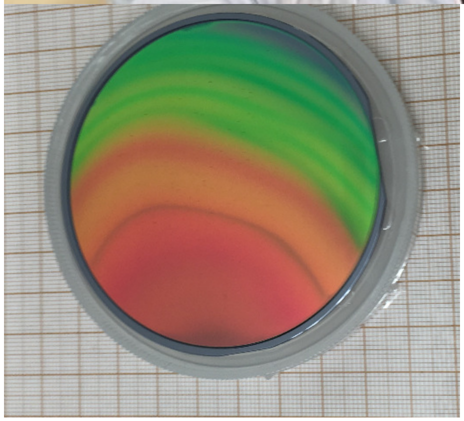


mgr K. Pakuła, opieka prof. Roman Stępniewski


Y (mm)
X (mm)
1369
1370
1371
1372
1373
1374
Mapa ramanowska
R. Stępniewski (2018)
Krzysztof Pakuła (2014)

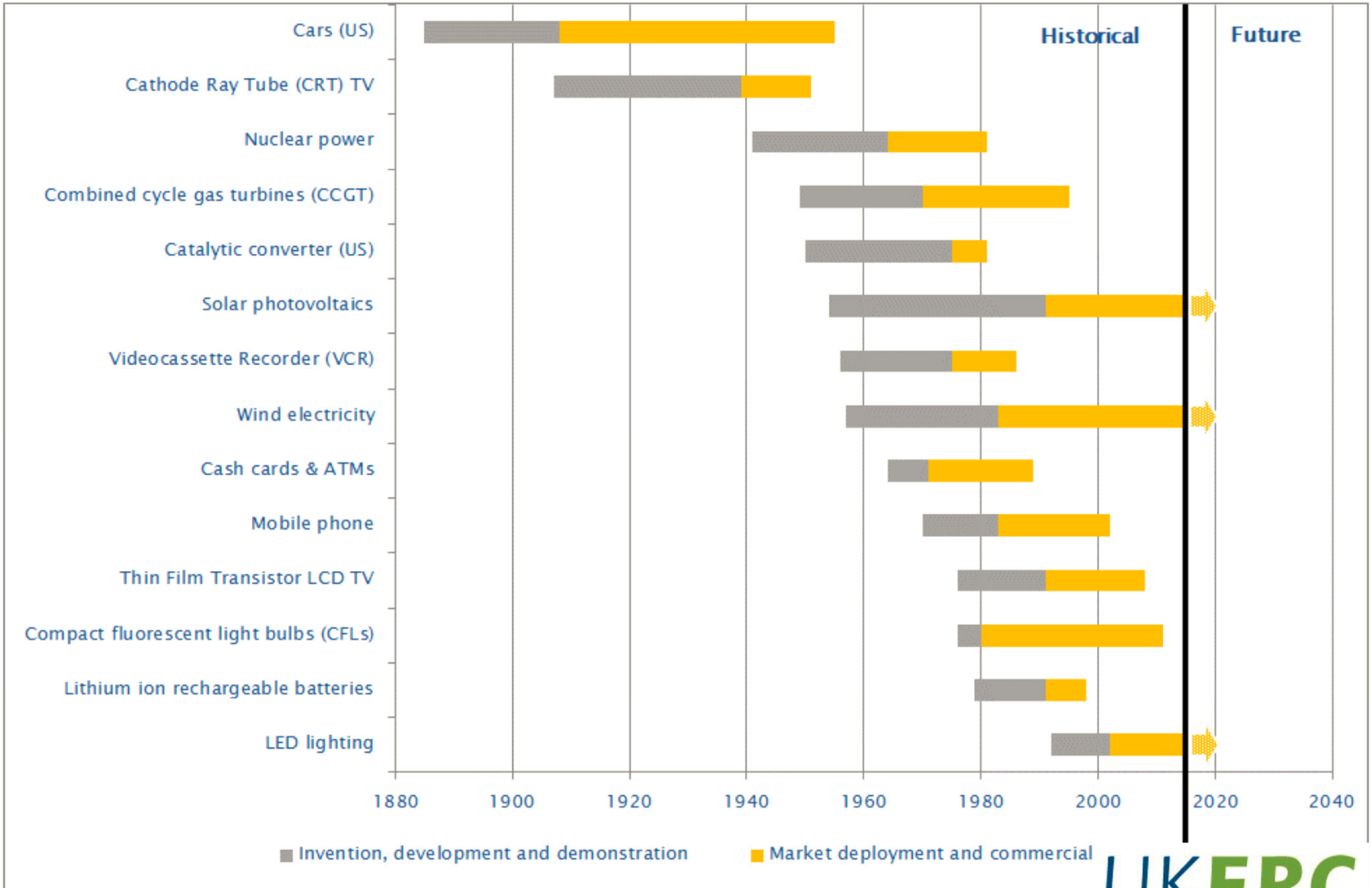
Epitaksja z wiązek molekularnych (MBE)





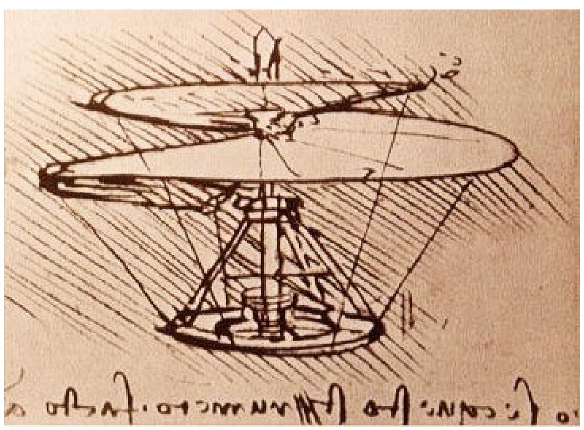
Dr hab. Wojciech Pacuski i studenci ☺

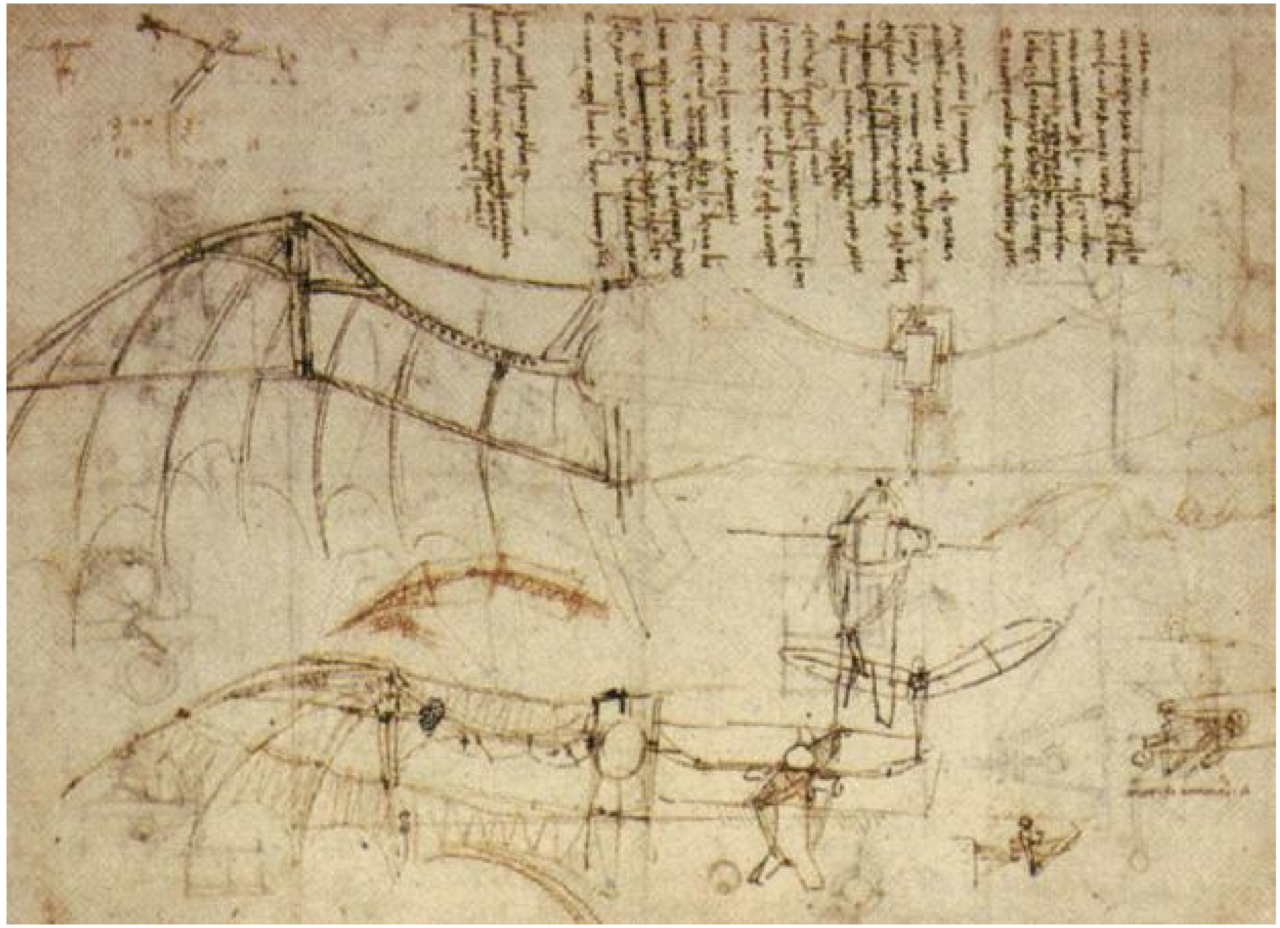
Figure ES2: Historical timeline and duration of innovation for all technologies reviewed



UKERC
UK Energy Research Centre

Leonardo da Vinci i jego idee

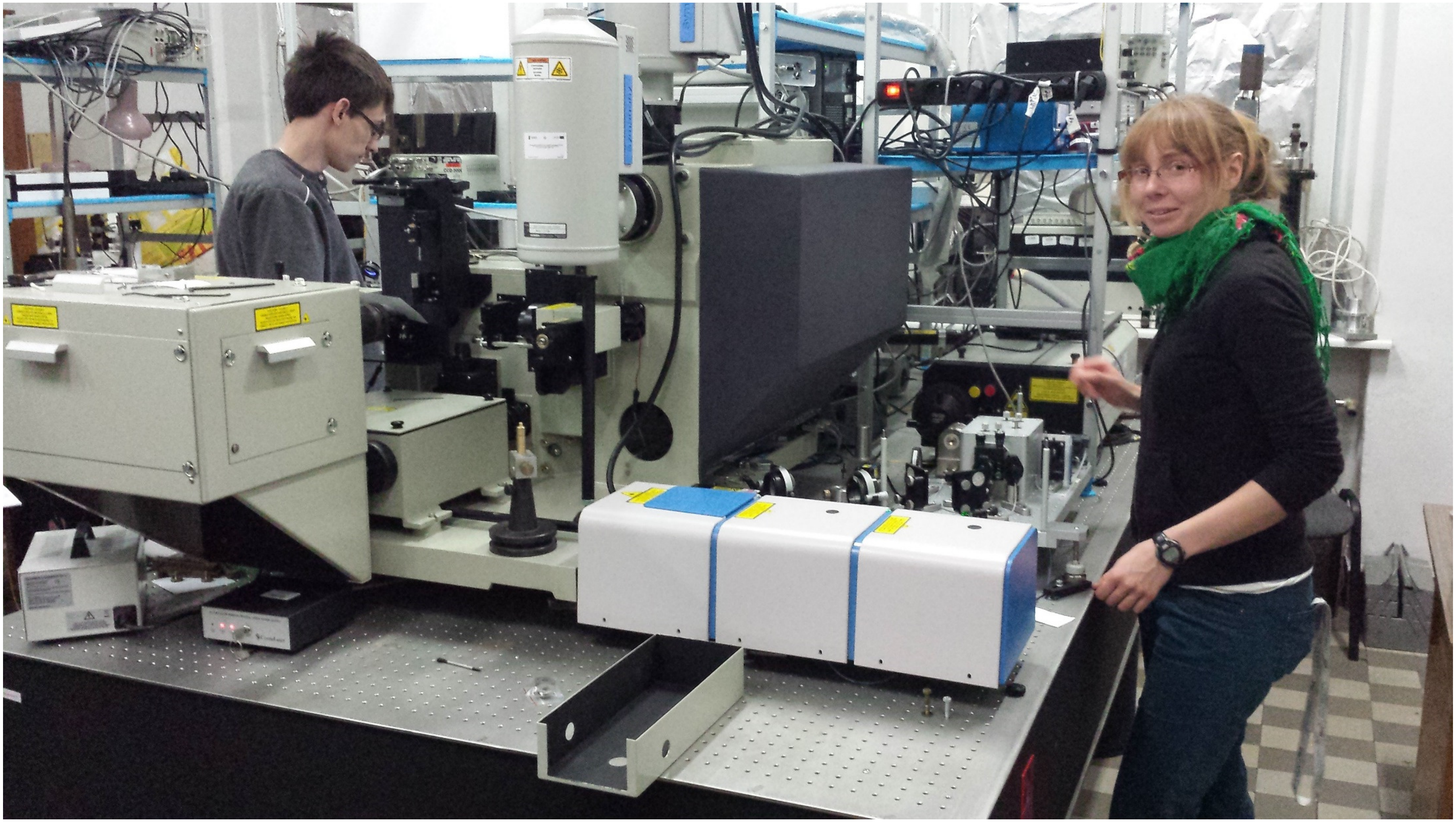




Latającej maszyny…
https://en.wikipedia.org/wiki/

Bez pomysłów nie ma postępu!

Na kogo można liczyć?



Zapraszamy do współpracy ☺

Przyszłość grafenu i innych materiałów 2D?

Przyszłość zależy od nas☺