

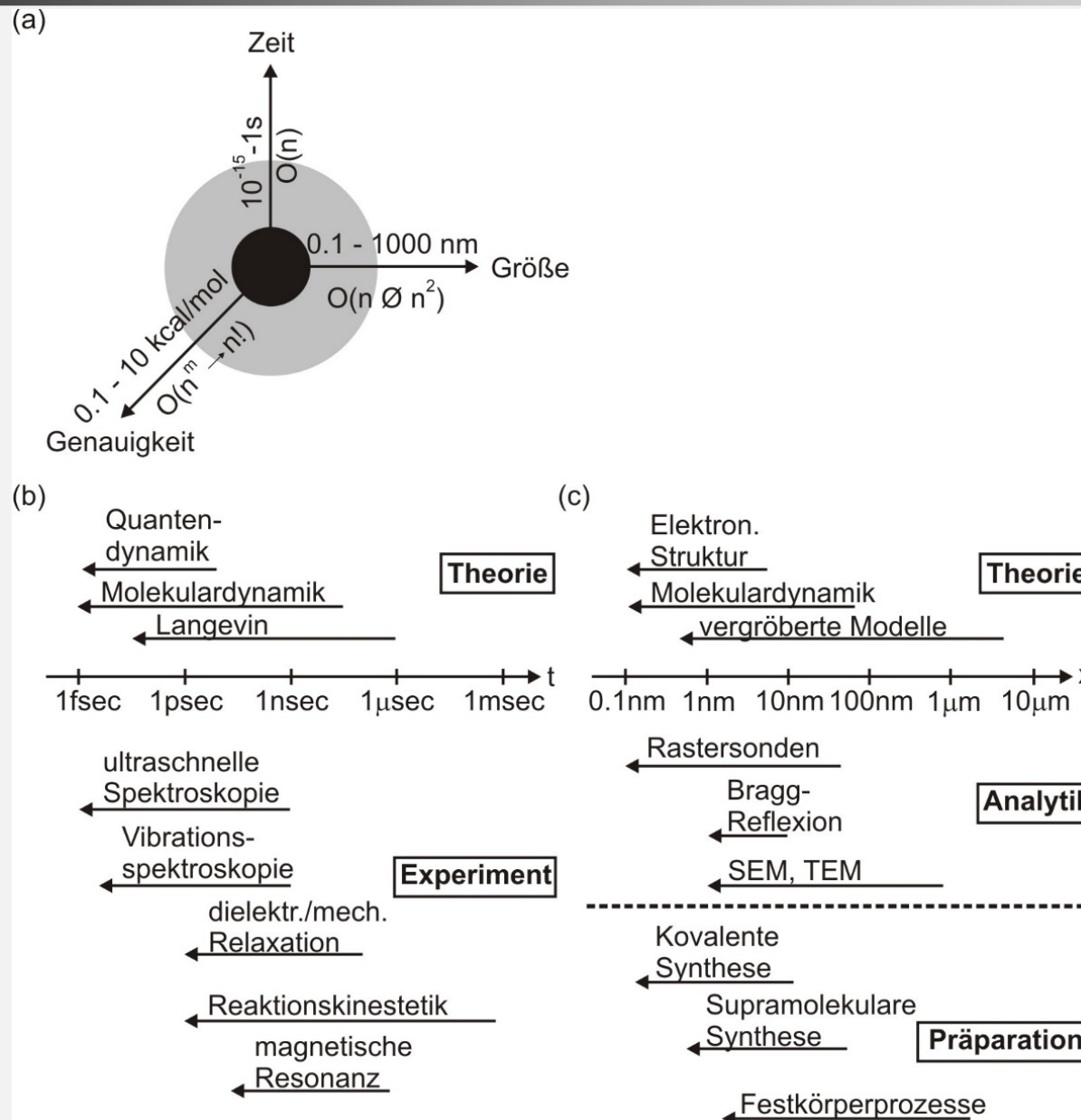
Vorlesung Nanostrukturphysik IIa

1. Motivation

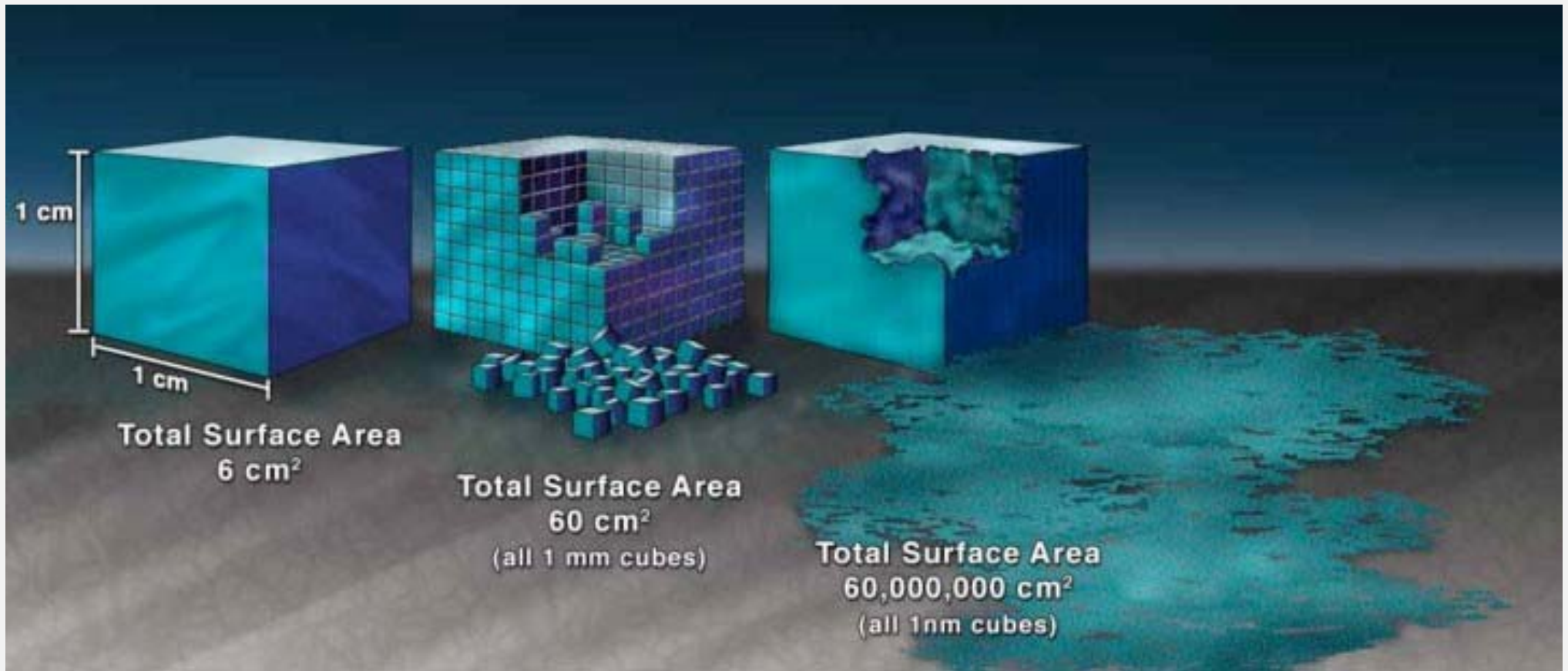
Sommersemester 2022

Prof. Dr. Uwe Hartmann





Nanoskala und die Rolle der Oberflächen





Nanotechnologie und Quantenmechanik

Quantenmechanik

- Theorie der Quantisierungseffekte
- Phänomene hinreichend kleiner Objekte
- Quantentechnologien

Nanotechnologie

- Realisierung von Nanosystemen
- Voraussetzung für die Beobachtung und Nutzung von Quanteneffekten
- Realisierung von Quantentechnologien

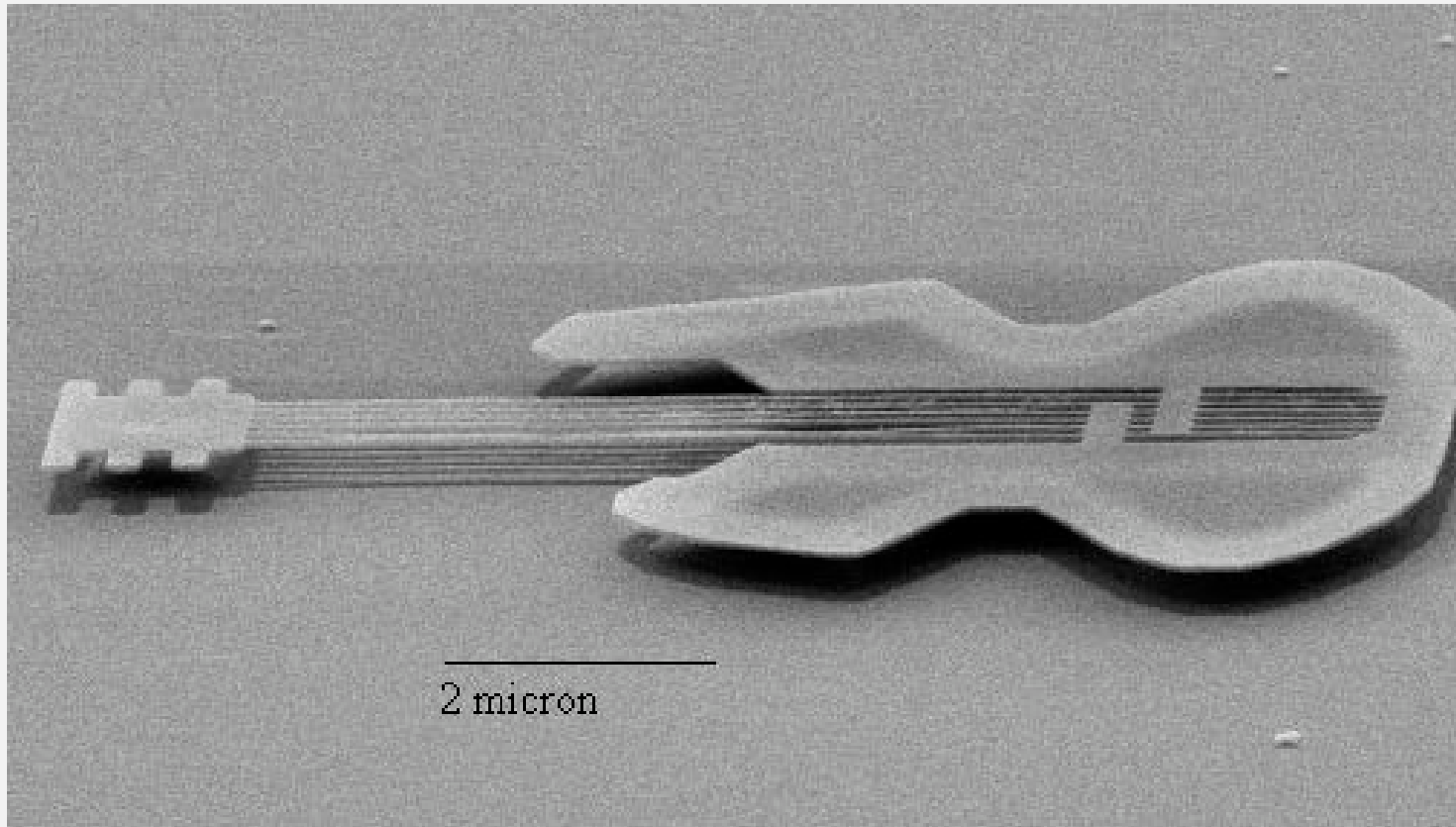


Vorlesung I: Skalierungsverhalten und –grenzen

Top-Down-Ansatz: Was passiert, wenn wir immer kleinere Strukturen herstellen? Skalierung möglich, solange Invarianz der Funktionsprinzipien gilt

Transistor heute: 10^{12} Atome
Nanotransistor: <1000 Atome

?



D. Carr and H. Craighead, Cornell

Gesamtlänge: 10 μm

Saite: 50 nm (d.h. ~ 100 Atome) im Durchmesser

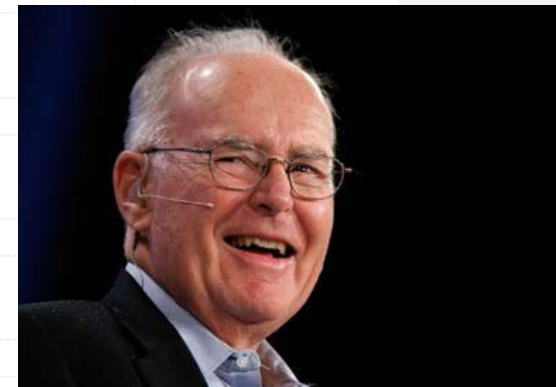
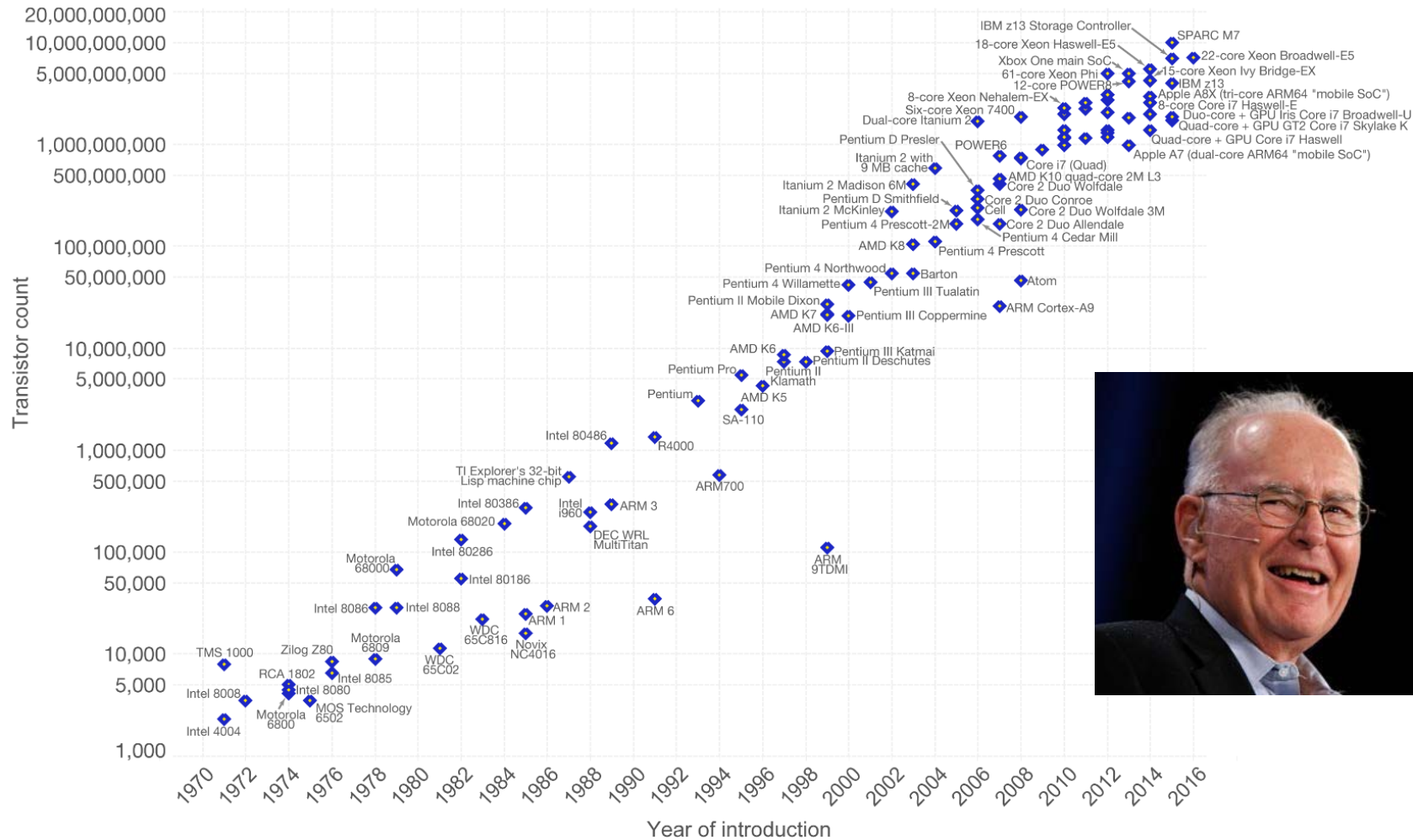
Frequenzen: Zentimeterbereich: 10^2 Hz

Nanometerbereich: 10^7 Hz

Moore's Law – The number of transistors on integrated circuit chips (1971-2016)



Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are strongly linked to Moore's law.



Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)

The data visualization is available at [OurWorldinData.org](https://www.ourworldindata.org). There you find more visualizations and research on this topic.

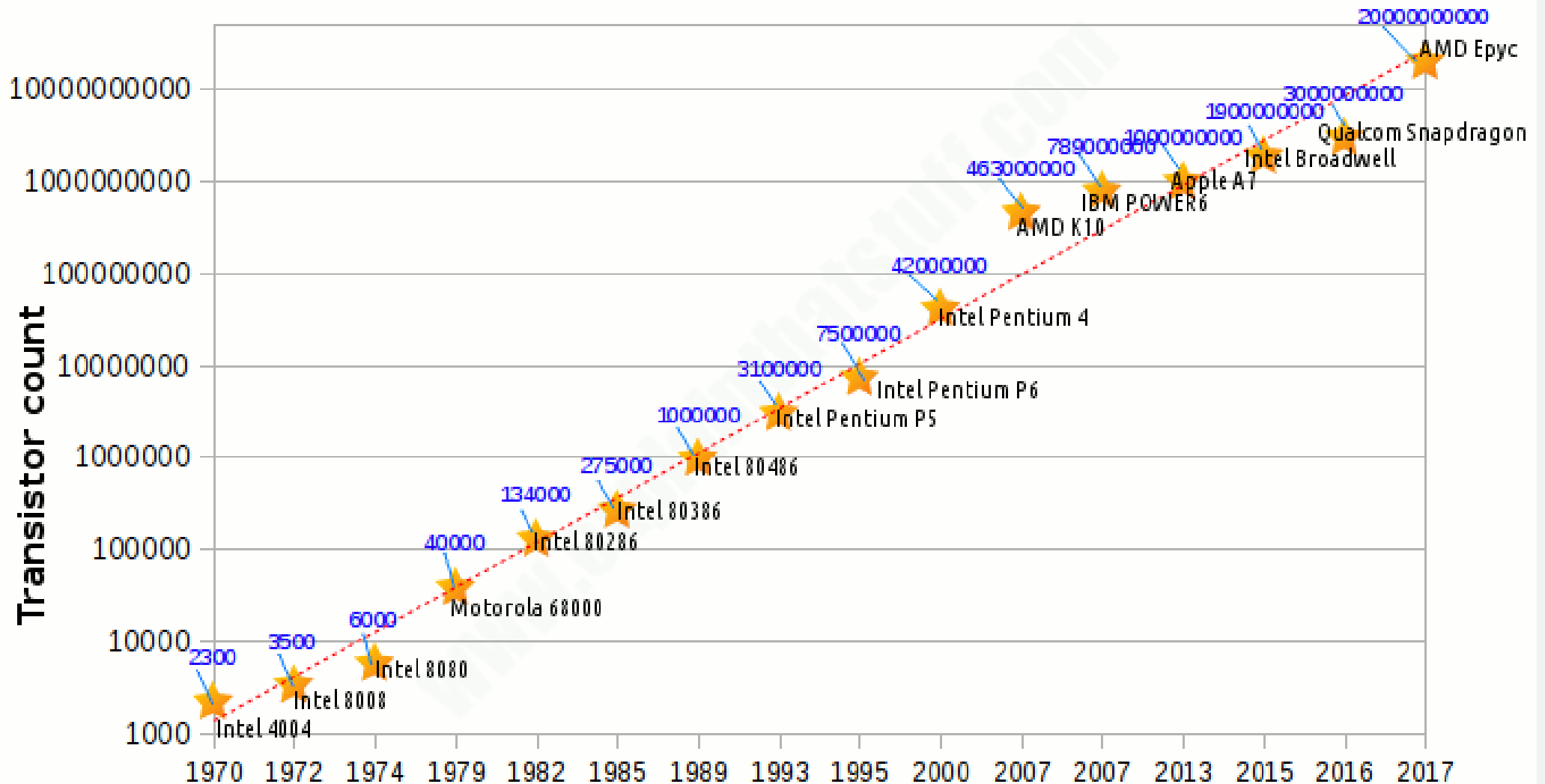
Licensed under [CC-BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) by the author Max Roser.



Moore'sches Gesetz

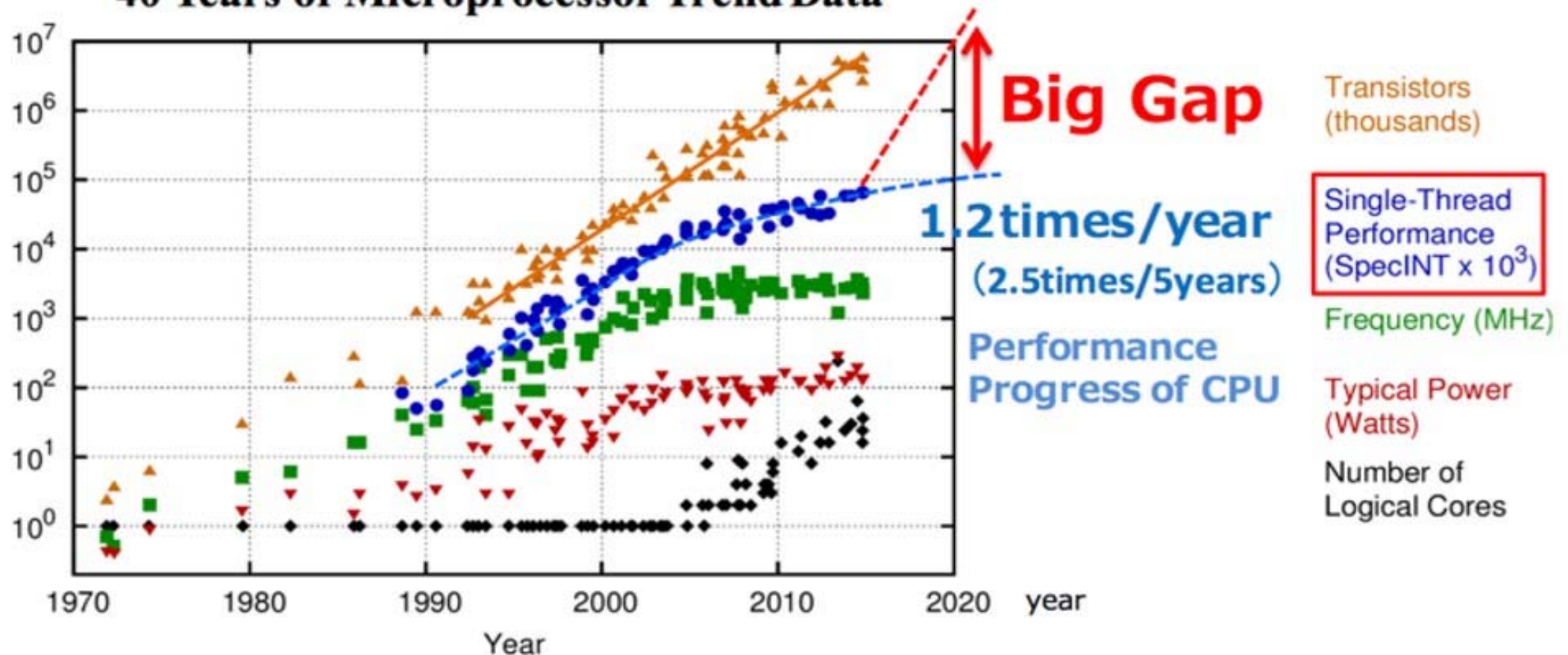
50 Years of Moore's law

www.explainthatstuff.com



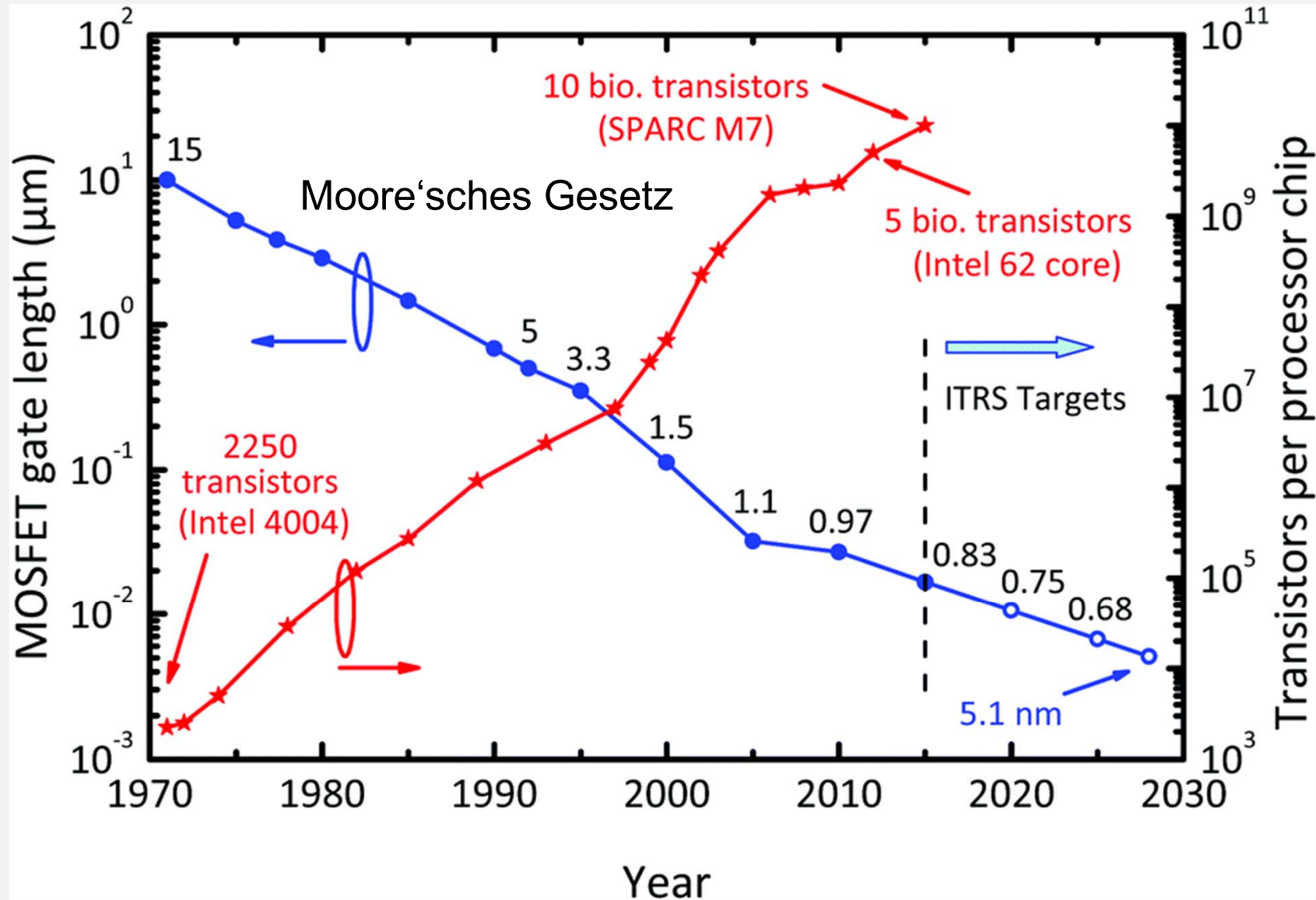
Moore'sches Gesetz – Prozessoren

40 Years of Microprocessor Trend Data



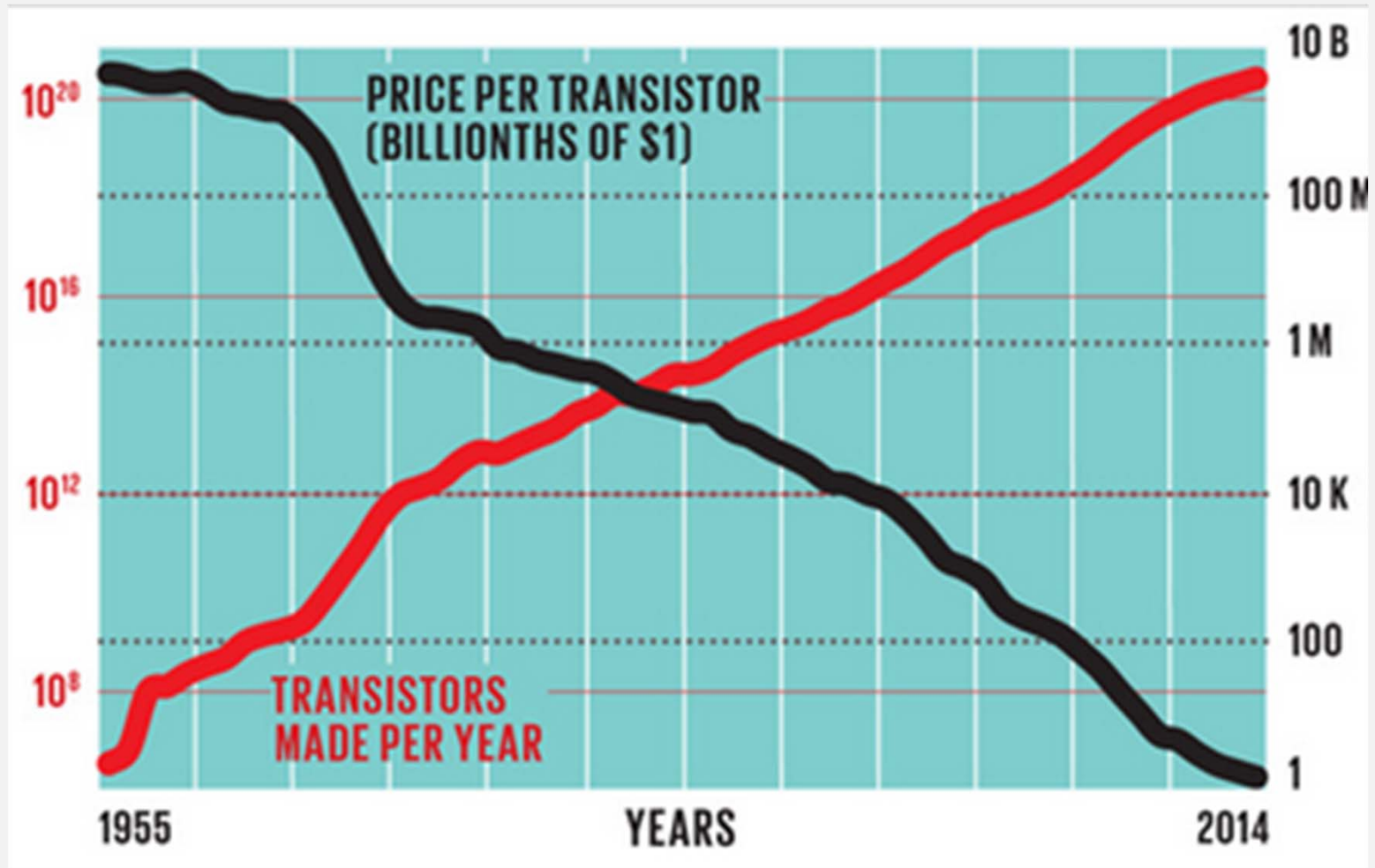
Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
 New plot and data collected for 2010-2015 by K. Rupp

Ref.: Ahmet Ceyhan, INTERCONNECTS FOR FUTURE TECHNOLOGY GENERATIONS—CONVENTIONAL CMOS WITH COPPER/LOW- κ AND BEYOND, Fig 2, 9

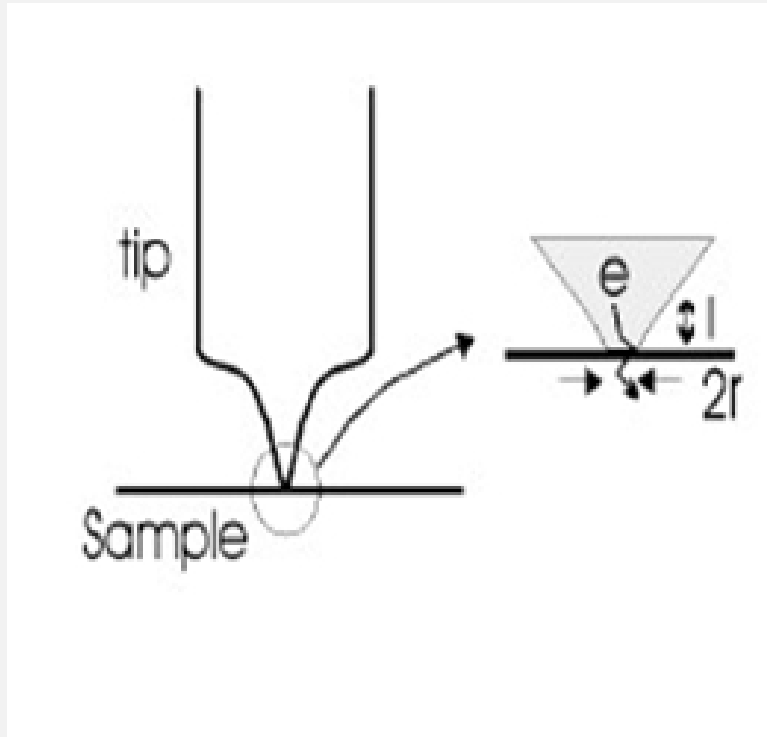


F. Schwierz *et al.*, *Nanoscale* 7, 8261 (2015)

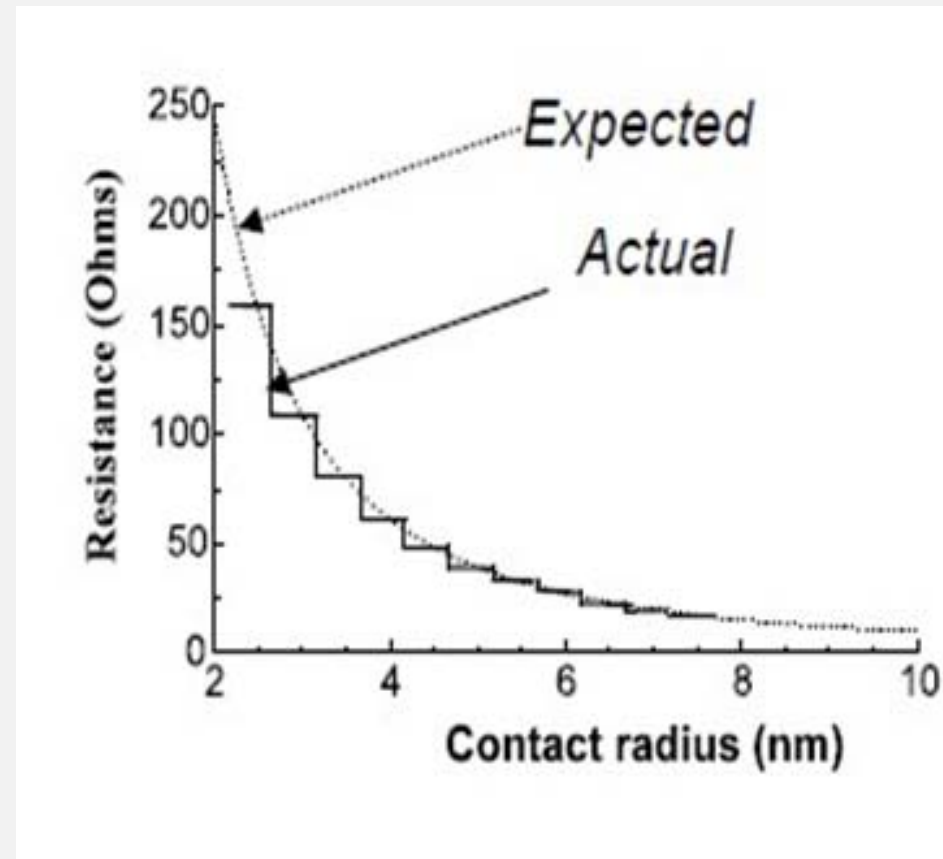
Moore'sches Gesetz



<http://www.politicalowl.com/home/2015/04/15/moores-law-at-50/>



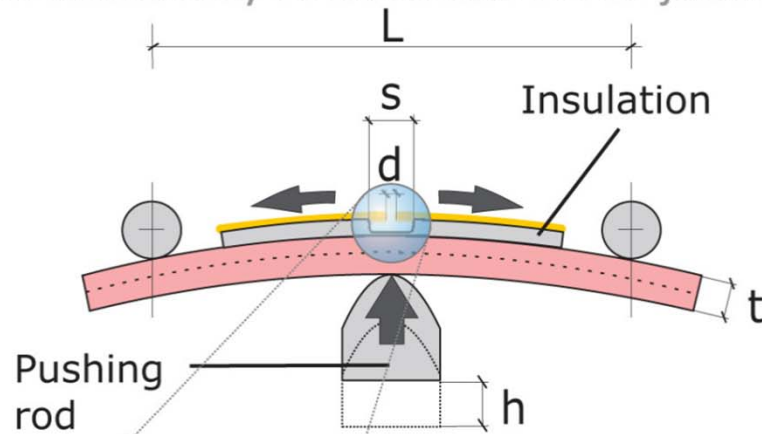
Wie ändert sich der Widerstand eines Punktkontakts, wenn er kleiner wird?



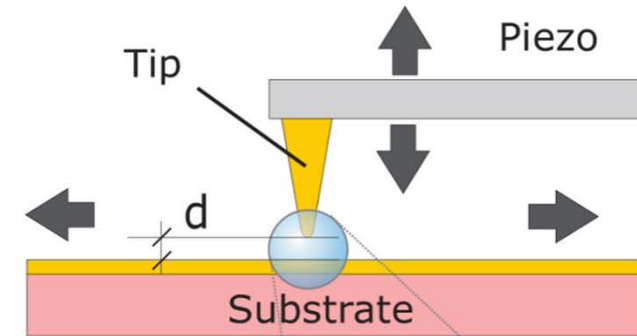
Quanteneffekte:

- fundamental
- diskret (Eigenschaften verändern sich stufenweise)

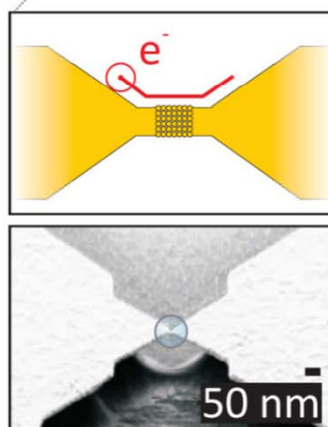
(a) Mechanically controllable break-junction



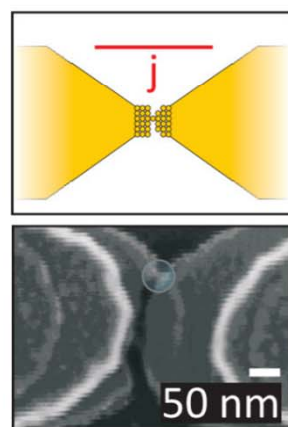
(b) Probe-based break-junction



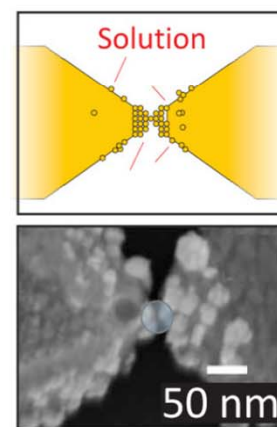
(c) Microstructured



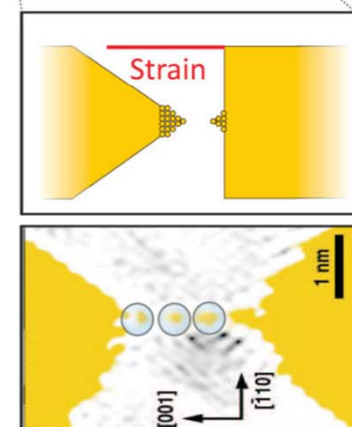
(d) Electromigrated



(e) Electrodeposited

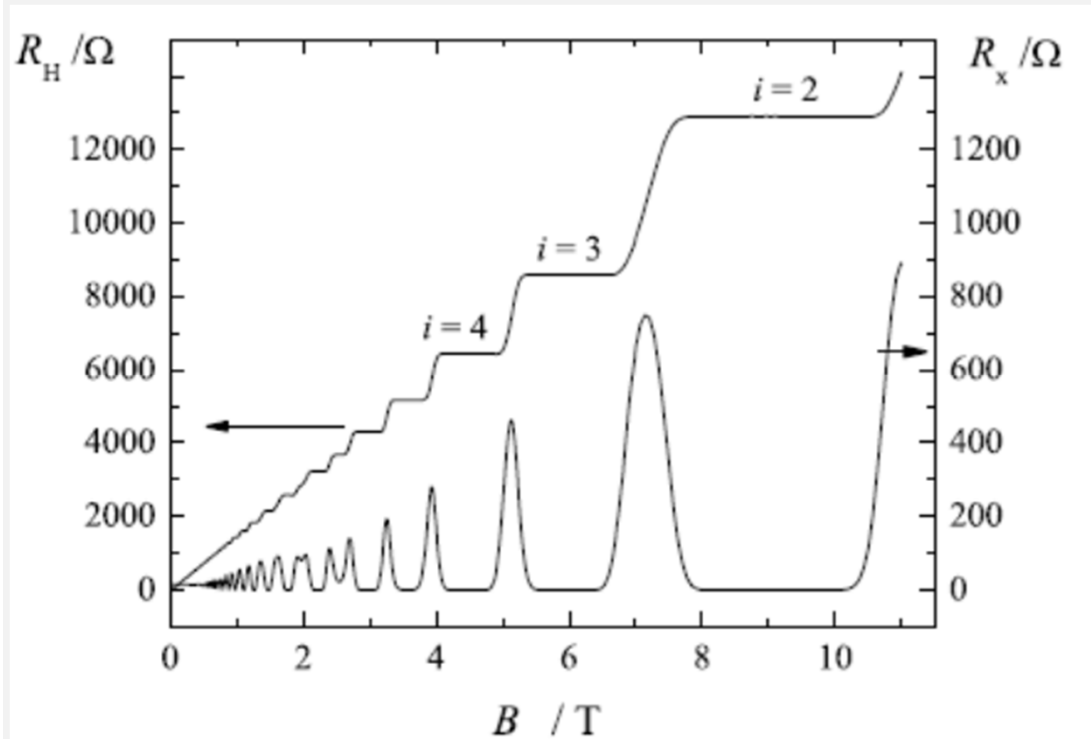


(f) Pulled Wires



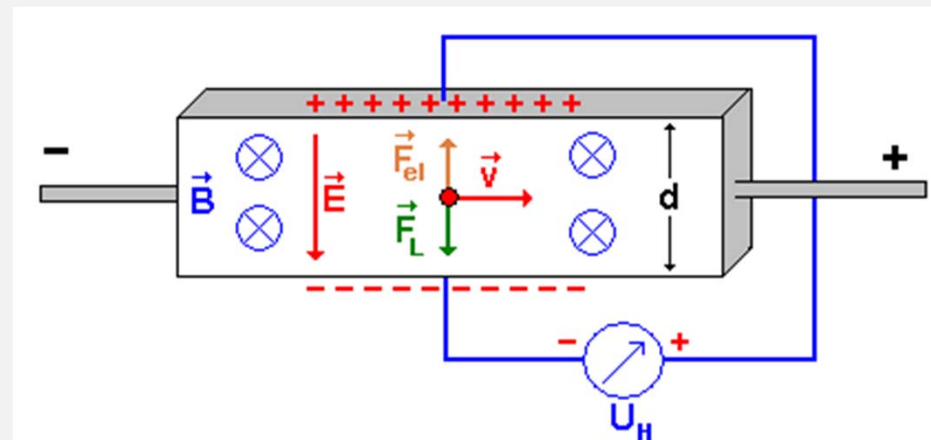
F. Schwarz, E. Lörtscher, J. Phys.: Condens. Matter **26**, 474201 (2014)

Quanten-Hall-Effekt



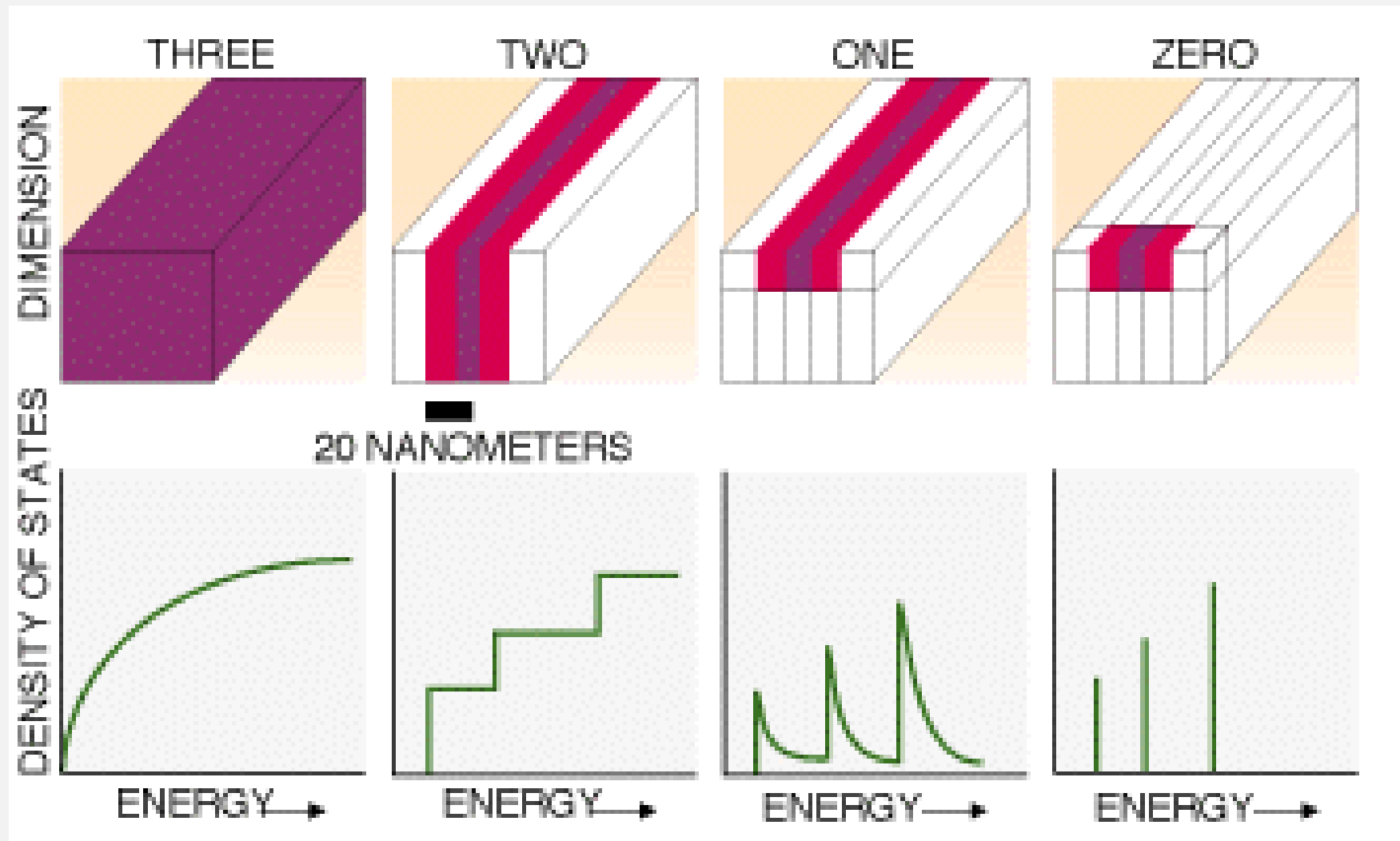
J. Schurr et al., Meas. Sci. Technol. 23 124009 (2012)

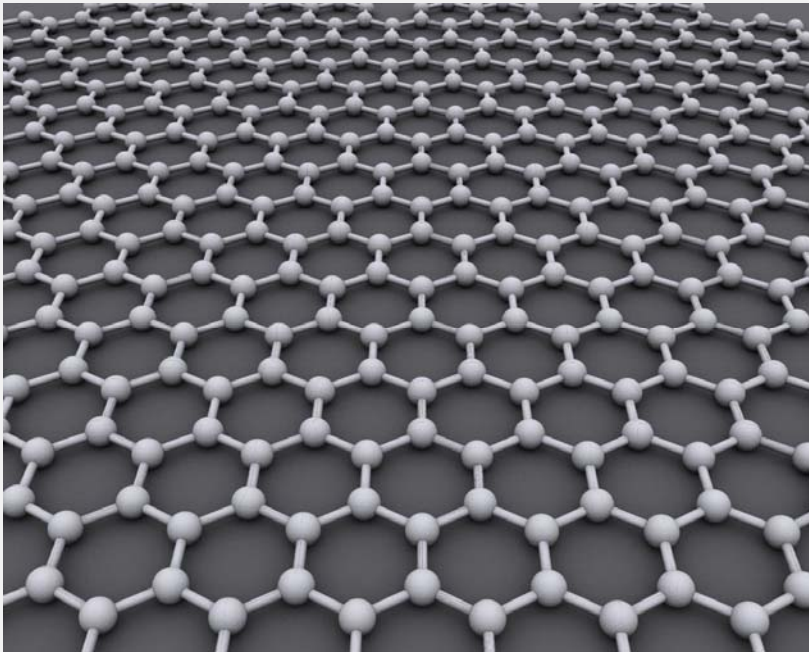
Der Hall-Effekt



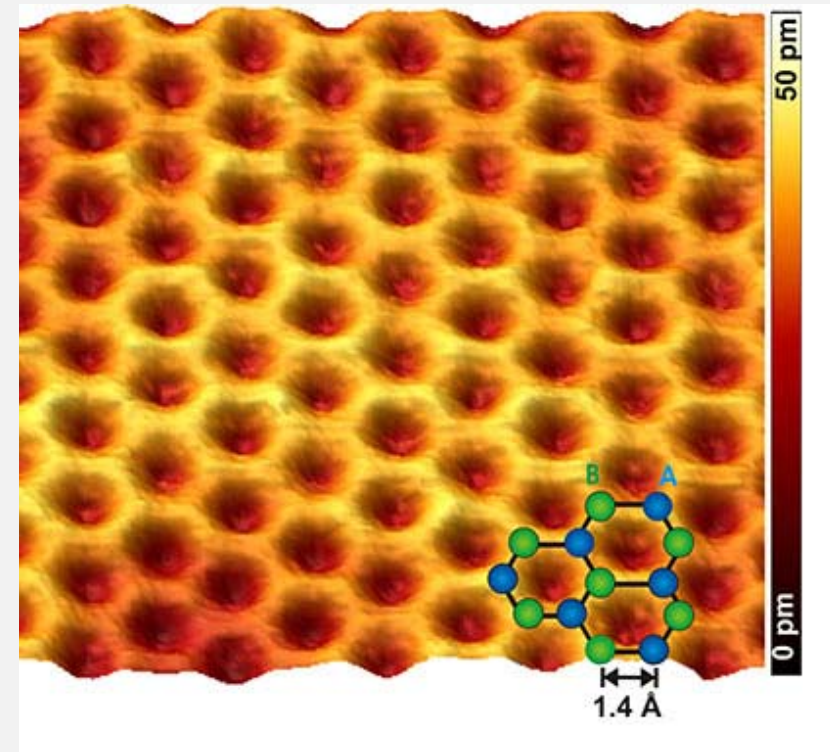
$$U_H = d \cdot v \cdot B$$

Einfluss der Dimensionalität





Graphene



<http://www.nanoscience.de/HTML/research/graphene.html>



Van-der-Waals-Heterostrukturen

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 , etc.	metallic dichalcogenides: NbSe ₂ , NbS ₂ , TaS ₂ , TiS ₂ , NiSe ₂ , etc.	
				layered semiconductors: GaSe, GaTe, InSe, Bi ₂ Se ₃ , etc.	
2D oxides	micas, BSCCO	MoO ₃ , WO ₃	perovskite-type: LaNb ₂ O ₇ , (Ca,Sr) ₂ Nb ₃ O ₁₀ , Bi ₄ Ti ₃ O ₁₂ , Ca ₂ Ta ₂ TiO ₁₀ , etc.	hydroxides: Ni(OH) ₂ , Eu(OH) ₂ , etc.	
	layered Cu oxides	TiO ₂ , MnO ₂ , V ₂ O ₅ , TaO ₃ , RuO ₂ , etc.		OTHERS	

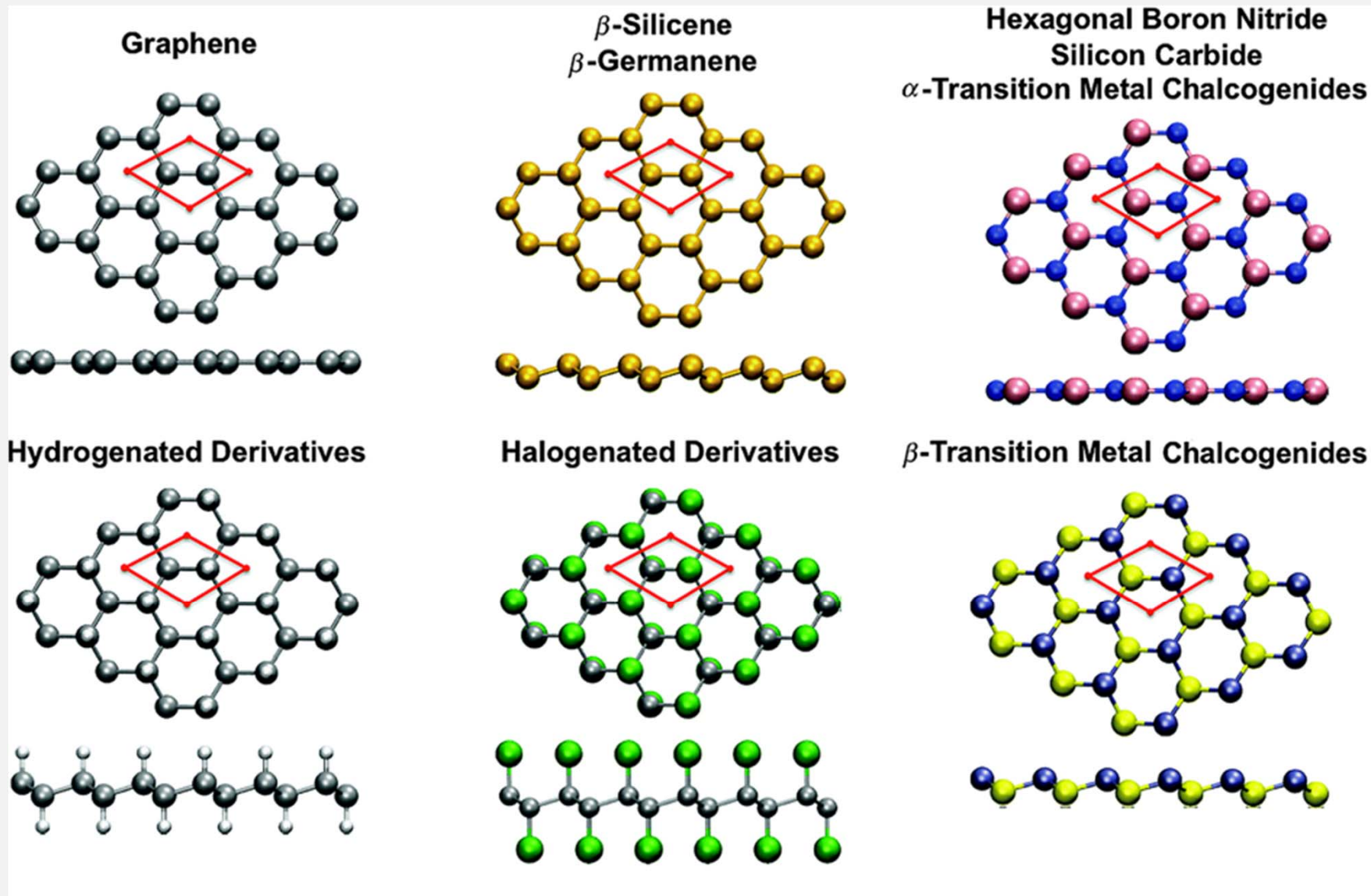
blau: stabil an Luft und bei Raumtemperatur

grün: stabil an Luft

gelb: instabil an Luft, aber stabil in inerter Atmosphäre

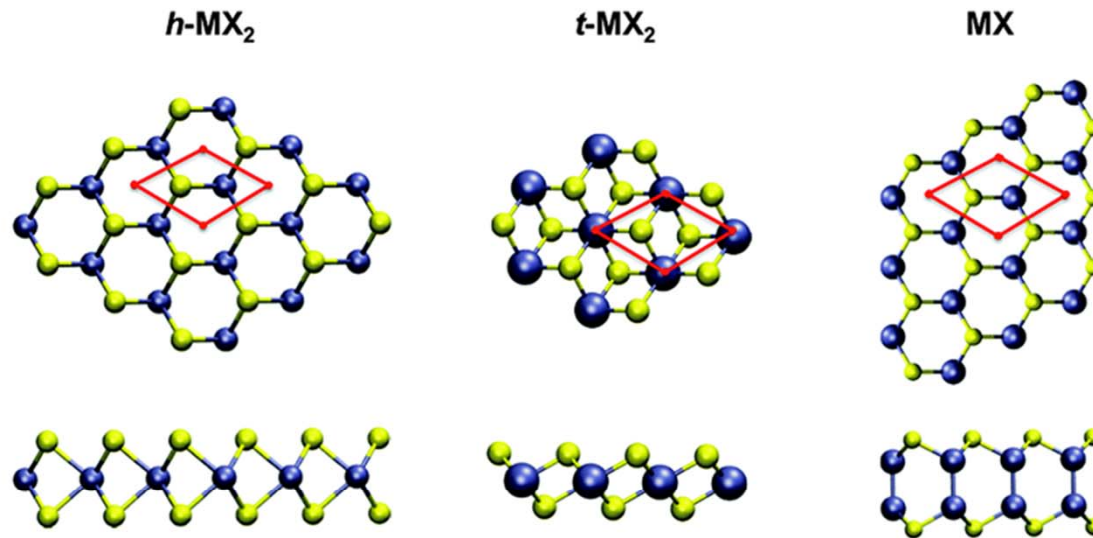
grau: 3D-Verbindungen, aus denen Monolagen hergestellt werden konnten

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

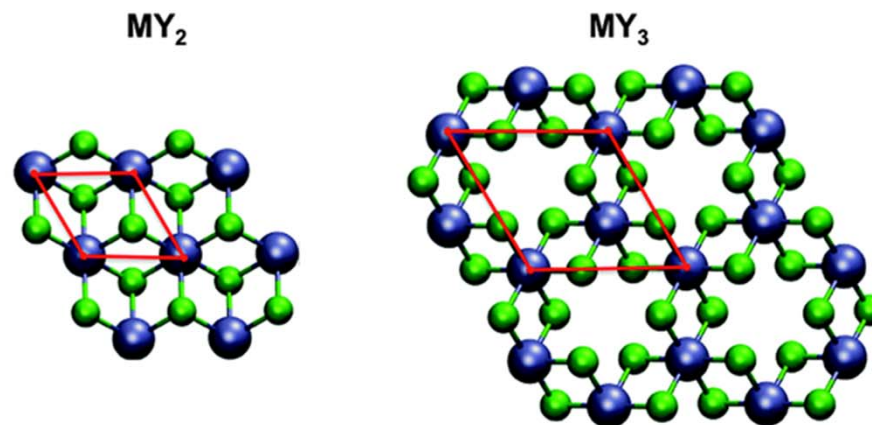


P. Miró et al., Chem. Soc. Rev., **43**, 6537 (2014)

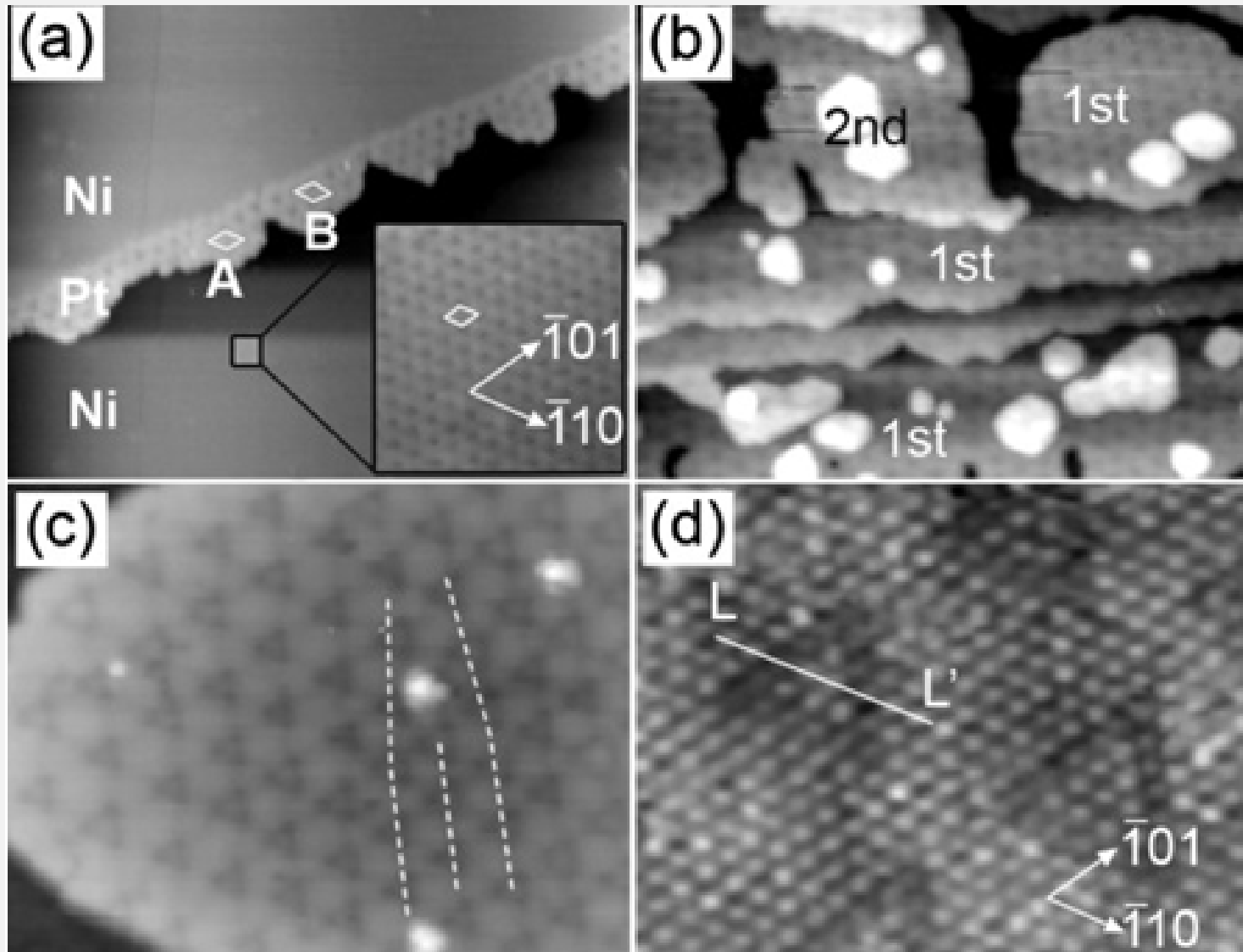
Transition Metal Chalcogenides



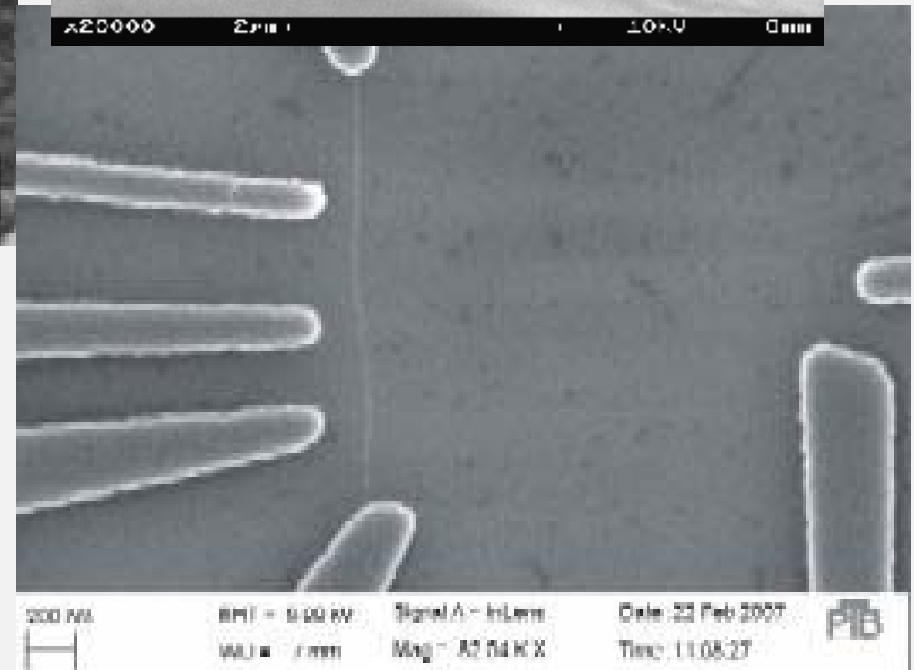
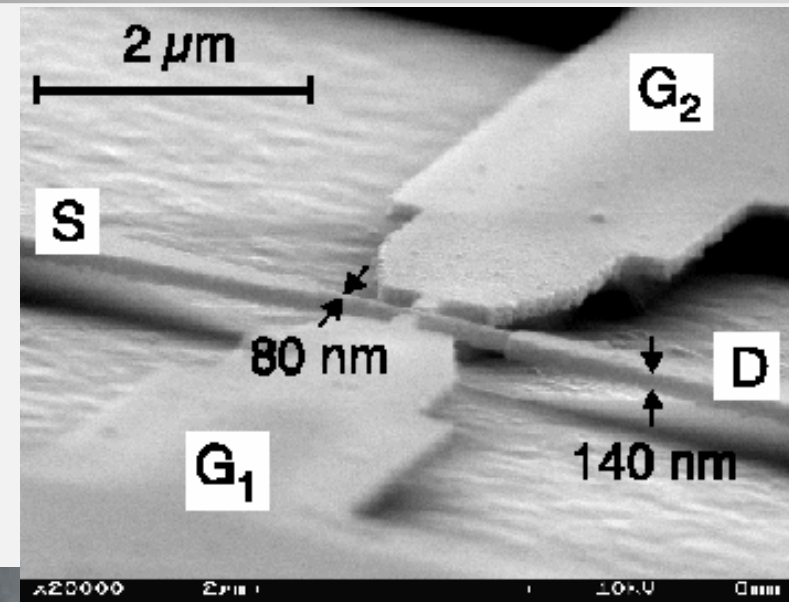
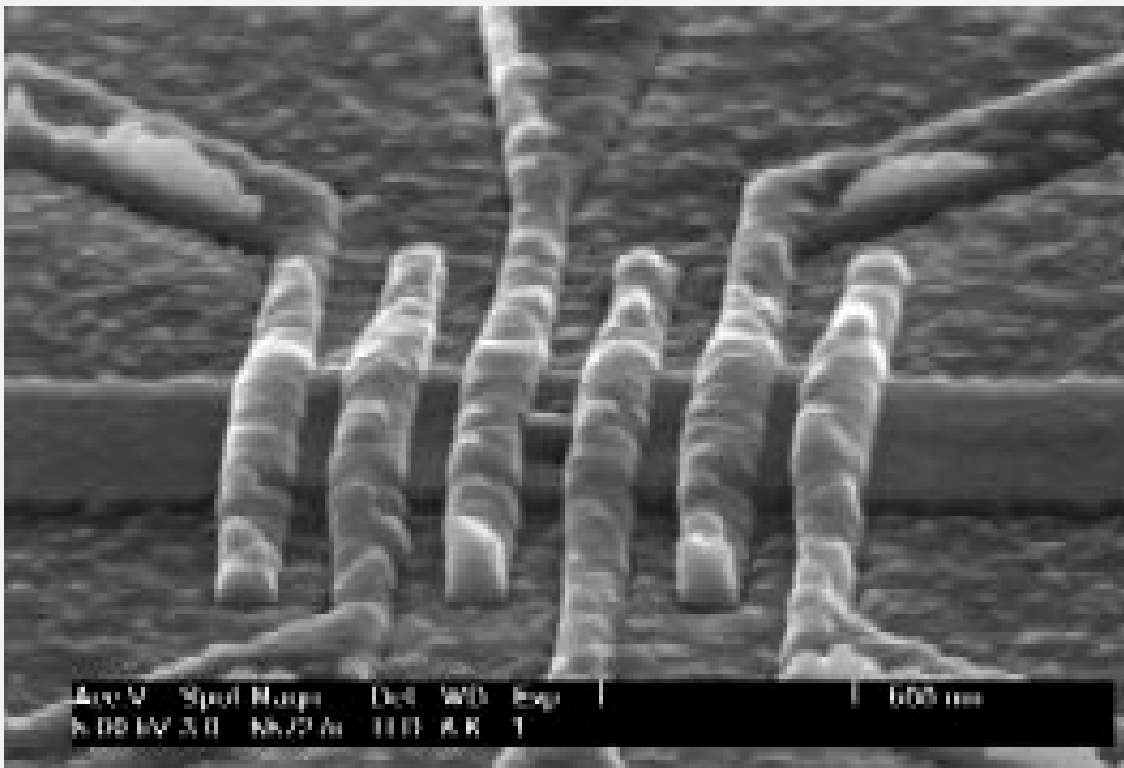
Transition Metal Halides



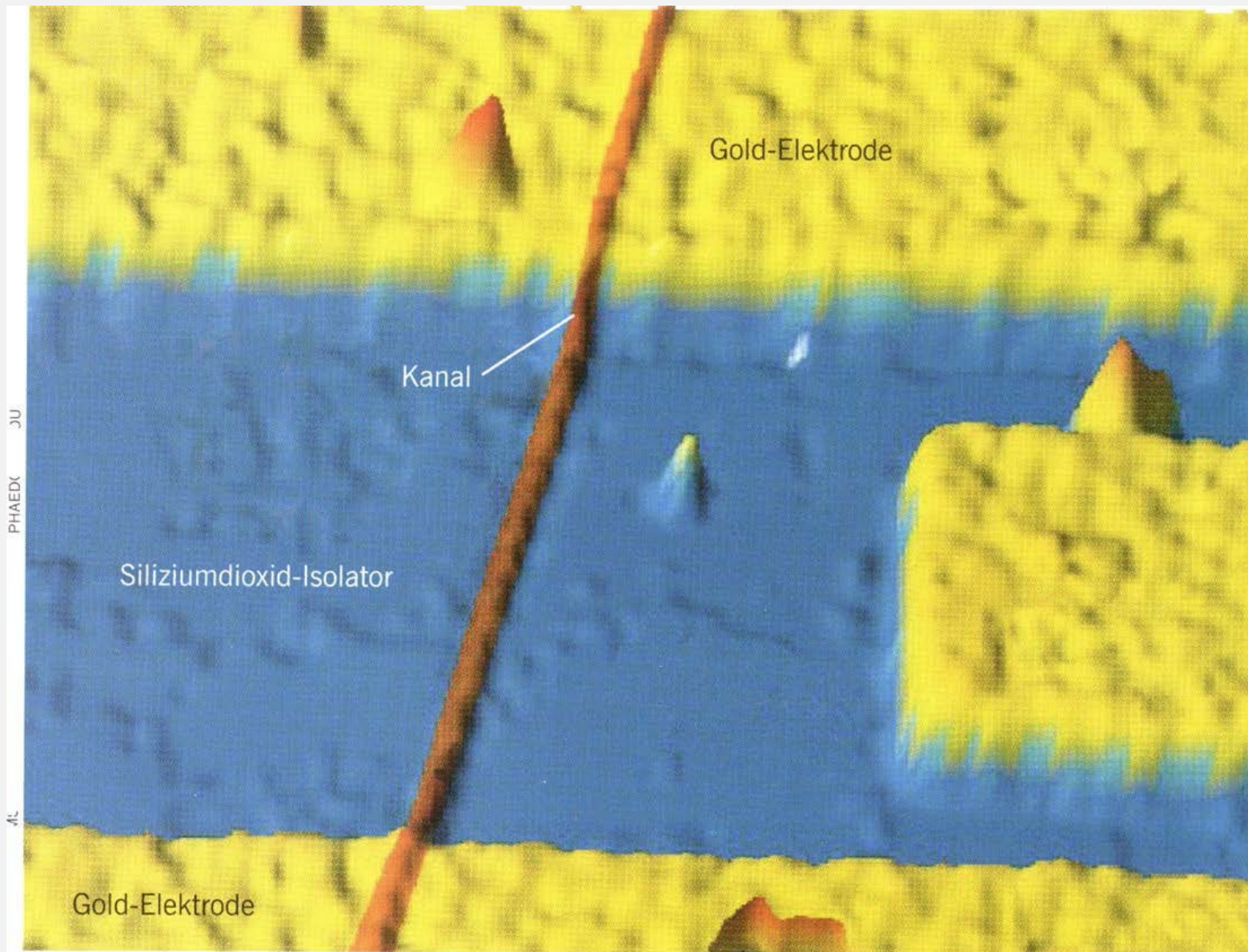
P. Miró et al., Chem. Soc. Rev., **43**, 6537 (2014)



Bai An *et al.*, JAP 108,103521 (2010)



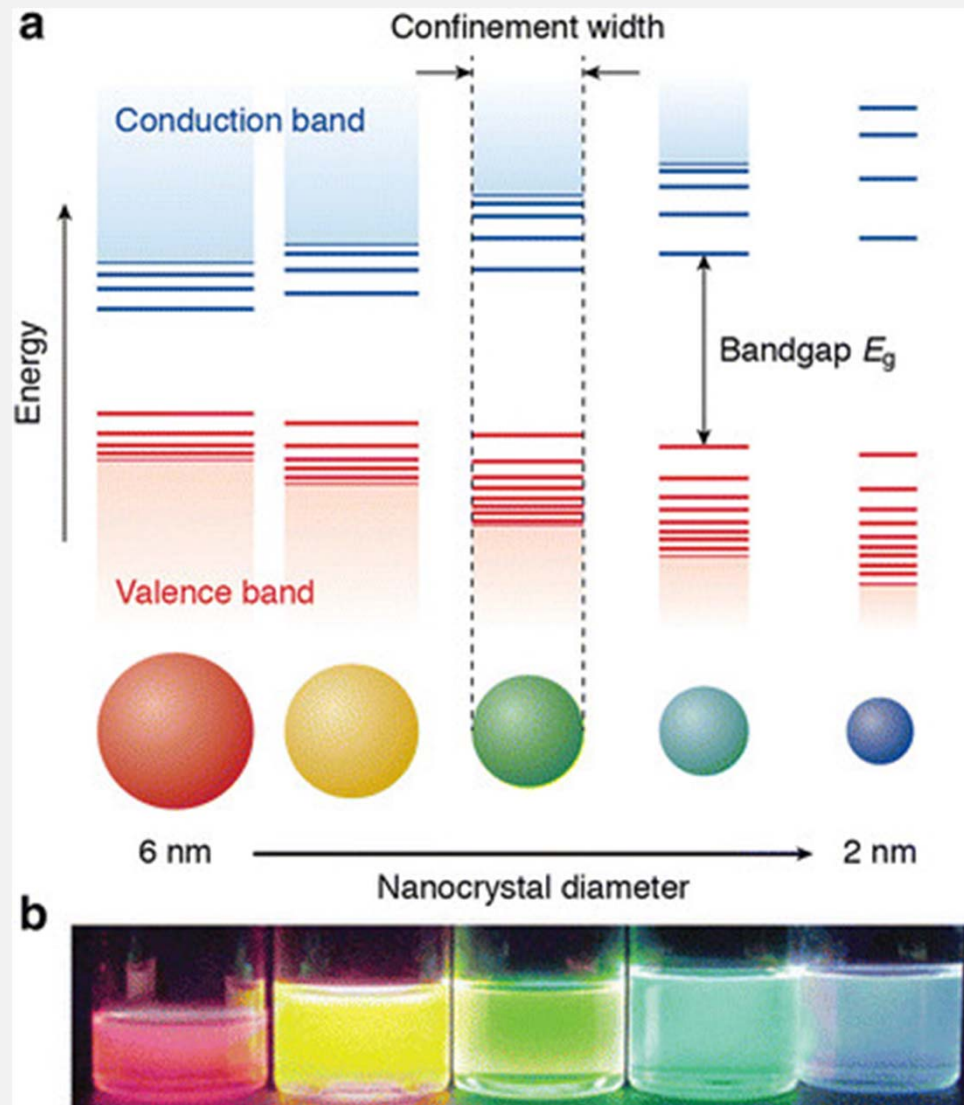
Quantendrähte
aus Metall, freitragend, C-Nanoröhre



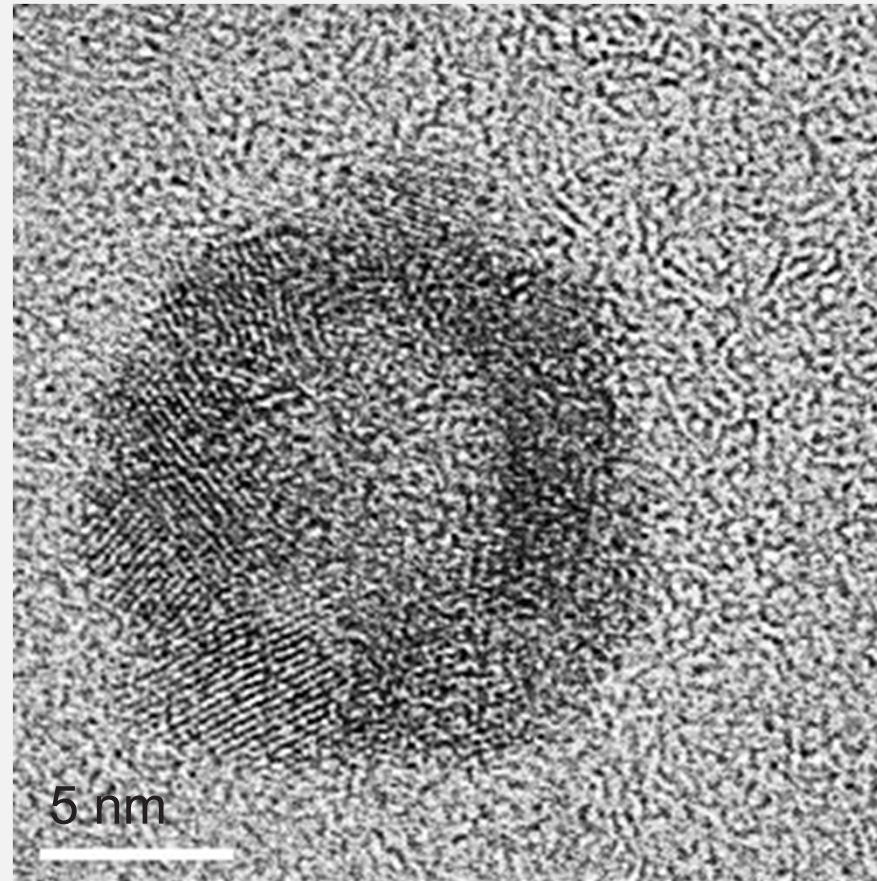
C-Nanoröhre
als Kanal



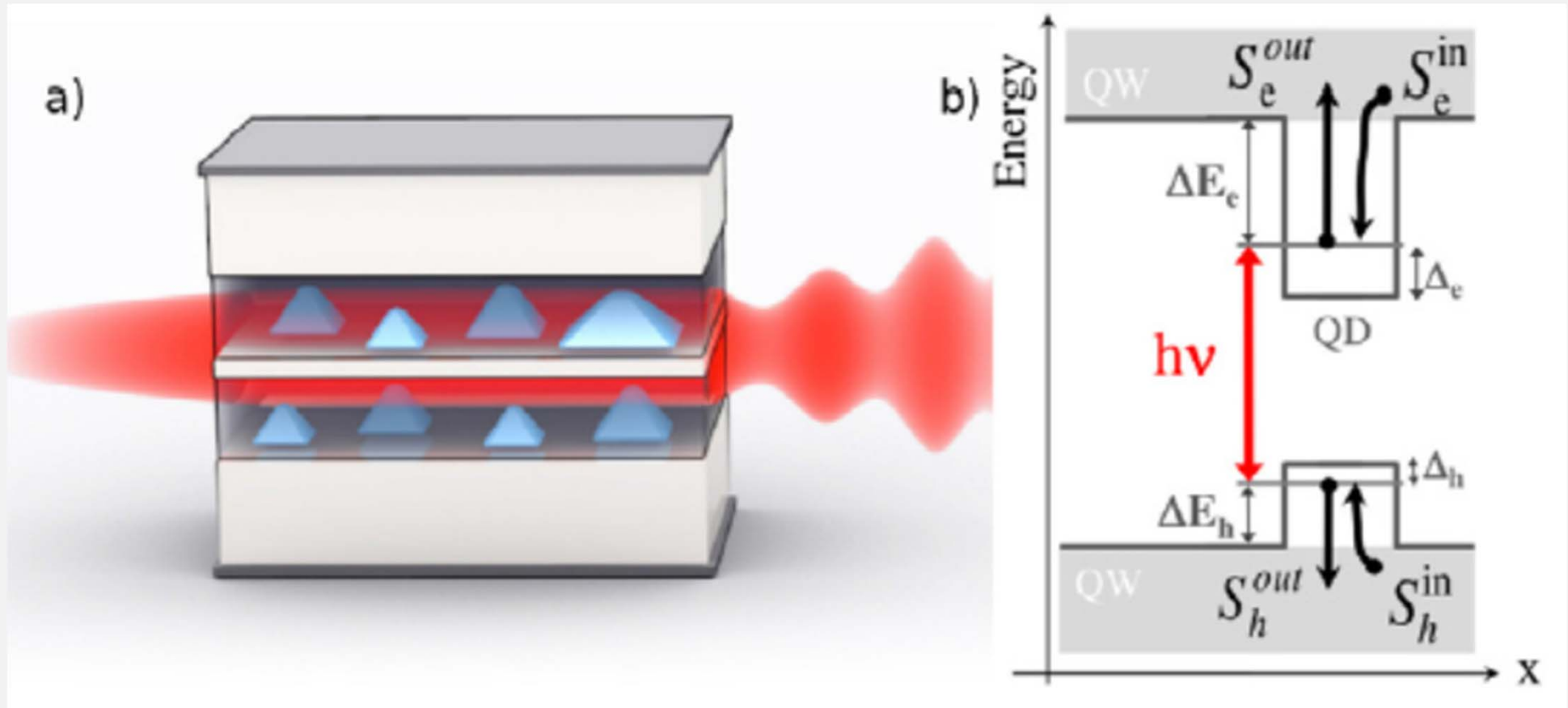
Computersimulation von
Elektronenbewegungen in einem
Nanodraht



Donega , Chem Soc Rev 40, 1512 (2011)



ZnSe/CdSe-Heteropartikel



(a) Schema eines optisch gepumpten QD Lasers.
 (b) Energiediagramm der Bandstruktur des QD.

J. Pausch *et al.*, *New J. Phys.* **14** 053018 (2012)

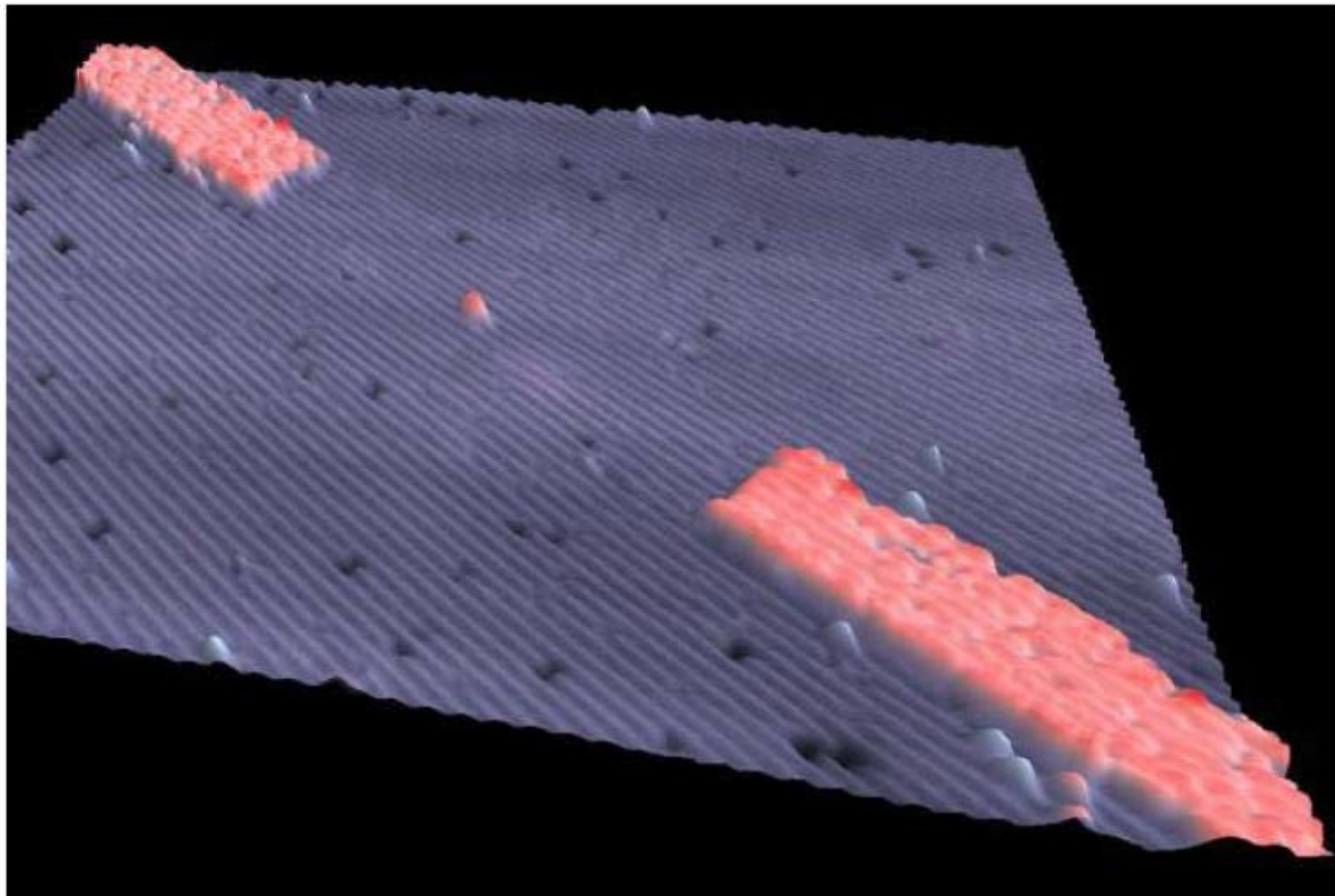
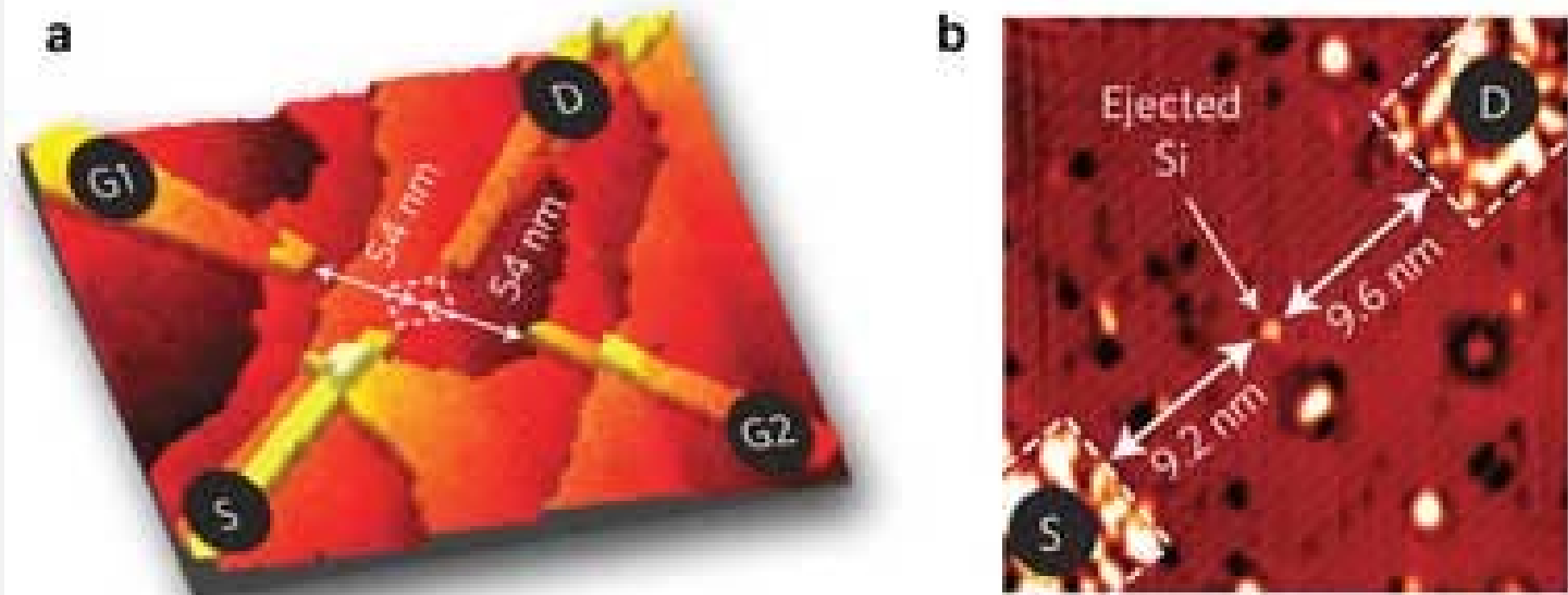


Foto: dapd

Fuechsel *et al.* /Nature Nanotechnology

Der kleinste Transistor der Welt besteht aus nur einem Atom

Atomtransistor mit Phosphorelektroden (links) und Ausschnitt mit dem zentralen Atom



(D: Drain, G: Gate, S: Source)

M. Fuechsle et al., Nature Nanotechnology, 7, 242 (2012)



Vielen Dank für Ihre Aufmerksamkeit.

