

Skenovací elektronová mikroskopie

Úvod do historie spíše než použití

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Elektronová mikroskopie

Proč byla vyvinuta?

- Má větší rozlišení než optická mikroskopie
- Umožňuje sledovat:
 - Poruchy krystalové mříže
 - Buněčné struktury
- Pracuje s dobře zvládnutou elektřinou

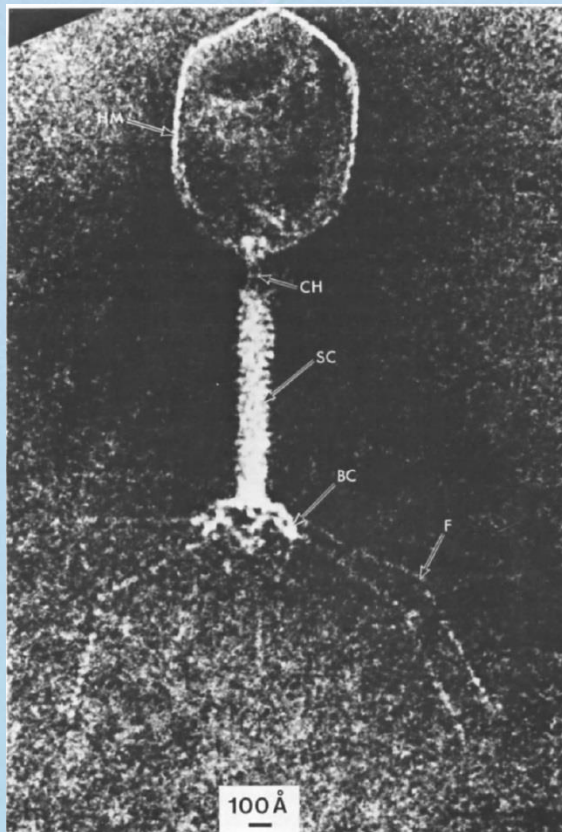
Elektronová mikroskopie

Proč byla vyvinuta?

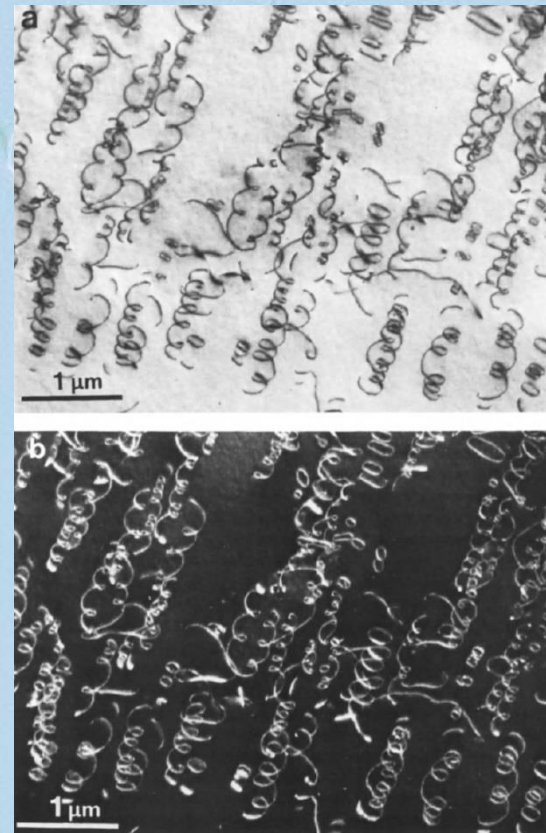
COLOPHON					
OPTICAL EQUIPMENT	Unaided eye	Hand lens	Light microscope	Scanning electron microscope	Transmission electron microscope
(Approximate) SIZE OF SUBJECT IN METERS	$10^{-3} - 10^{-1}$	$10^{-4} - 10^{-2}$	$10^{-6} - 10^{-4}$	$10^{-8} - 10^{-2}$	$10^{-9} - 10^{-5}$

Typické cíle EM

Virus 1962



Dislokace v Al-Cu, 1969



Dva přístupy

Mikroskopický – cílem je co nejostřejší svazek, který co nejméně poškozuje vzorek

Spektroskopický – cílem je co nejintenzivnější, stabilní svazek, který co nejméně poškozuje vzorek

Výsledkem pak, že jsme nespokojeni buďto s rozlišením prostorovým nebo energiovým.

Skenovací elektronový mikroskop

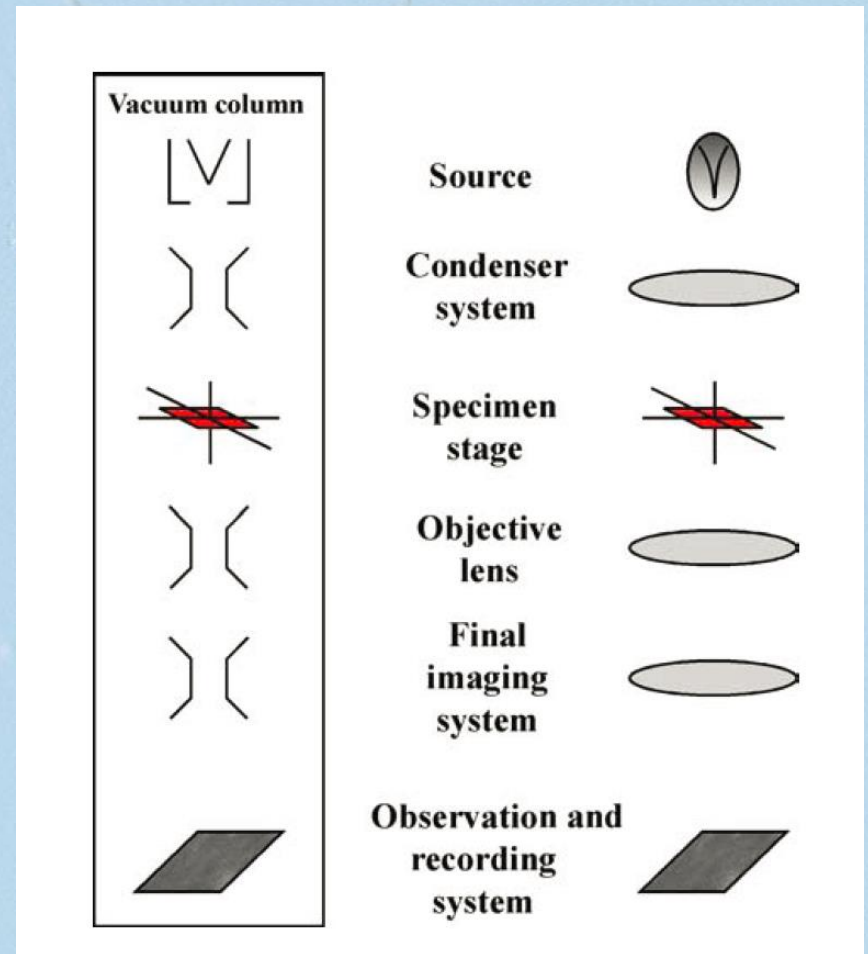
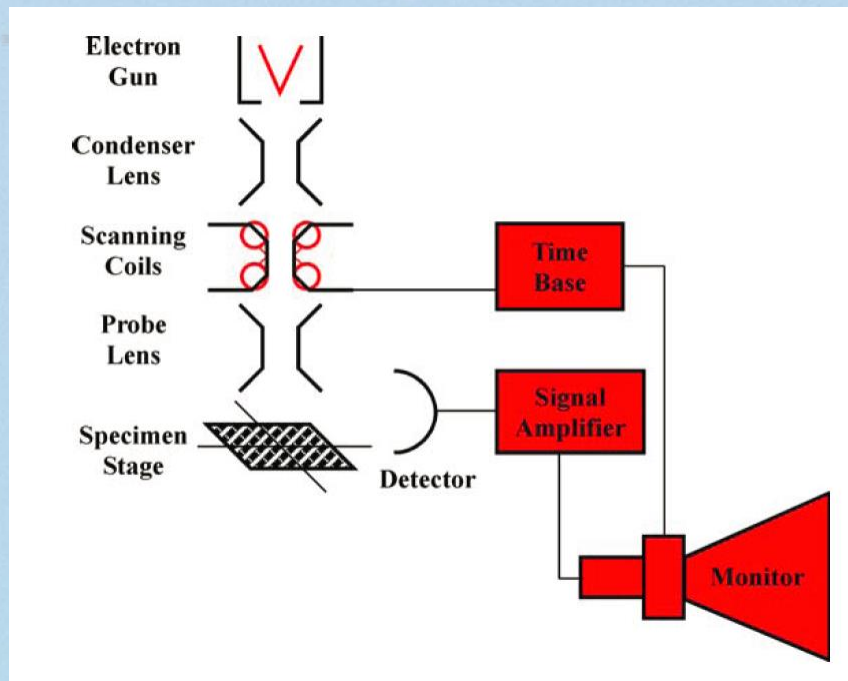
Tescan FERA 3



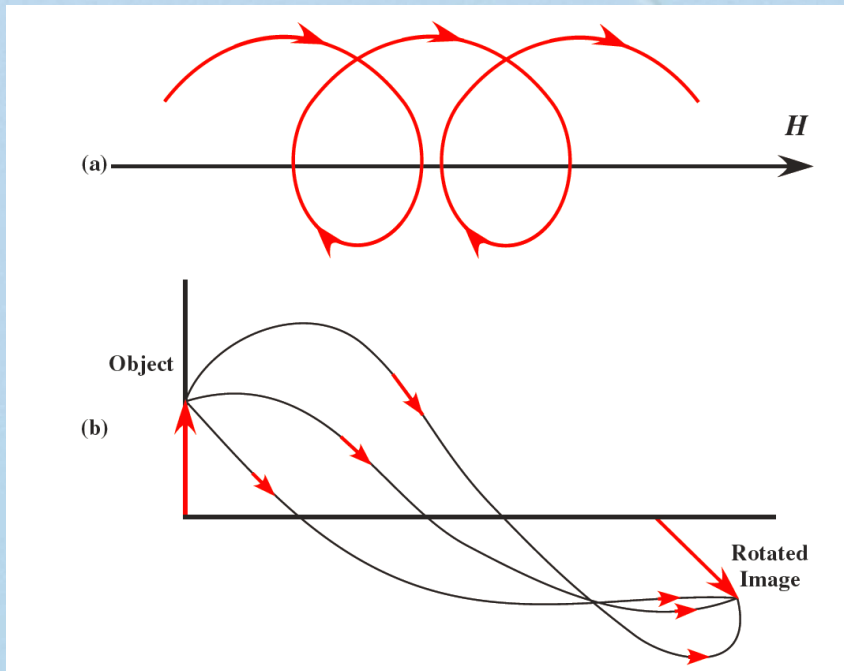
Jeol JXA-733



Princip SEM a TEM



Pohyb elektronu v elektromagnetickém poli



Lorentzova síla:

$$\vec{F} = -e(\vec{E} + \vec{v} \times \vec{B})$$

Díky ní se elektron
pohybuje po Landauových
hladinách a stáčí se o φ :

$$\varphi = \sqrt{\frac{e}{8m_0U}} \int_{-\infty}^{+\infty} B_z dz$$

Pro $k^2 \ll 1$ je $\varphi = \pi k$

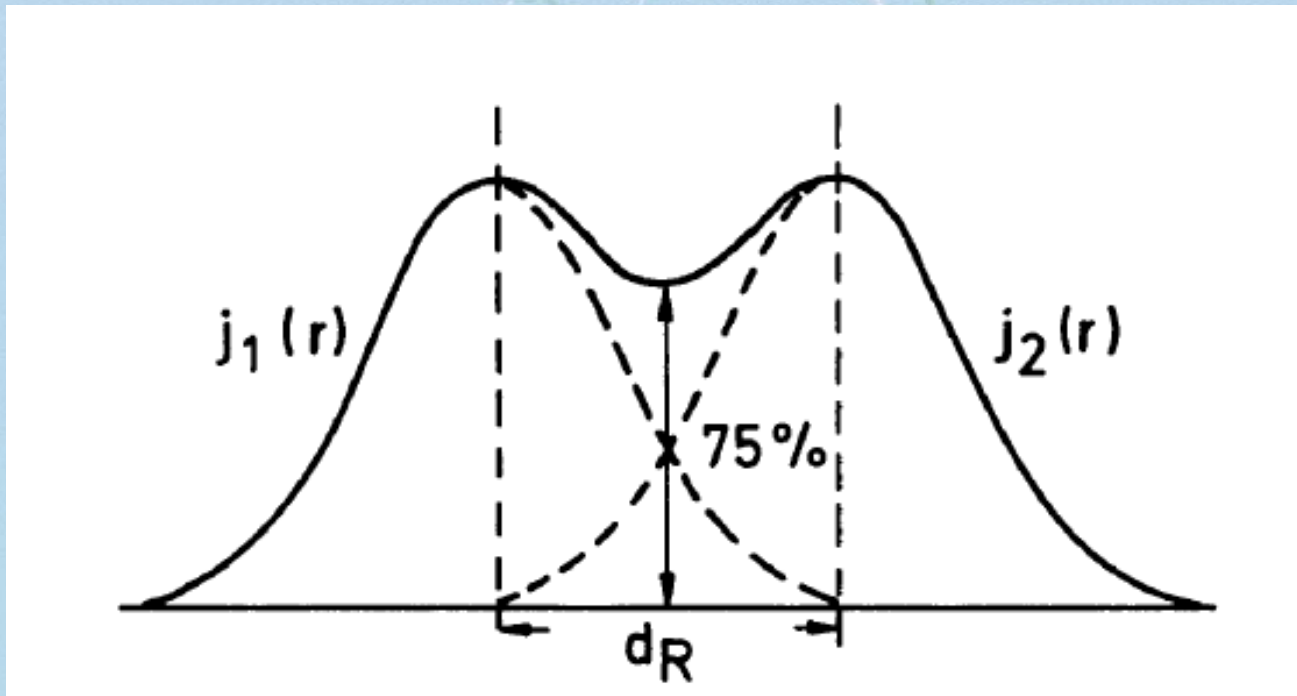
Síla magnetické čočky

$$k^2 = \frac{eB_0^2 a^2}{8mU}$$

„Fyzikální“ rozlišení SEM

Rayleighyho kritérium, kdy ještě dokážeme rozlišit dva blízké body:

$$d_d = 0.6\lambda/\alpha$$



„Fyzikální“ rozlišení SEM

S využitím de Broglieho hypotézy je vlnová délka elektronu ($E_0 = 511 \text{ keV}$):

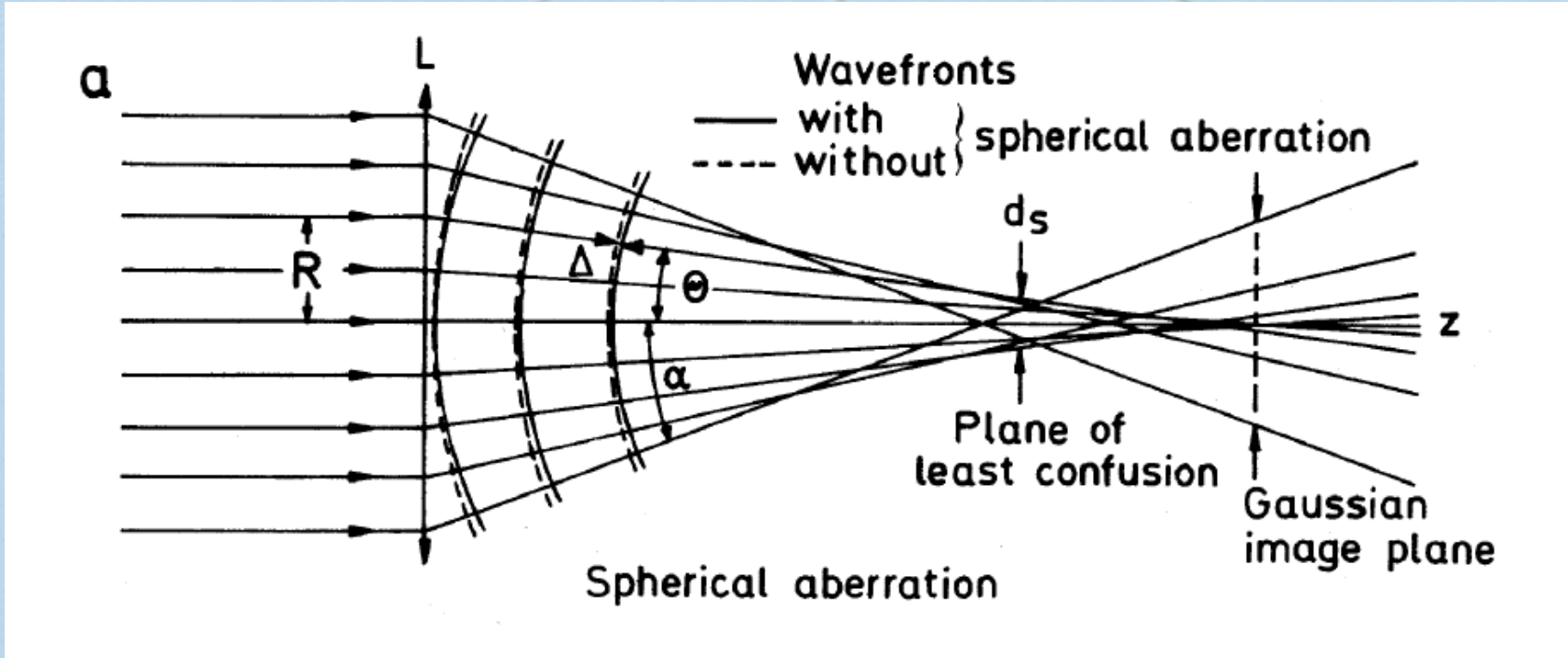
$$\lambda = h/mv = hc(2EE_0 + E^2)^{-1/2}$$

$$1 \text{ eV} \equiv 1.6021 \cdot 10^{-19} \text{ J}$$

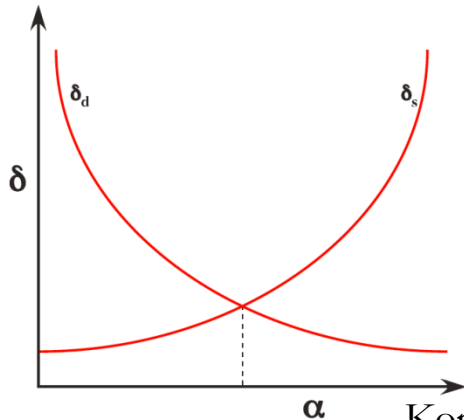
$$\lambda = \frac{1.226}{[U(1 + 0.9788 \times 10^{-6}U)]^{1/2}}$$

Což je $\lambda = 38.8 \text{ pm}$ pro $E = 1 \text{ keV}$ a 6.98 pm pro 30 keV .

Kulová vada



$$\delta_S \sim C_S \alpha^3$$



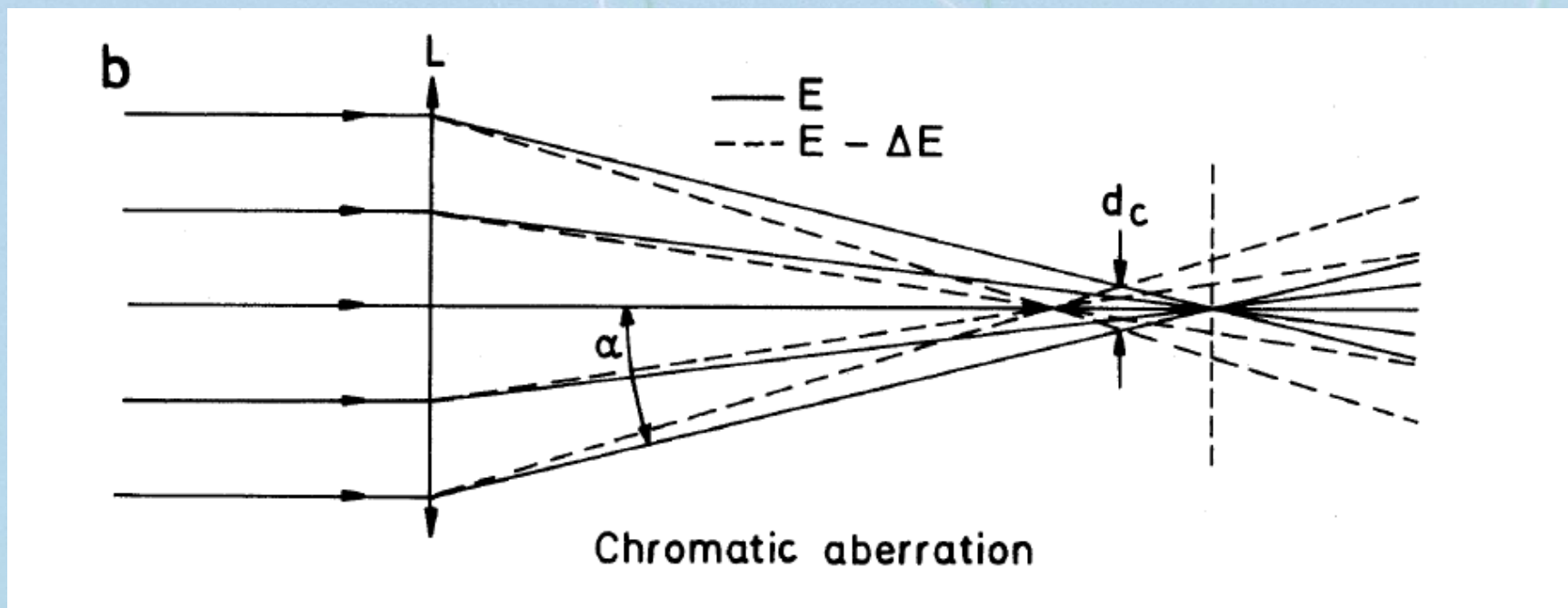
Rayleighho kritérium:

$$\delta_d \sim 0,61\lambda/\alpha$$

$$\sim 0,75/[\alpha\sqrt{V(1+10^{-6}V)}]$$

Barevná vada

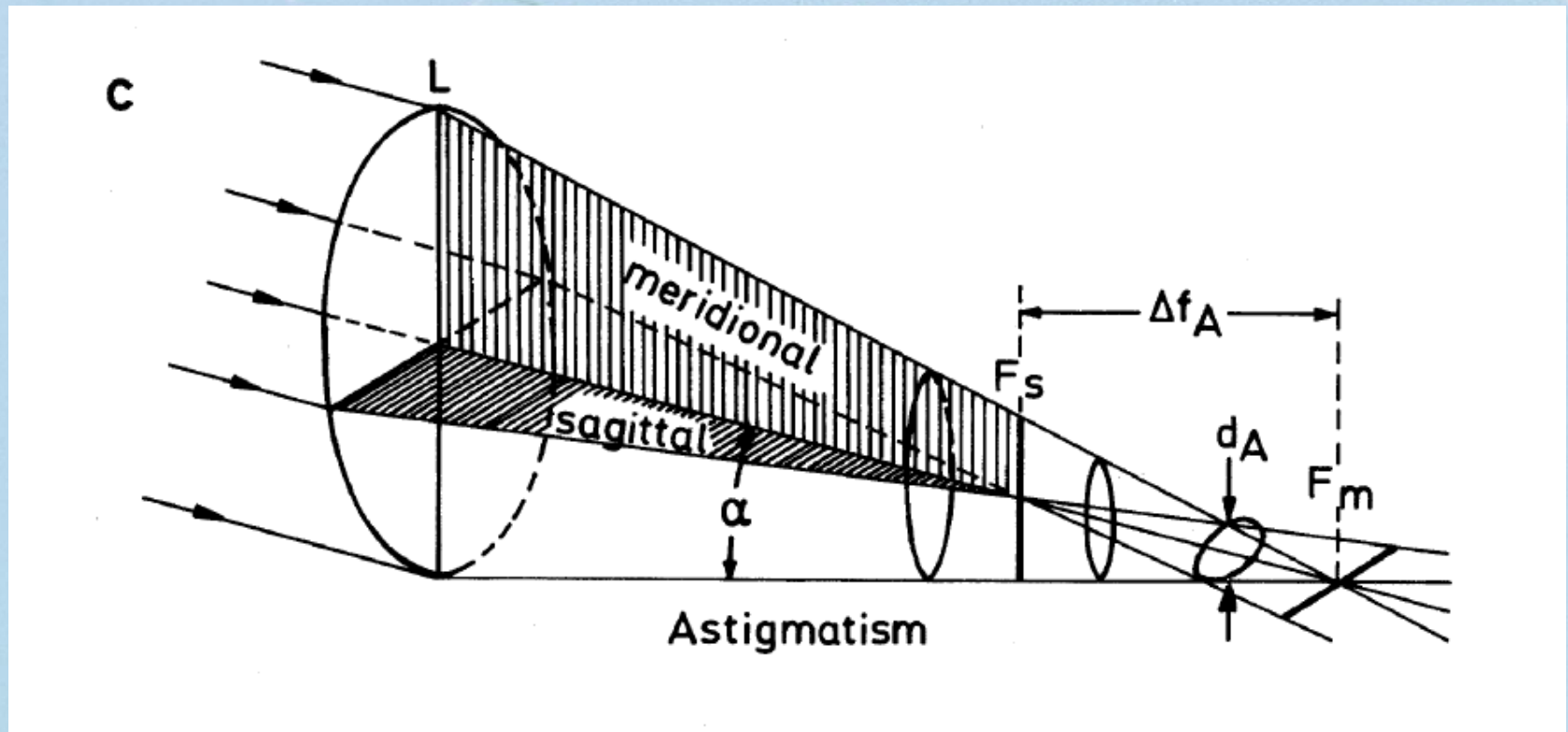
$$\delta_c = C_c \frac{\Delta E}{E_0} \alpha$$



Astigmatismus

Axiální astigmatismus

$$\delta_A = \Delta f_A \alpha$$

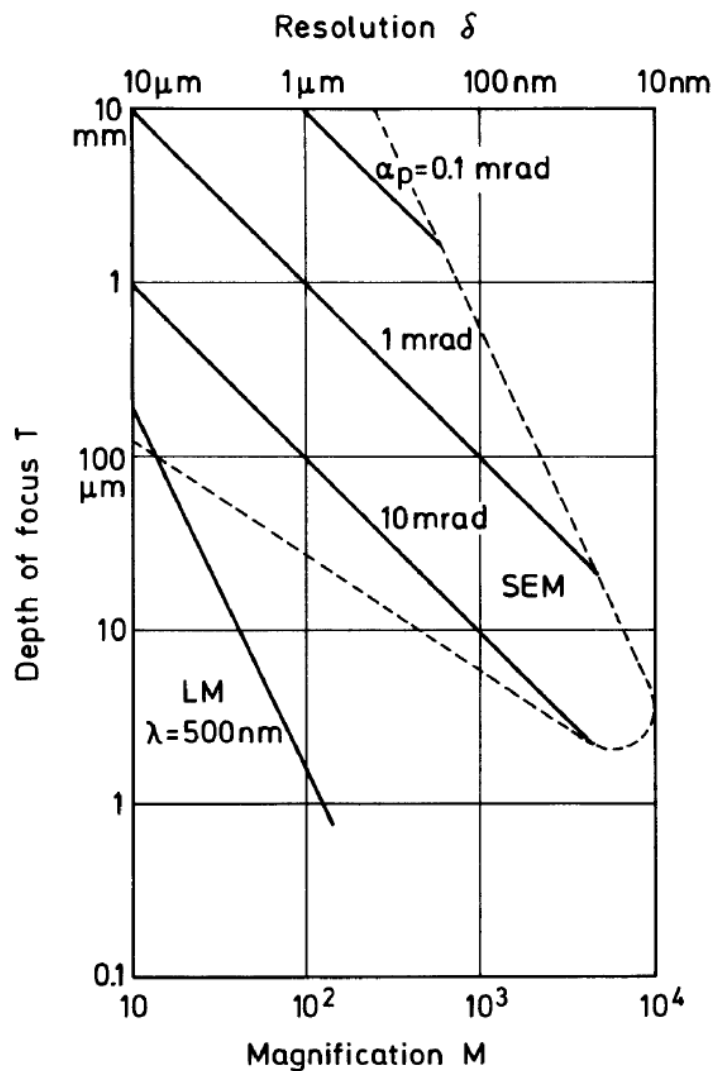


Celková chyba zobrazení

Předpokládáme, že příspěvky rozmazání zobrazovaného bodu jsou Gaussovské, proto jejich příspěvky sloučit konvolucí:

$$\begin{aligned}d_p^2 &= d_0^2 + d_d^2 + d_s^2 + d_c^2 \\ &= [C_0^2 + (0.6\lambda)^2]\alpha_p^{-2} + \frac{1}{4}C_s^2\alpha_s^6 + \left(C_c \frac{\Delta E}{E}\right)^2 \alpha_p^2\end{aligned}$$

Rozlišení, hloubka ostrosti a zvětšení



T – hloubka ostrosti

Δ – rozlišení

M – zvětšení

α_p – výstupní apertura
objektivu

LM – limity optické
mikroskopie

$$T = \delta \sqrt{\delta^2 / \lambda^2 - 1}$$

Složení SEM

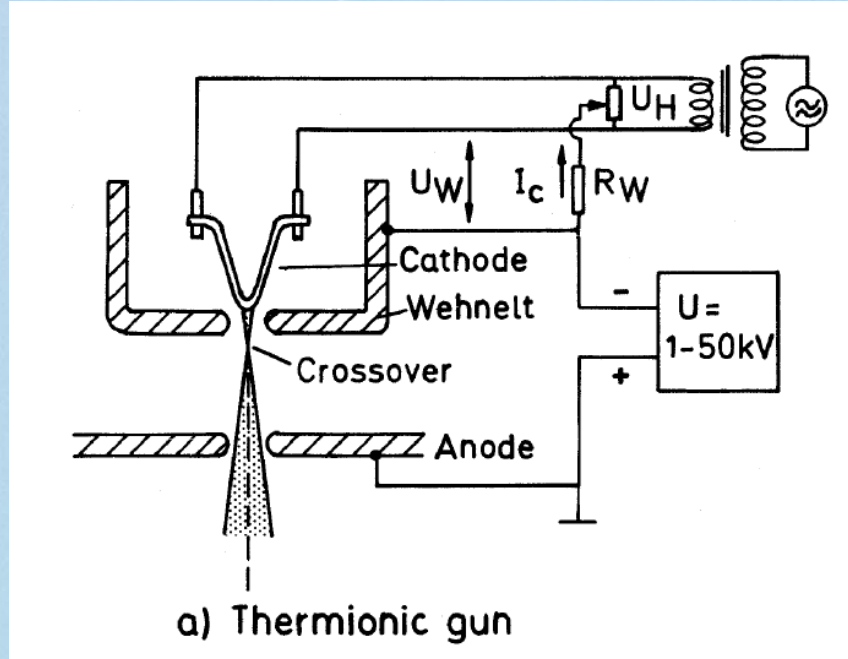
- Zdroj elektronů
- Zobrazovací soustava – čočky
- Interakce se vzorkem
- Detektory

Zdroje elektronů

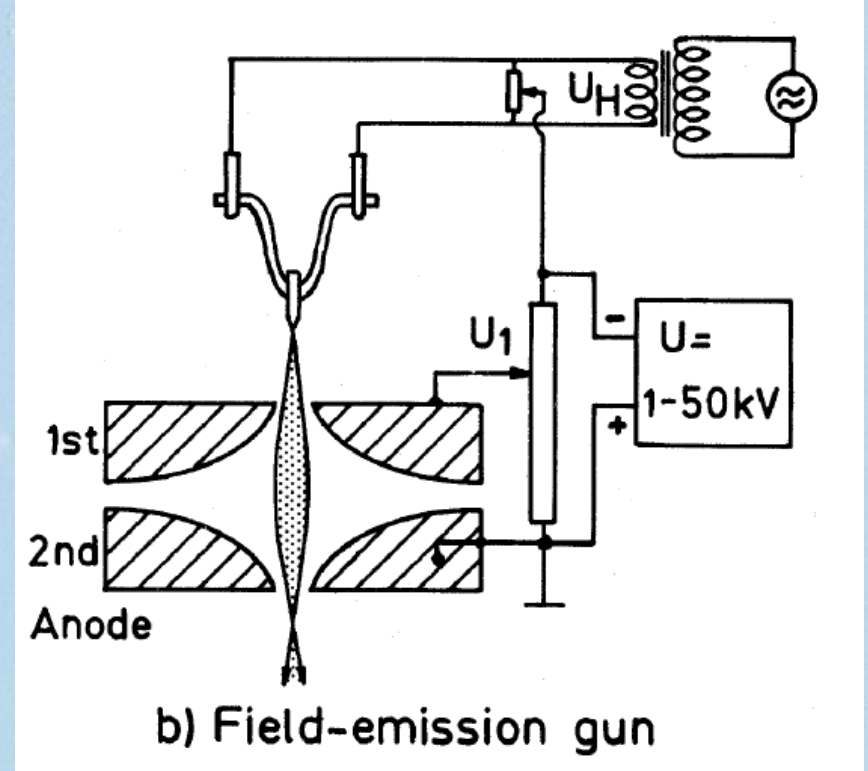
	Tlak	Jas	Velikost stopy (ze zdroje)	Energiový rozptyl
	[Pa]	[A/cm ² sr]	r [μm]	ΔE [eV]
Termoemise	10 ⁻³	2×10 ⁴	10-50	1-3
LaB ₆	10 ⁻⁴	10 ⁵	10-50	0,5-2
Schottkyho	10 ⁻⁶	10 ⁸	1	0,4-0,6
Autoemise	10 ⁻⁸	10 ⁹	0,003	0,2-0,4

Konstrukce zdrojů elektronového svazku

Termoemisioní zdroj – W drát

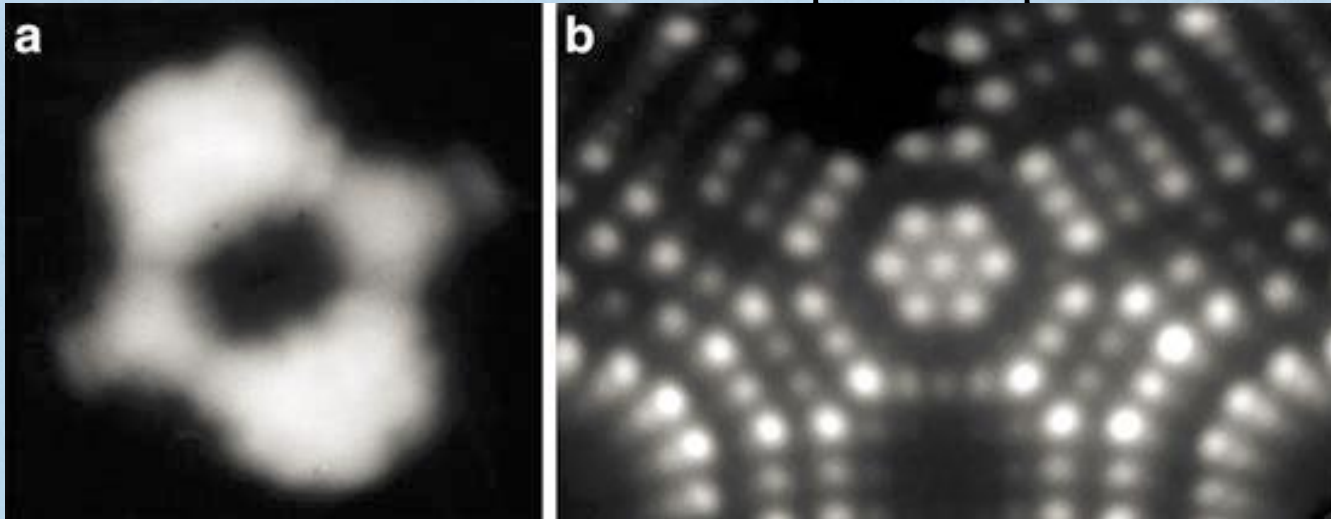


Elektronové dělo Butlerova typu s polní emisí (autoemisioní)



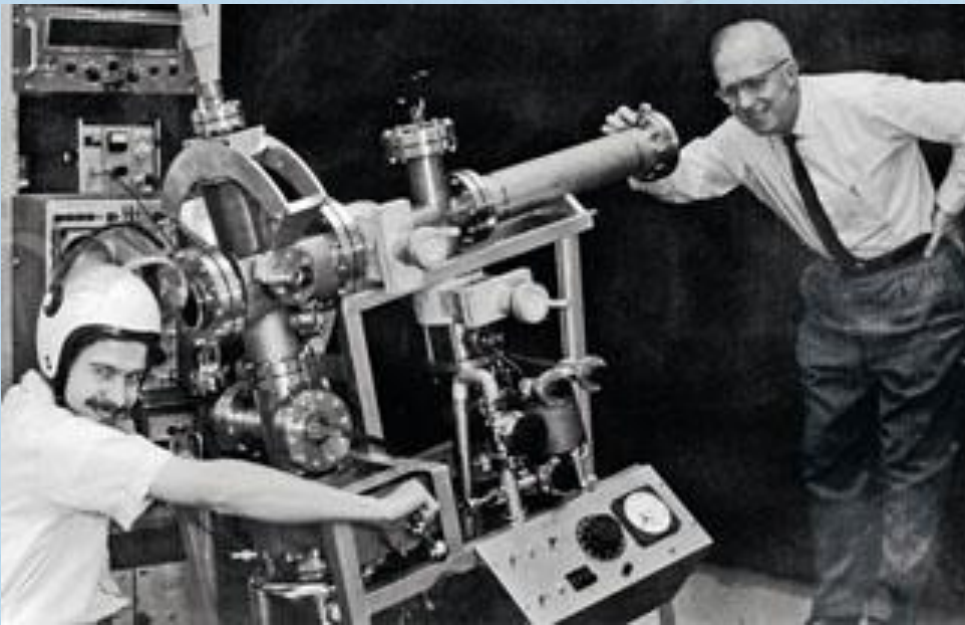
Field electron microscope

- Zkonstruován Müllerem 1937
- Zvětšení do 10^5 x, rozlišení 60 pm a lepší!



- Na snímku a) hrot W (110) s povrchovou kontaminací a b) W(111) hrot

Erwin Wilhelm Müller



John Panitz
1968



První, kdo pozoroval atom, se studentem Kanwarem Bahadurem

Erwin Wilhelm Müller — Biographical Memoirs of the National Academy of Sciences.pdf

13. 6. 1911 –17. 5. 1977

Student Gustava Hertze, Ing. 1935, doktor 1936 (FIM s rozlišením 2 nm), Výzkumný ústav Siemensu,

Vynalezl:

FEEM

FIM

Atom Probe



Interakce elektronového svazku

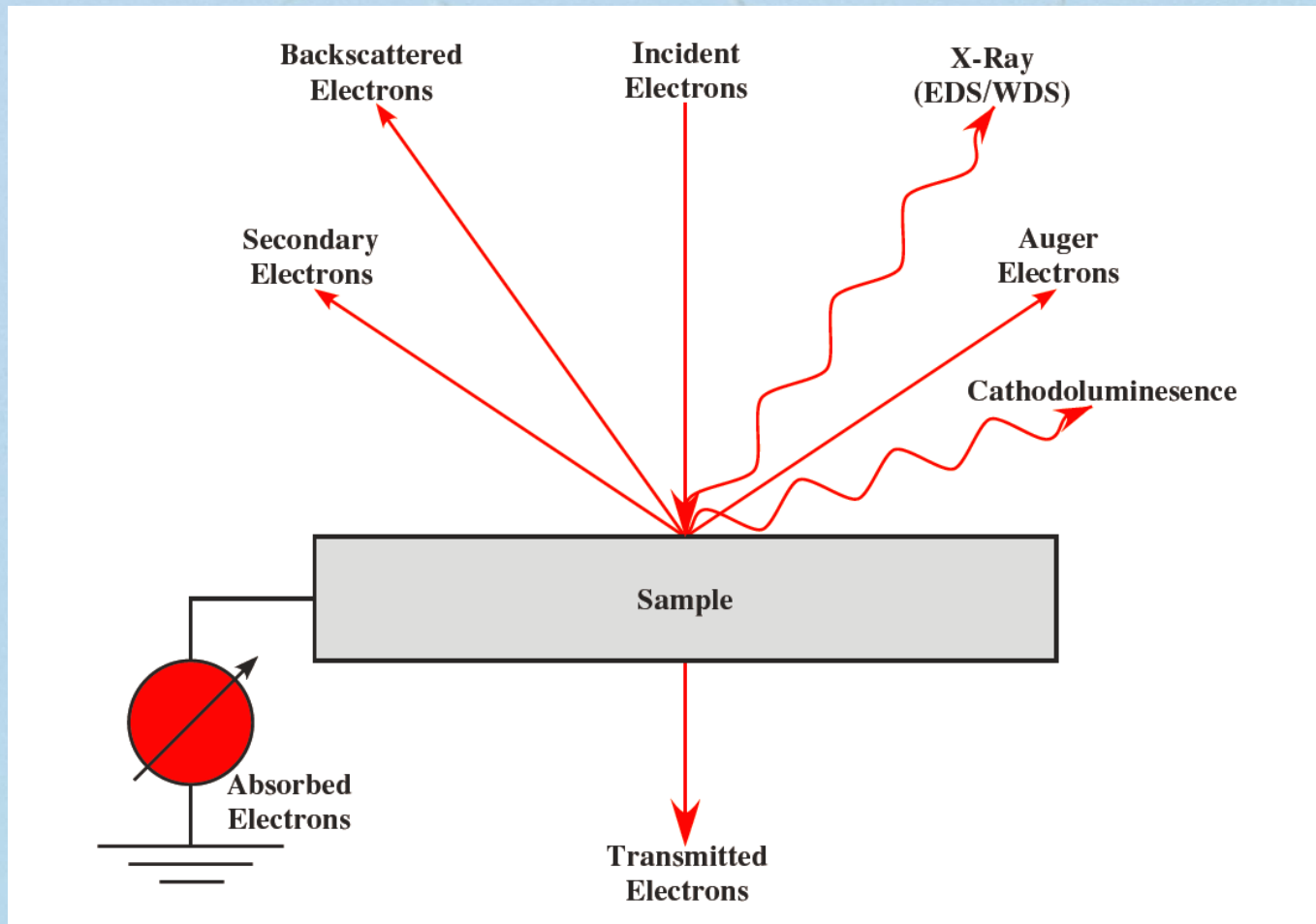
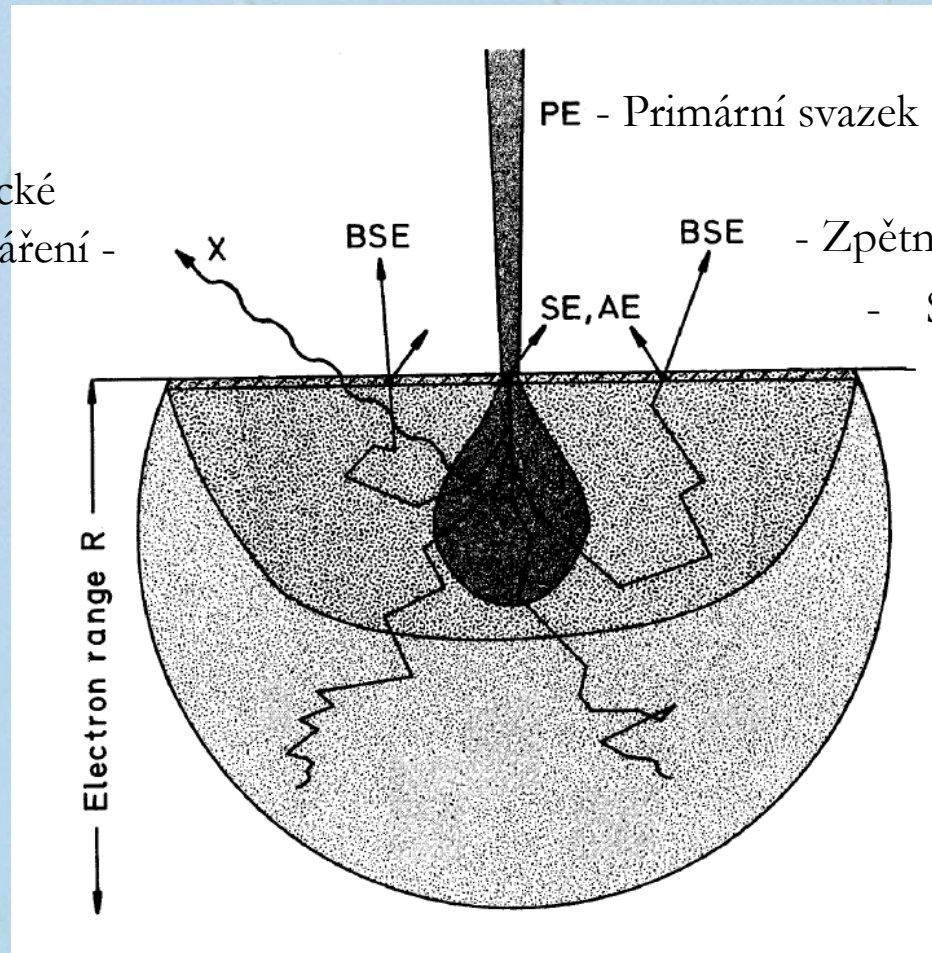


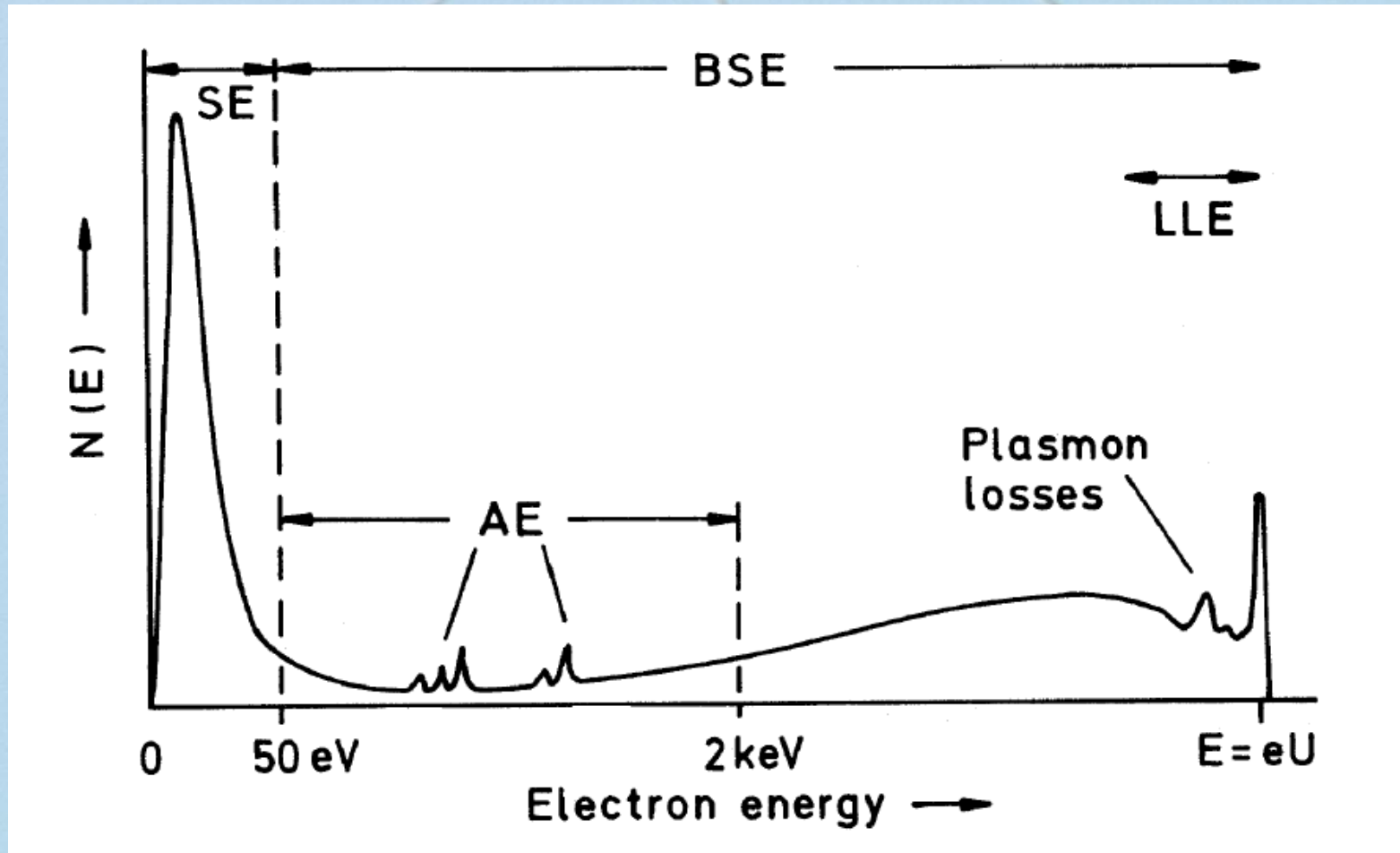
Schéma interakční oblasti

Charakteristické
rentgenové záření -



- Zpětně odražené elektrony
- Sekundární elektrony,
Augerovy elektrony

Spektrum elektronů ze vzorku



Sekundární elektrony $E_{SE} \leq 50 \text{ eV}$, low-loss electrons (LLE) ztráta energie oproti primárnímu svazku je jen několik stovek eV, backscattered electrons (BSE) – zpětně

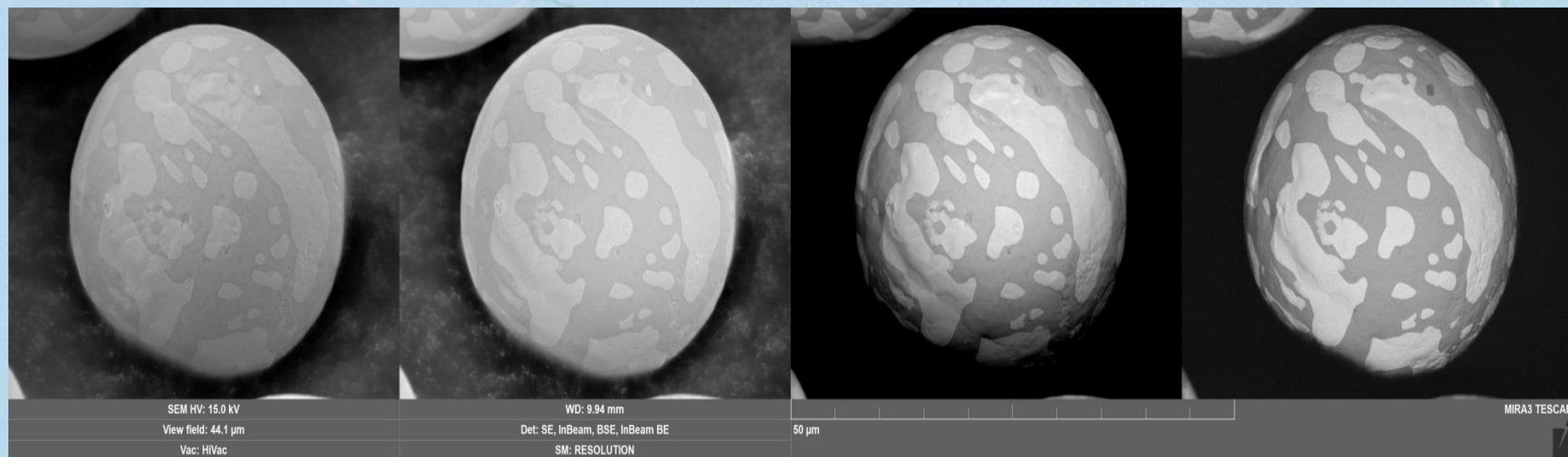
Srovnání zobrazovacích módů

SE E-T

In-Beam SE

R-BSE

In-Beam BSE

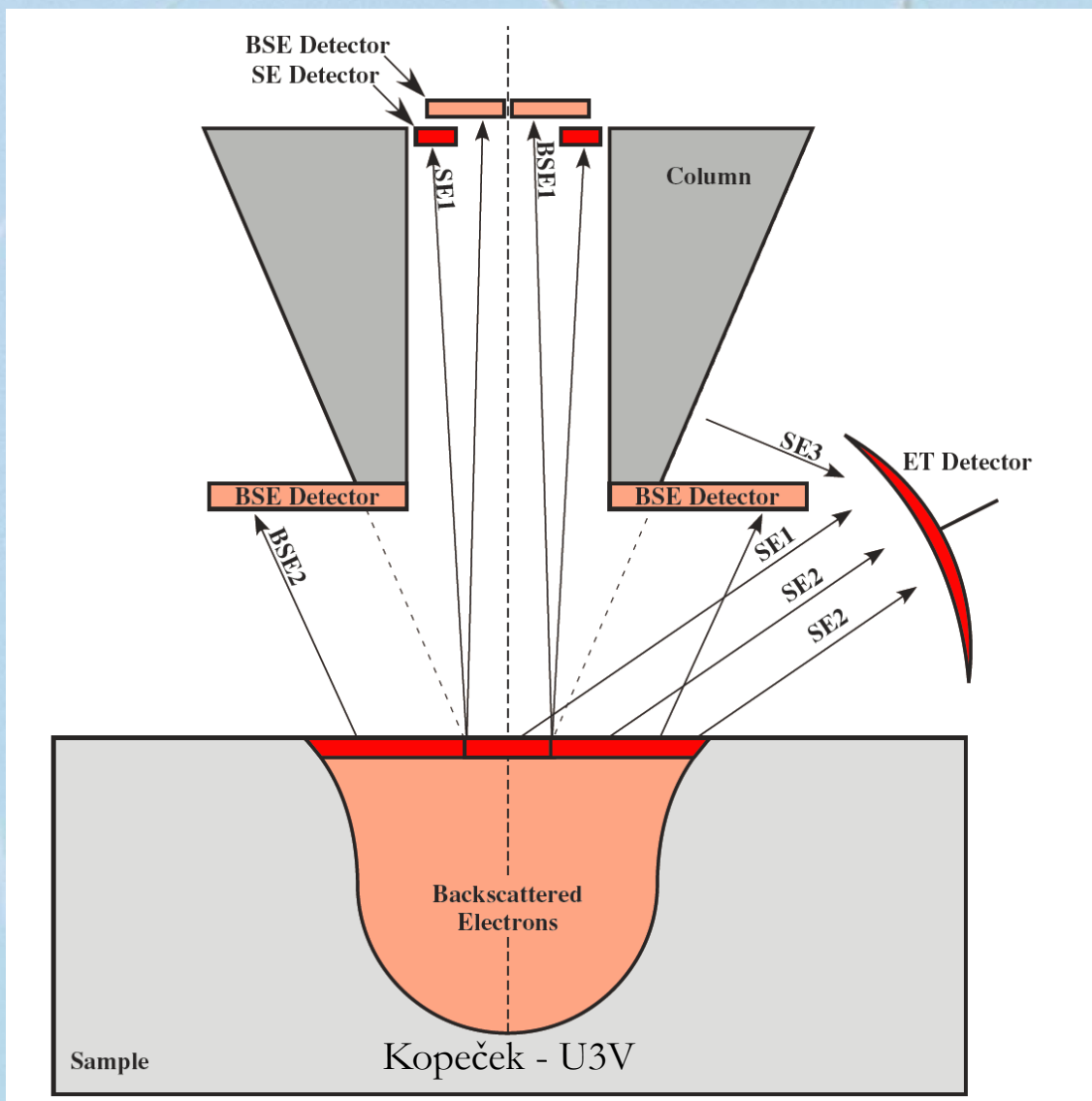


+ Higher surface
sensitivity
= better resolution

+ Large field of
view

+ lower topography
info

Detekce elektronů



Pohled do komory SEM



Ernst August Friedrich Ruska



25. 12.1906 – 27. 5. 1988

1986 Nobelova cena za elektronovou optiku

1931 ukázal, že cívka funguje jako čočka pro elektrony

1933 sestavil z více čoček elektronový mikroskop

Od 1937 pracoval v Siemens-Reiniger-Werke AG a nechal zřídit „visiting scientist“ laboratoř,

kterou řídil jeho bratr

Helmut, který

prosazoval aplikace

v medicíně



Manfred von Ardenne

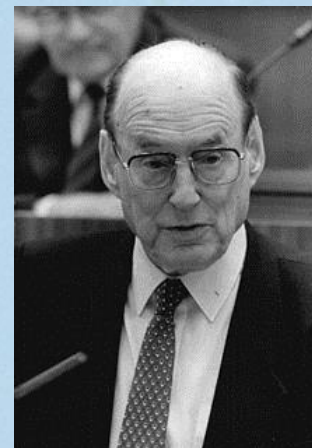


20 January 1907 – 26 May 1997

Asi 600 patentů

1928 – 1945 řídil svou vlastní
Forschungslaboratorium für
Elektronenphysik, pak v SSSR jaderné
zbraně (získal Stalinovu cenu).

1931 poprvé předvedl princip televize –
skenování obrazu.



Max Knoll

17 July 1897 – 6 November 1969

Elektroinženýr, šéf Rusky

Po konstrukci EM 1931 v dubnu 1932
odešel do Telefunken, kde vyvíjel televizi.

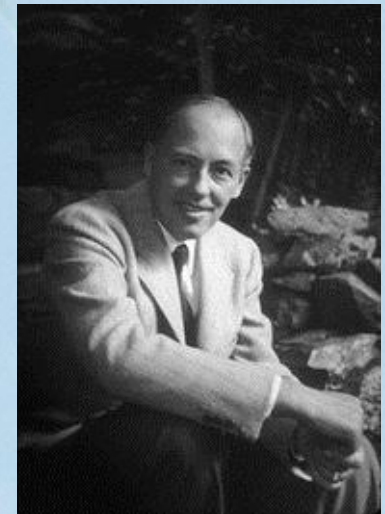
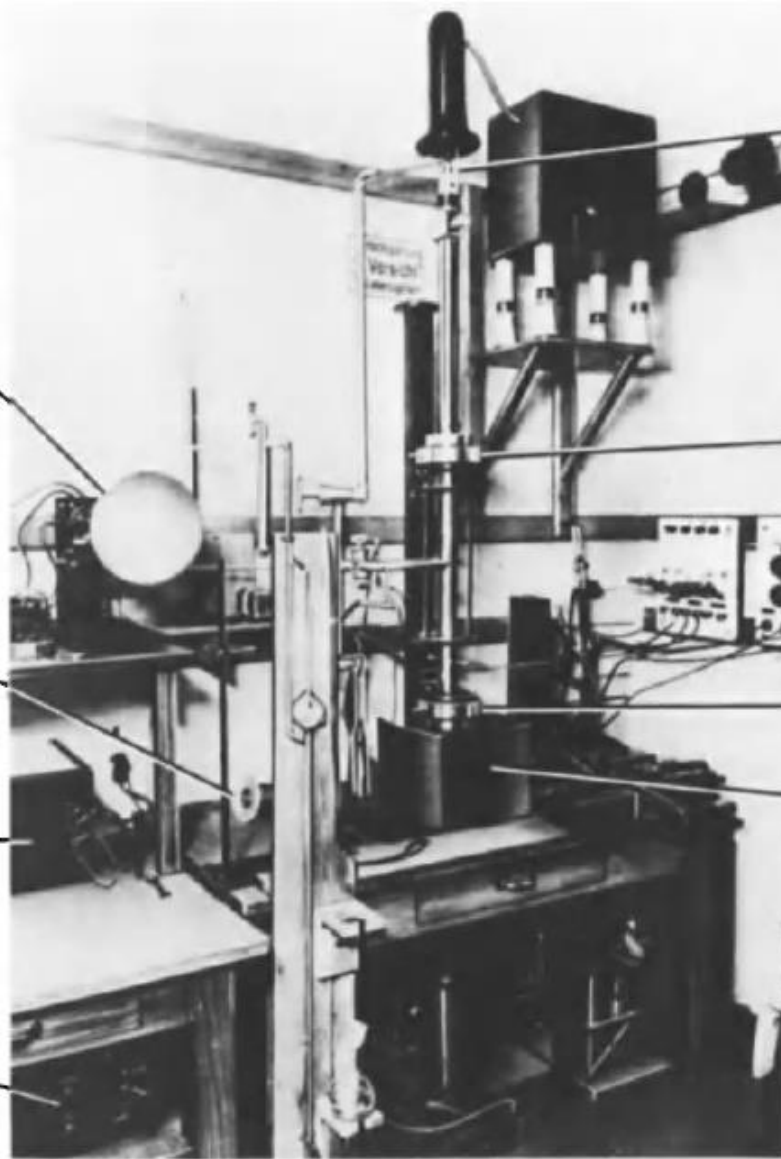


image reproduction tube with a synchronous swept electron beam modulated by the signal of the secondary electrons (long-persistence screen)

a further version of an exchangeable collector unit for secondary electrons

wide-band amplifier for the signal of the secondary electrons

image raster deflection unit



electron directional radiator (20 to 50 keV)

1. reduction lens

deflection system (x-y direction)

2. reduction lens

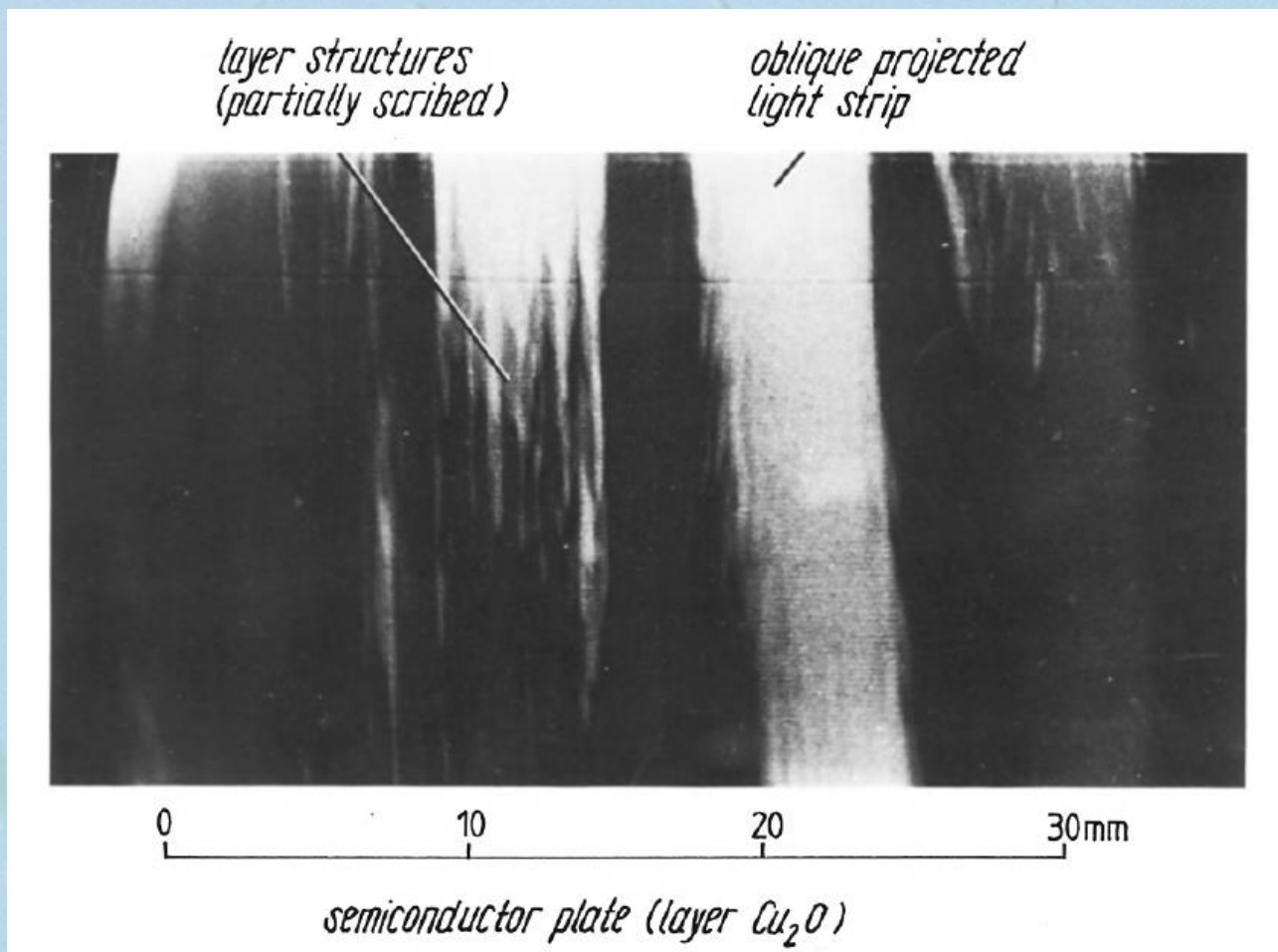
collector unit for the secondary electrons

První skenovací elektronový mikroskop pro zobrazování povrchů s rozlišením 100 nm. 1937,



Univerzální
elektronový
mikroskop pro energie
200 až 300 keV, M.
von Ardenne, 1941-43

První BSE skenovací obraz, von Ardenne



Historie SEM

Zásadní titul: *The Beginnings of Electron Microscopy*, Peter W. Hawkes (Ed), Advances in Electronics and Electron Physics, Supplement 16, Peter W. Hawkes (Ed) - Academic Press, Inc., Orlando, 1985

FACTS ABOUT THE HISTORY OF THE SCANNING ELECTRON MICROSCOPE (SEM) AND THE ELECTRON MICROPROBE

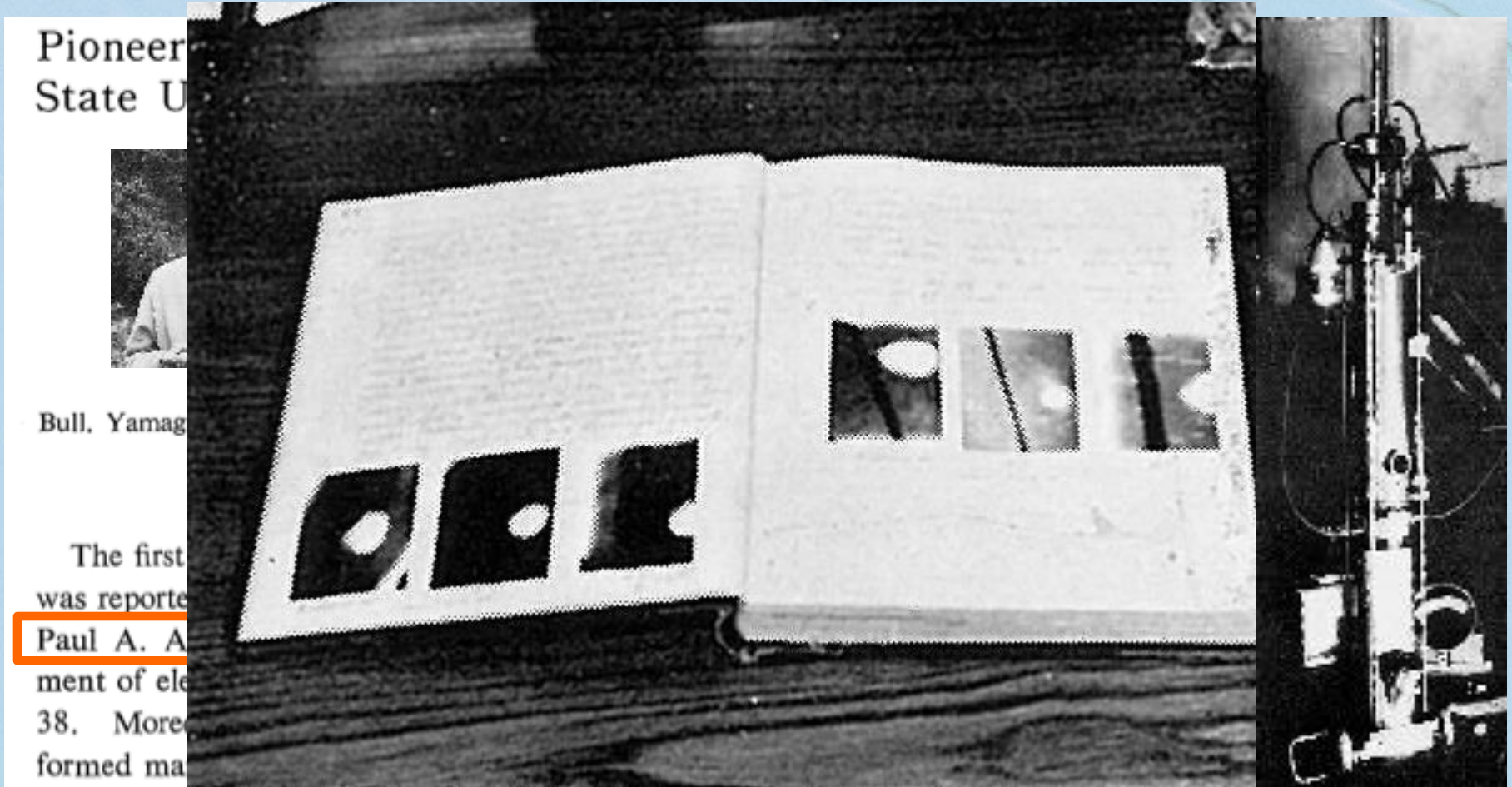
Year	Names	Facts	Resolution (δ)	References (comments)
1932	E. Ruska, B. von Borries	1. Invention of the short-focal-length magnetic pole-piece lens (reduction of image aberrations)	—	11,12 (predecessor: iron-clad coil of D. Gabor)
1933	M. von Ardenne	2. First imaging of surfaces by means of secondary electrons of a raster-shaped (x, y) deflected electron beam; beam energy 1200 eV	0.3 mm	13,14 (structured semiconductor surface)
1934	M. Knoll	3. Experimental arrangements and circuit as in 1; beam energy 3000 eV	0.1–1 mm	15 (siliconized sheet iron)
1937	M. von Ardenne	4. Invention of the scanning electron microscope; concept for surface imaging and transmission imaging	—	16 (February 16, 1937)
1937	M. von Ardenne	5. First scanning electron microscope for the imaging of object surfaces with large depth of focus	≈ 100 nm	1–3
1938	M. von Ardenne	6. First scanning electron microscope for transmission imaging of specimens, even of considerable thickness	≈ 40 nm	1–3 (bright field, dark field)
1938	M. von Ardenne	7. Reduction of sensitivity to vibration of the electron microscope by the principle of pressing the specimen holder onto the lens polepiece		2,3 (about twice the former resolution)
1940	M. von Ardenne	8. Introduction of the stereo method in electron microscopy	—	17

1938–1942	M. von Ardenne	9. Layouts, experiments, and proposals for electron microprobe analysis with the scanning electron microscope	—	1,2,18
1942	V. K. Zworykin, J. Hillier, R. L. Snyder	10. Introduction of the secondary-electron detector with postacceleration (9 keV), fluorescent screen, and photomultiplier	50 nm	19 (improvement of signal-to-noise ratio)
1942	M. von Ardenne, E. Ruska	11. First single-field condenser–objective lens with specimen plane between the polepiece (and side-entry specimen changer)	1.2 nm	9 (see Fig. 1)
1944	—	12. Obliteration of the von Ardenne scanning electron microscope installation of by means of an air raid on March 25, 1944	—	This and other consequences of the war terminated work of von Ardenne on SEM
1946	J. Hillier, E. G. Ramberg	13. Introduction of the stigmator for the correction of axial astigmatism	0.6 nm	20,21
1960	T. E. Everhart, R. F. M. Thornley	14. Improvement of the secondary-electron detector of 10 by the introduction of organic scintillators with light guides		22; also see 22a (improvement of signal-to-noise ratio)
1965	C. W. Oatley	15. The “Stereoscan” apparatus of the Cambridge Instruments Company appears; the first commercial SEM (surface type)	20 nm	23
1970	A. V. Crewe, J. Wall	16. Introduction of the field emission electron gun into the scanning electron microscope (transmission type)	0.5 nm	24
From 1970		17. The Elmiskop ST 100F–Siemens microscope with field emission electron gun available commercially (transmission type, and also surface imaging)	≥0.2 nm	25

Jiný zdroj:

<http://www2.eng.cam.ac.uk/~bcb/semhist.htm>

Washington state, USA: 1st EM outside of Germany



U. of Washington did pioneering research in CFEG in 1938-45. Some of the students, e.g. Gertrude Fleming-Rempfer, later transferred to Oregon. FEI (=Field Emission Incorporated) can trace its origin directly to their efforts.

Early History of Electron Microscopy in Czechoslovakia

ARMIN DELONG

*Institute of Scientific Instruments of the Czechoslovak Academy of Sciences
Brno, Czechoslovakia*

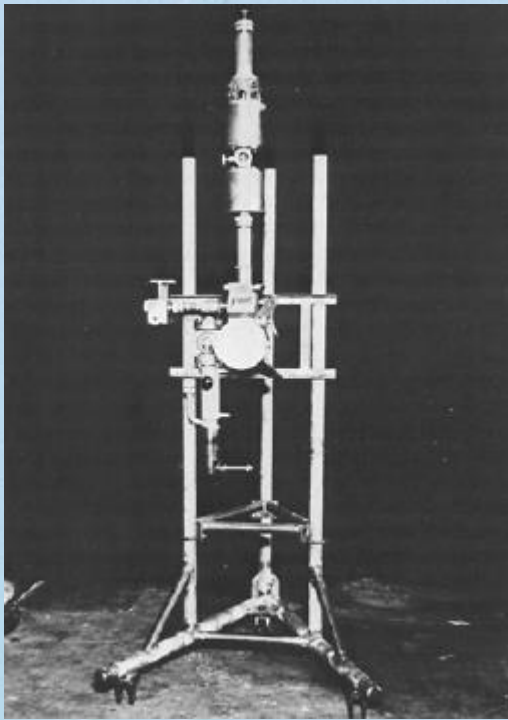
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I. INTRODUCTION

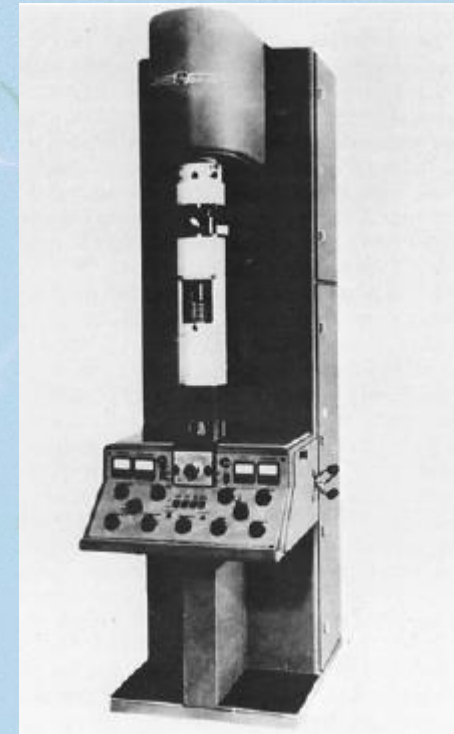
Czechoslovakia, with its 15 million inhabitants, ranges among the relatively small countries of Central Europe. On the average, there are some 0.36 ha. of soil, 0.32 ha. of woods, 0.15 automobiles, and not more than 0.000034 electron microscopes per citizen in the country. In other words, one electron microscope is shared by 30,000 people. Some 90% of available electron microscopes are of home production. This means that besides atomic power plants, locomotives, and automobiles, electron microscopes are also produced on a commercial scale in Czechoslovakia. In 30 years as many as 1800 electron microscopes of different types, from the two-stage

Historie EM v Československu

Experimentální dvoučočkový
elektronovo-optický mikroskop,
1947



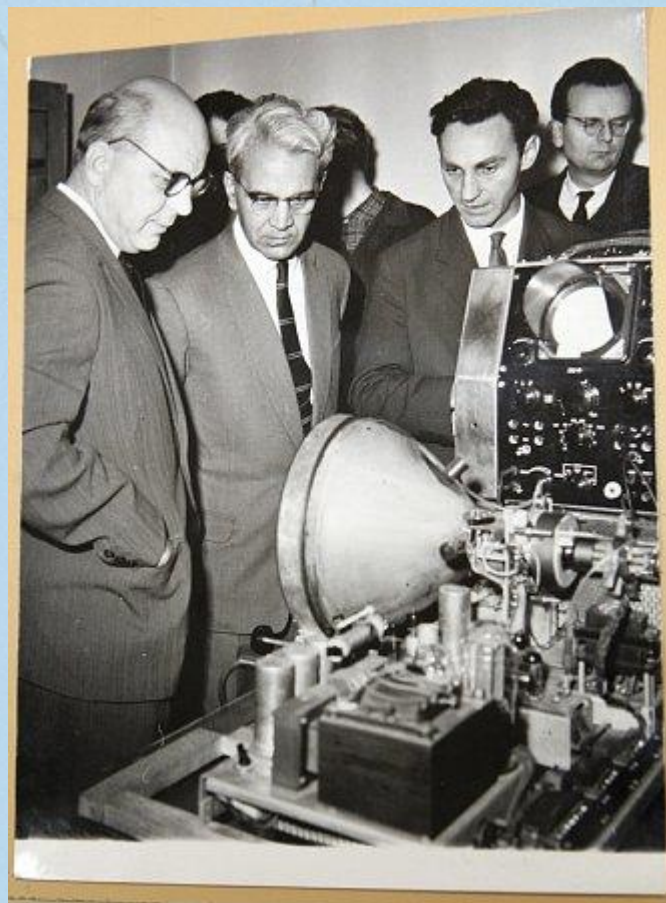
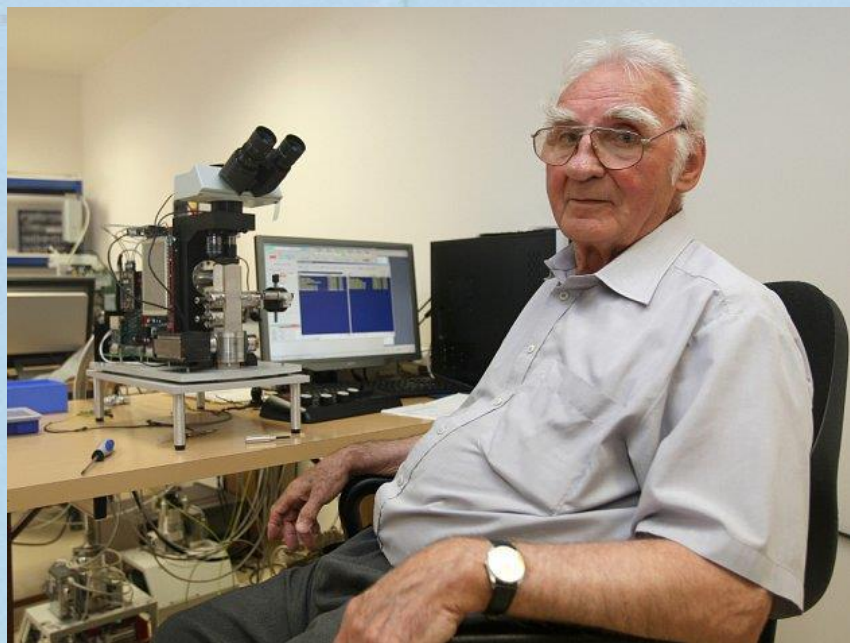
1. Elektronový mikroskop
vyrobený v ČSR



A. Delong, V. Drahoš, L. Zobač, J. Speciální

Armin Delong

29.1.1925 Bartovice (Ostrava) – 5. 10. 2017 Brno



<http://brnensky.denik.cz/serialy/jeden-z-nejlepsich-vedcu-sveta-bada20081013.html>

Delong Instruments: <http://www.delong.cz/>

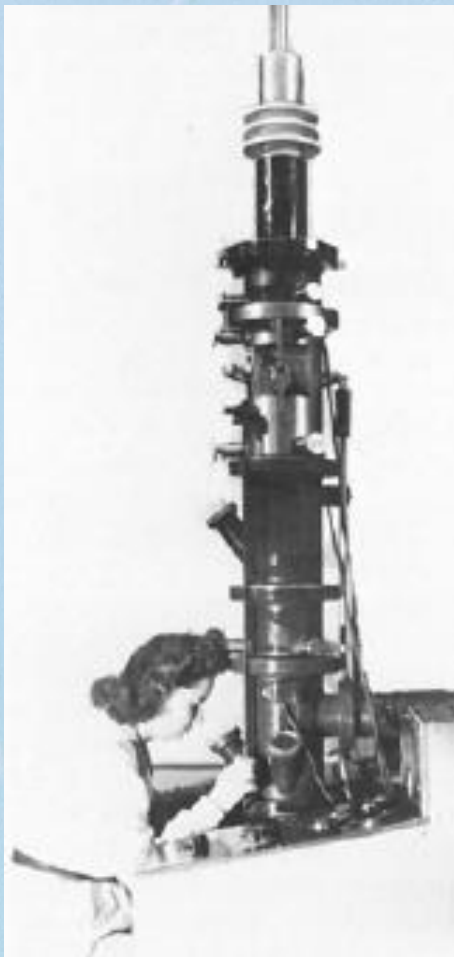
Přehled vyráběných typů

PRODUCTION OF ELECTRON MICROSCOPES IN CZECHOSLOVAKIA

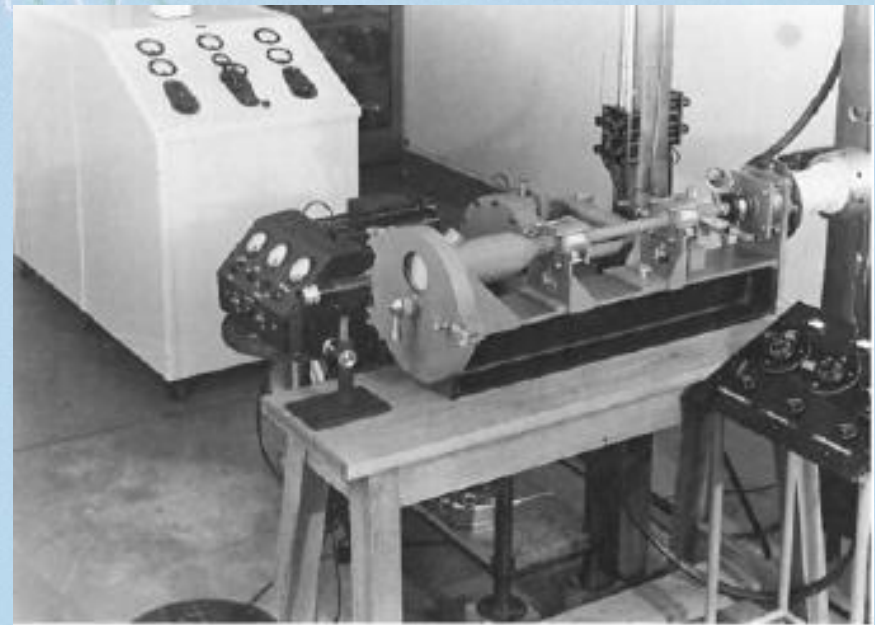
Type	Production		Number of instruments ^a	Developed
	Started	Ended		
TEM BS	1952	1953	25	Institute of Theoretical and Experimental Electrotechnology
TEM BS 242 (desk type)	1957	1973	827	Czechoslovak Academy of Sciences
TEM BS 413 (high resolution)	1964	1973	358	Czechoslovak Academy of Sciences
TEM BS 500 (540)	1973	—	399	Tesla Brno
SEM BS 300	1976	—	142	Tesla Brno
SEM BS 350	1977	—	18	Czechoslovak Academy of Sciences

Historie EM v Evropě

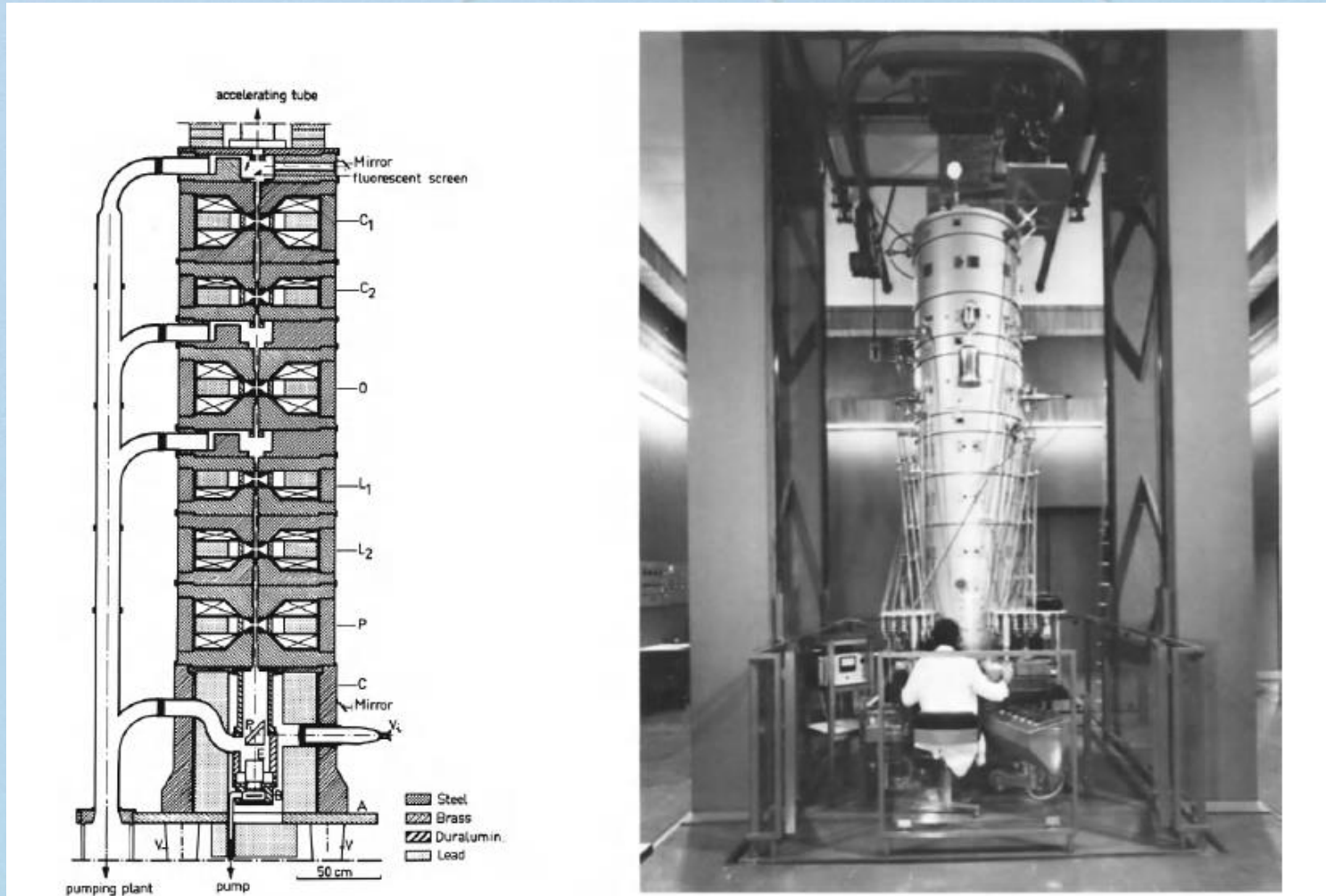
Toulouse, 1942



Siegbahn-Schönanderův
electronový mikroskop,
Stockholm, okolo 1943.



Francie 3MeV SEM



G. Dupouy, F. Perrier: 12. 1960 1 MeV, 5. 1969 2 MeV

TEM, MeV

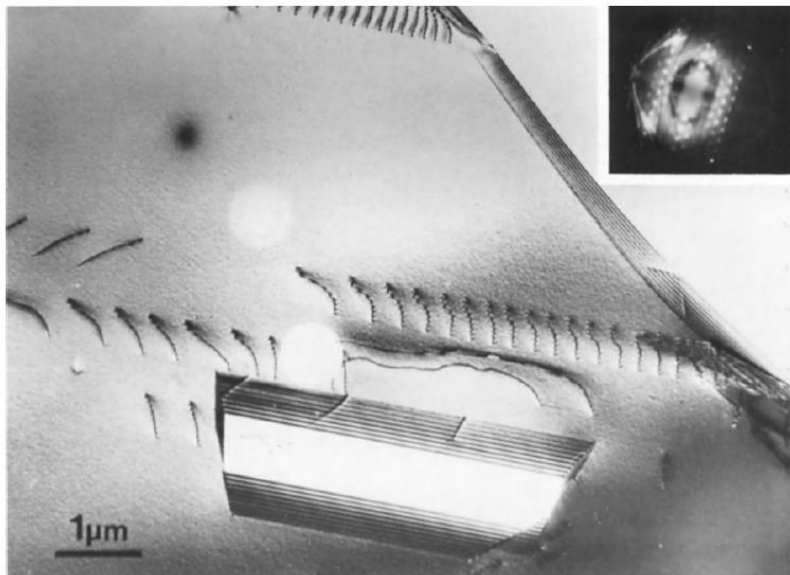


FIG. 15. Stainless steel: twin boundary dislocations; diffraction pattern from the overprinted selected area; $V = 1$ MV.

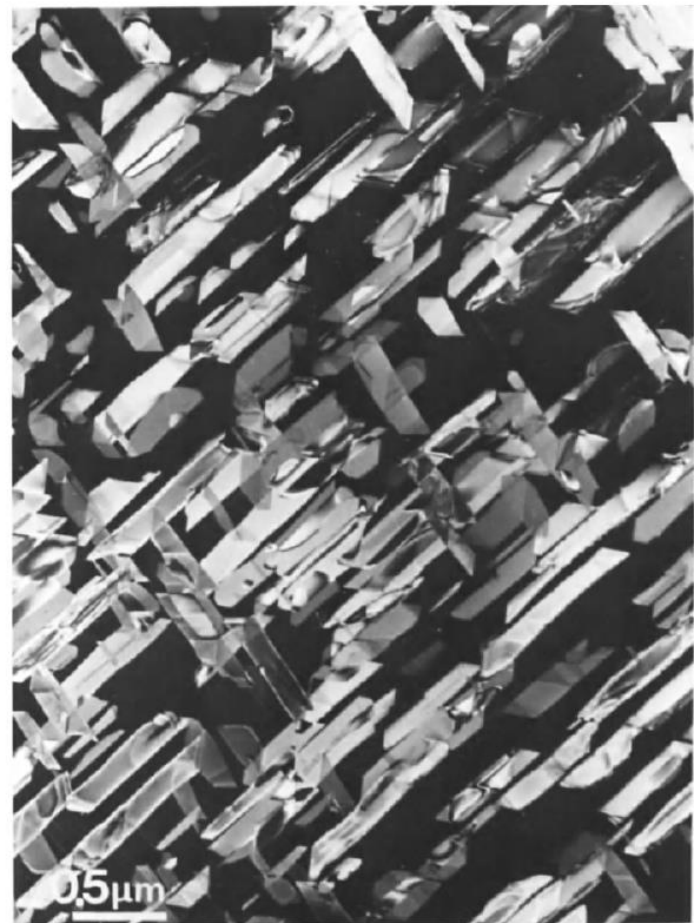


FIG. 21. First image obtained at 2 MV: precipitates in an Al-Cu alloy.

Výhoda velmi vysokého urychlovacího napětí – kontrast na magnetických doménách v Fe-Si

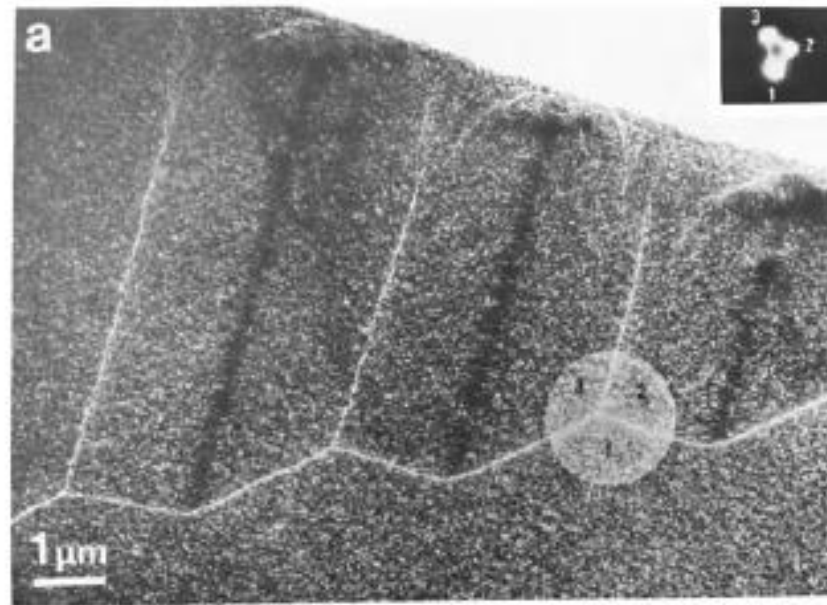


FIG. 27. (a) Defocused image of an Fe-Si alloy specimen showing three magnetic domains. (b) The domain corresponding to spot 3.

EM v biologii

ARKIV FÖR ZOOLOGI.

BAND 40 A. N:o 6.

Examination of Brain Tumor Tissue with the Electron Microscope.

By

HUMBERTO FERNÁNDEZ-MORÁN.

With 13 figures in the text.

Communicated June 4th 1947 by MANNE SIEGBAHN and HUGO THEORELL.

**Examination of Brain Tumor Tissue with the Electron
Microscope.**

Kopeček - U3V

Brusel, 1932, L.L. Marton (aka Ladislaus László)

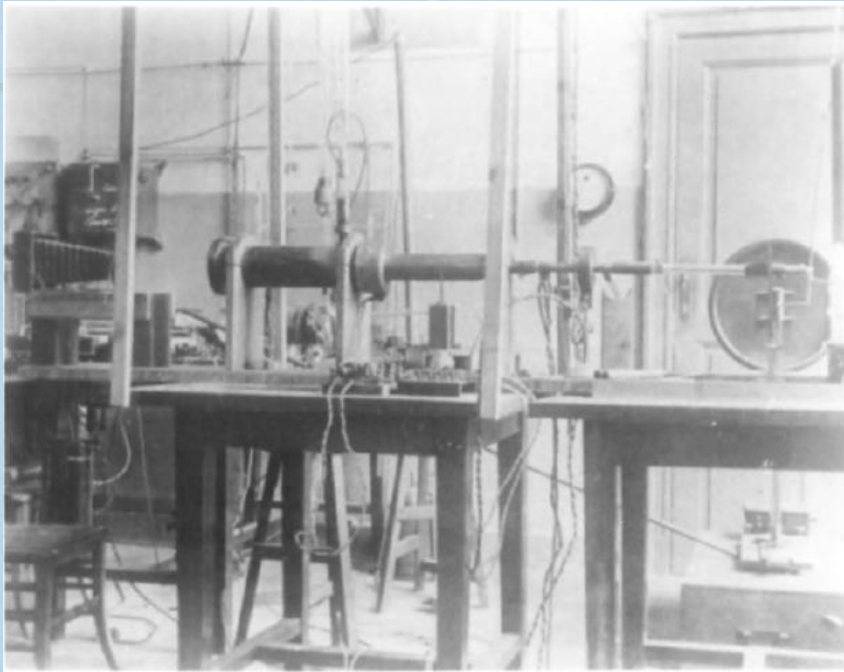


FIG. 2. Marton's No. 2 electron microscope (Brussels, 1934).

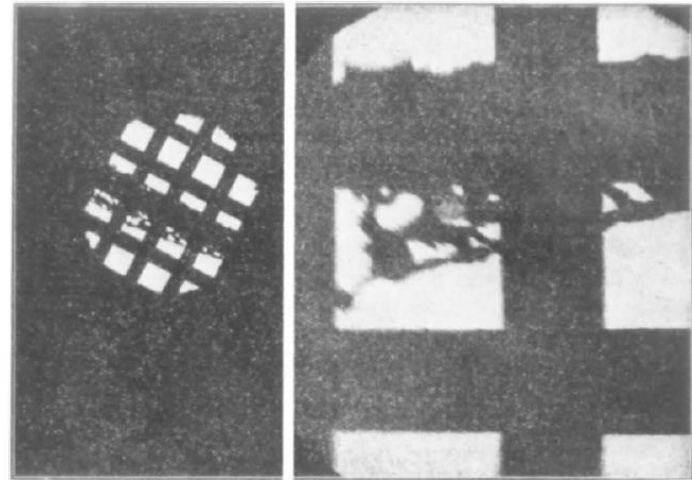
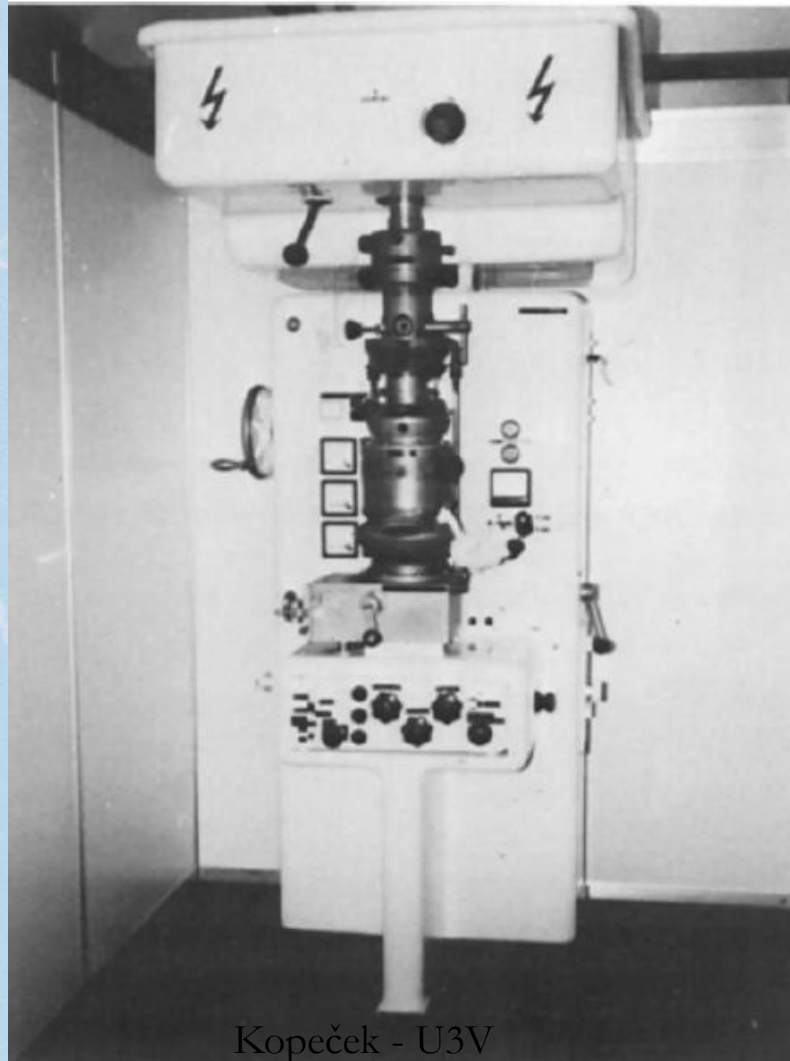
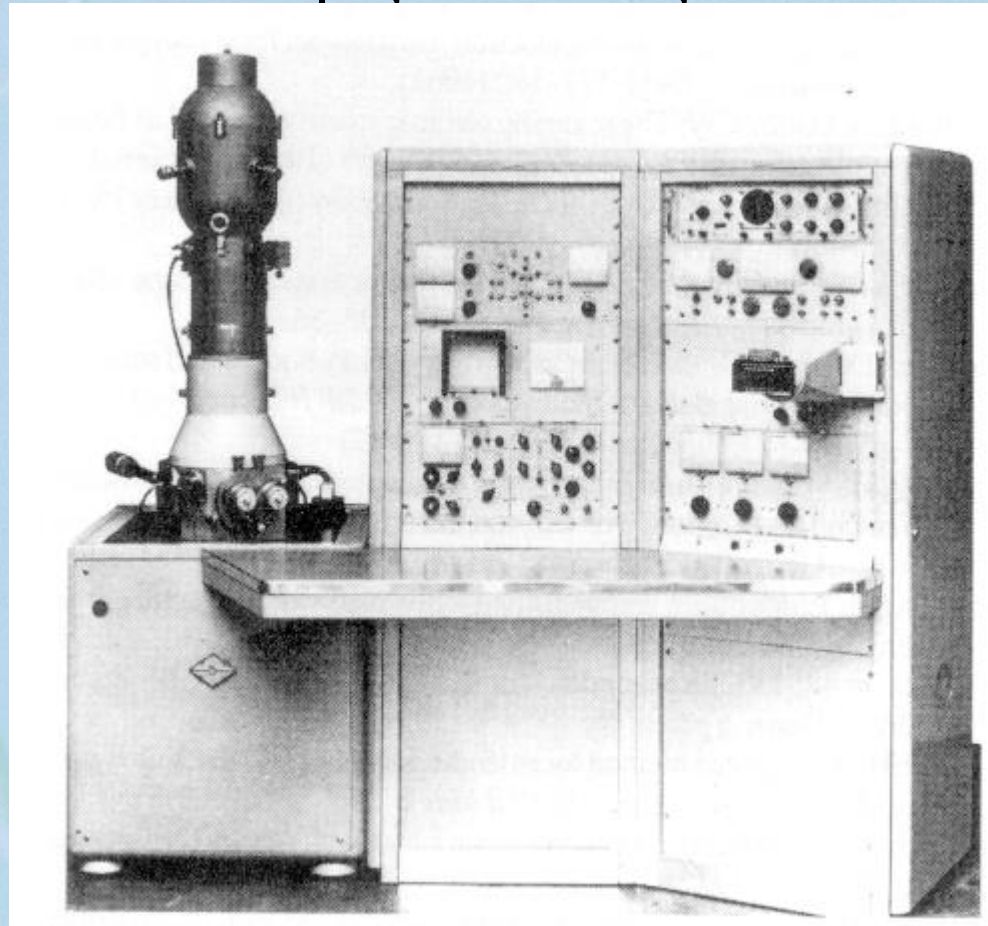


FIG. 3. First electron micrographs of biological sample (15- μ m-thick slice of *Drosera intermedia* leaf on copper net), April 4, 1934.

První komerčně, sériově vyráběný EM, Siemens ÜM 100, 1939

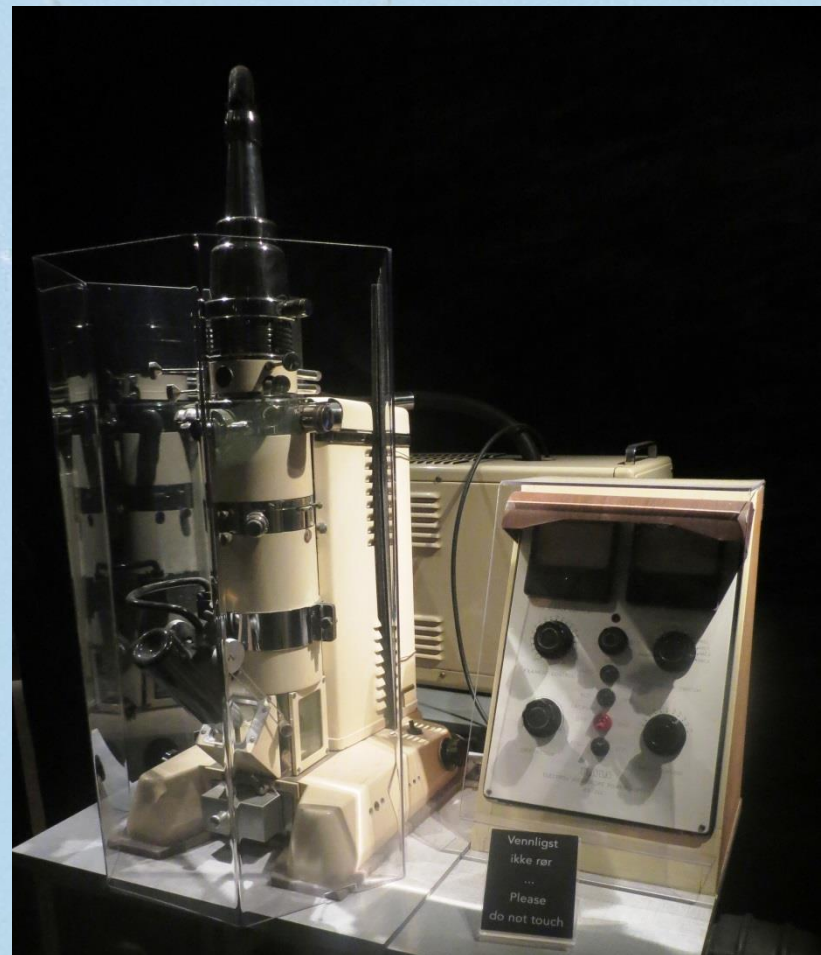
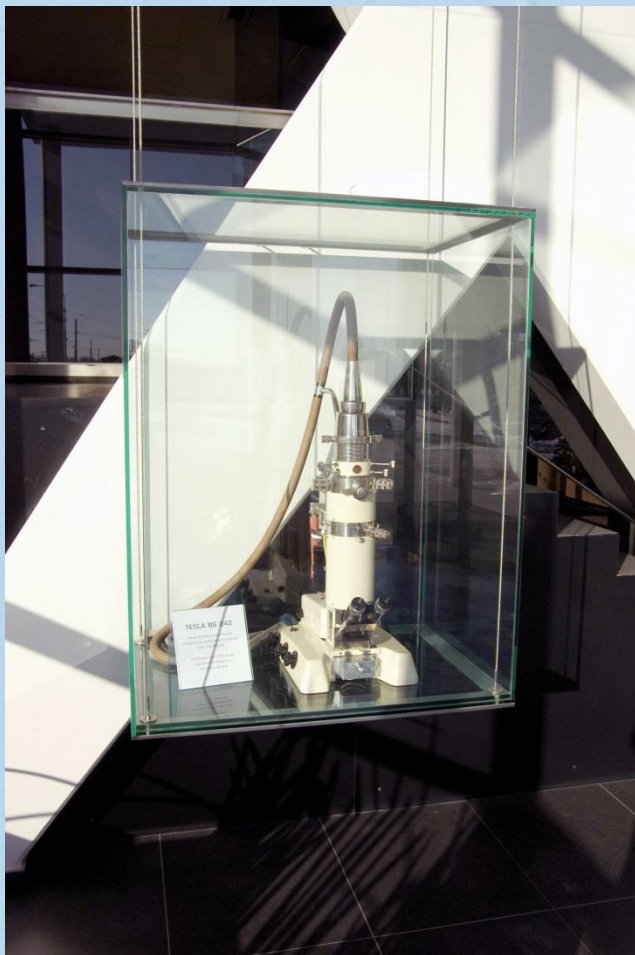


První komerčně dodaný SEM Stereoscan
Cambridge Instrument Company do du Pont
Comp., U.S.A., 1965



*1953
rok
výroby!*

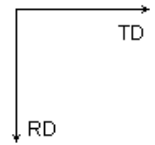
Tesla BS 242 oceněný 1958 v Bruselu



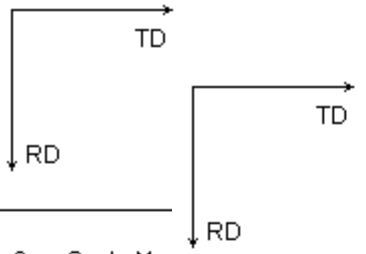
Další, „analytické“ metody doprovázející v instalacích SEM

- EBSD (orientace)
- EDS (složení)

Ocel A



0000 °C



Gray Scale Map Type: Image Quality
47.449...3909.13 (47.449...3909.13)

Color Coded Map Type: <none>

Gray Scale Map
Color Coded Map
Austenite

Boundaries: Rotation Angle

	Min	Max	Fraction	Number	Length
	2°	5°	0.020	5193	6.00 mm
	5°	10°	0.012	3060	3.53 mm
	15°	180°	0.950	243496	28.12 cm
	10°	15°	0.017	4452	5.14 mm

Ferrite

	Min	Max
	0	20
	20	50
	50	100
	100	500
	500	1000
	1000	50000

Boundaries: CSL

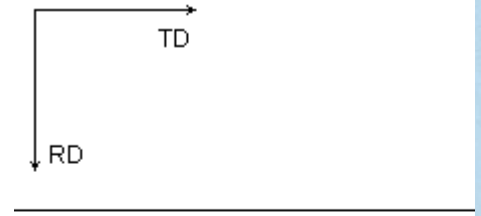
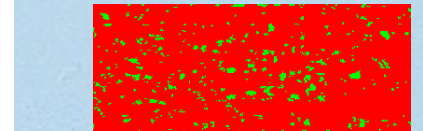
	Sigma	Tolerance	Fraction	Volume	MDF Value	Number	Length
	3	8.66	0.239	0.0176	13.61	61273	7.07519 cm
	9	5.00	0.025	0.0102	2.48	6447	7.44435 mm
	5	6.71	0.006	0.0123	0.50	1566	1.80826 mm
	7	5.67	0.006	0.0099	0.57	1448	1.67201 mm
	11	4.52	0.006	0.0075	0.76	1461	1.68702 mm
	13a	4.16	0.002	0.0029	0.56	418	482.665 microns
	13b	4.16	0.003	0.0039	0.68	676	780.577 microns
	15	3.87	0.005	0.0094	0.53	1287	1.4861 mm
	17a	3.64	0.001	0.0020	0.41	205	236.714 microns
	17b	3.64	0.003	0.0039	0.76	766	884.5 microns
	19a	3.44	0.002	0.0033	0.63	536	618.919 microns
	19b	3.44	0.002	0.0022	0.72	405	467.654 microns
	21a	3.27	0.001	0.0019	0.66	323	372.968 microns
	21b	3.27	0.003	0.0057	0.52	755	871.799 microns
	23	3.13	0.002	0.0050	0.45	579	668.571 microns
summary	-	-	0.305	0.0976	3.13	-	-

Boundaries: Rotation Angle

	Min	Max	Fraction
	15°	180°	0.950

*For statistics - any point pair with misorientation exceeding 2° is considered a boundary
total number = 256201, total length = 29.58 cm)

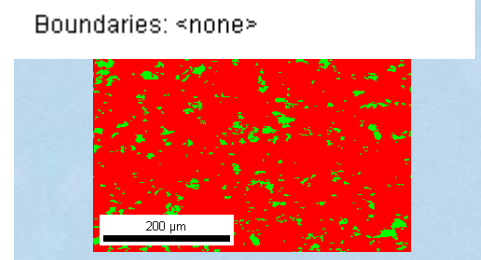
*For statistics - any point pair with misorientation exceeding 2° is considered a boundary
total number = 256201, total length = 29.58 cm)

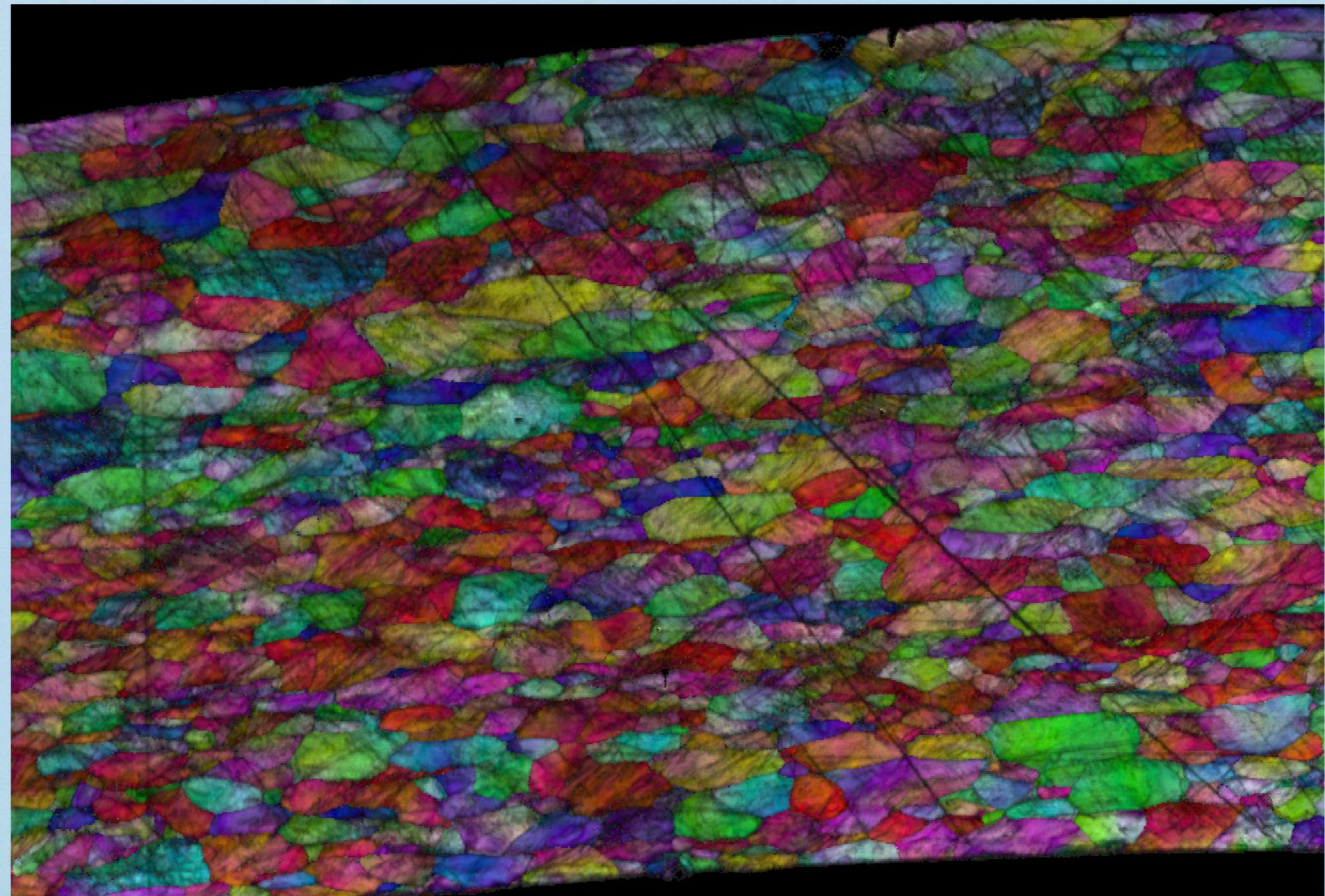


Gray Scale Map Type: <none>

Color Coded Map Type: Phase

Phase	Total Fraction	Partition Fraction
	0.909	0.909
	0.091	0.091

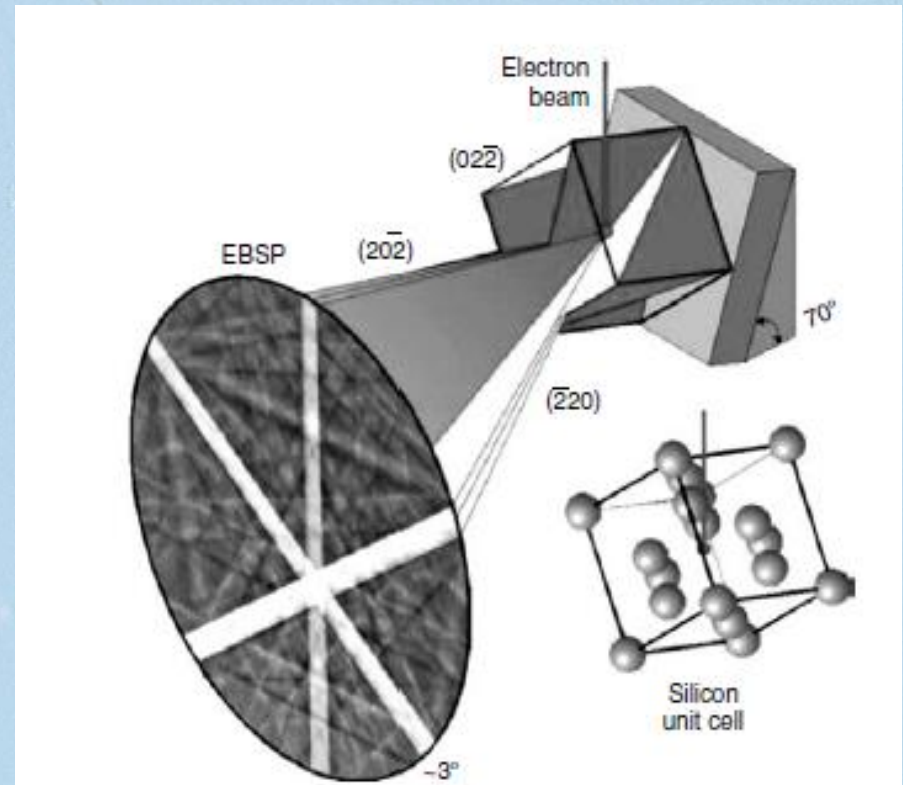
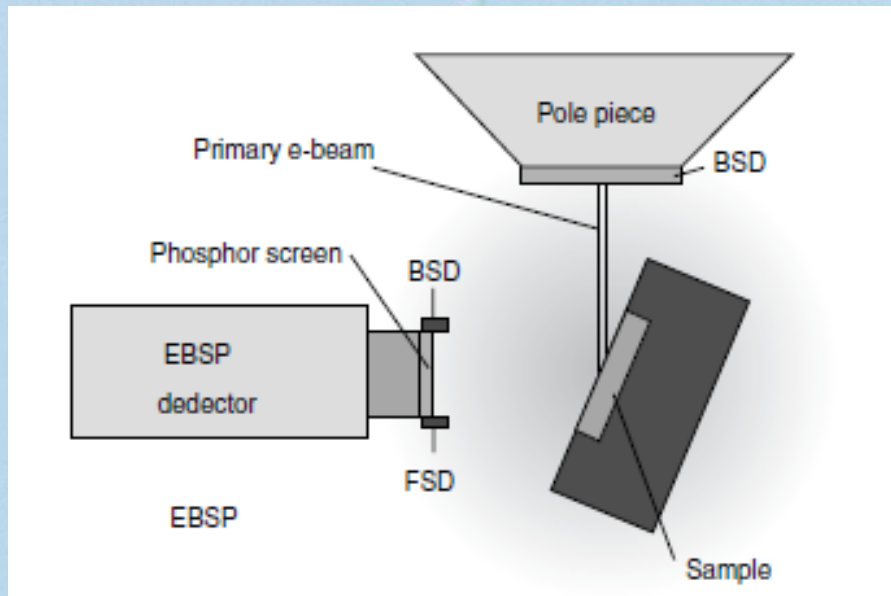




100 um

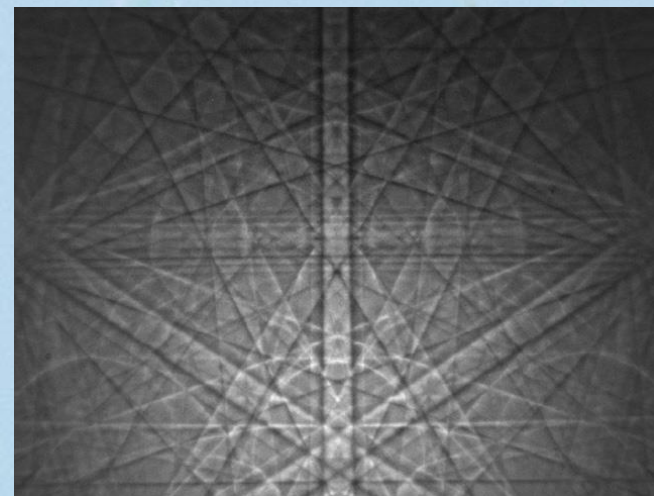
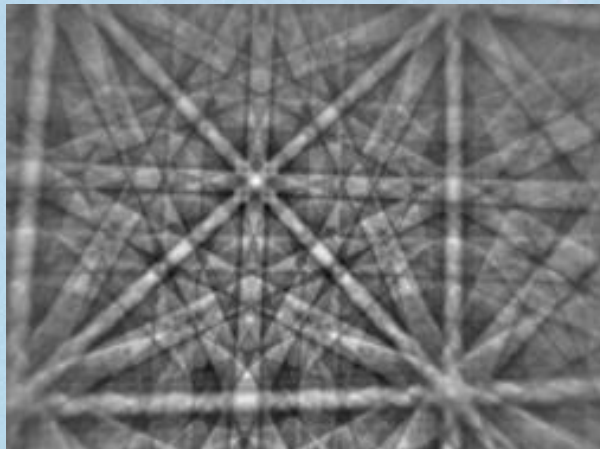
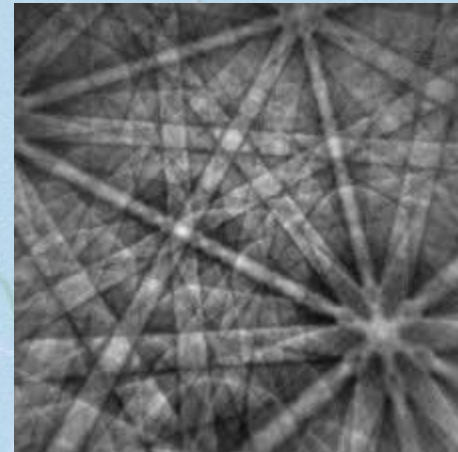
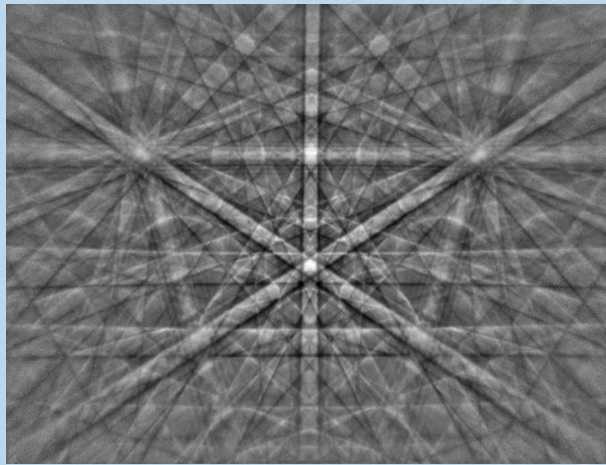
Phase Map

EBSD – principy a pozice detektorů



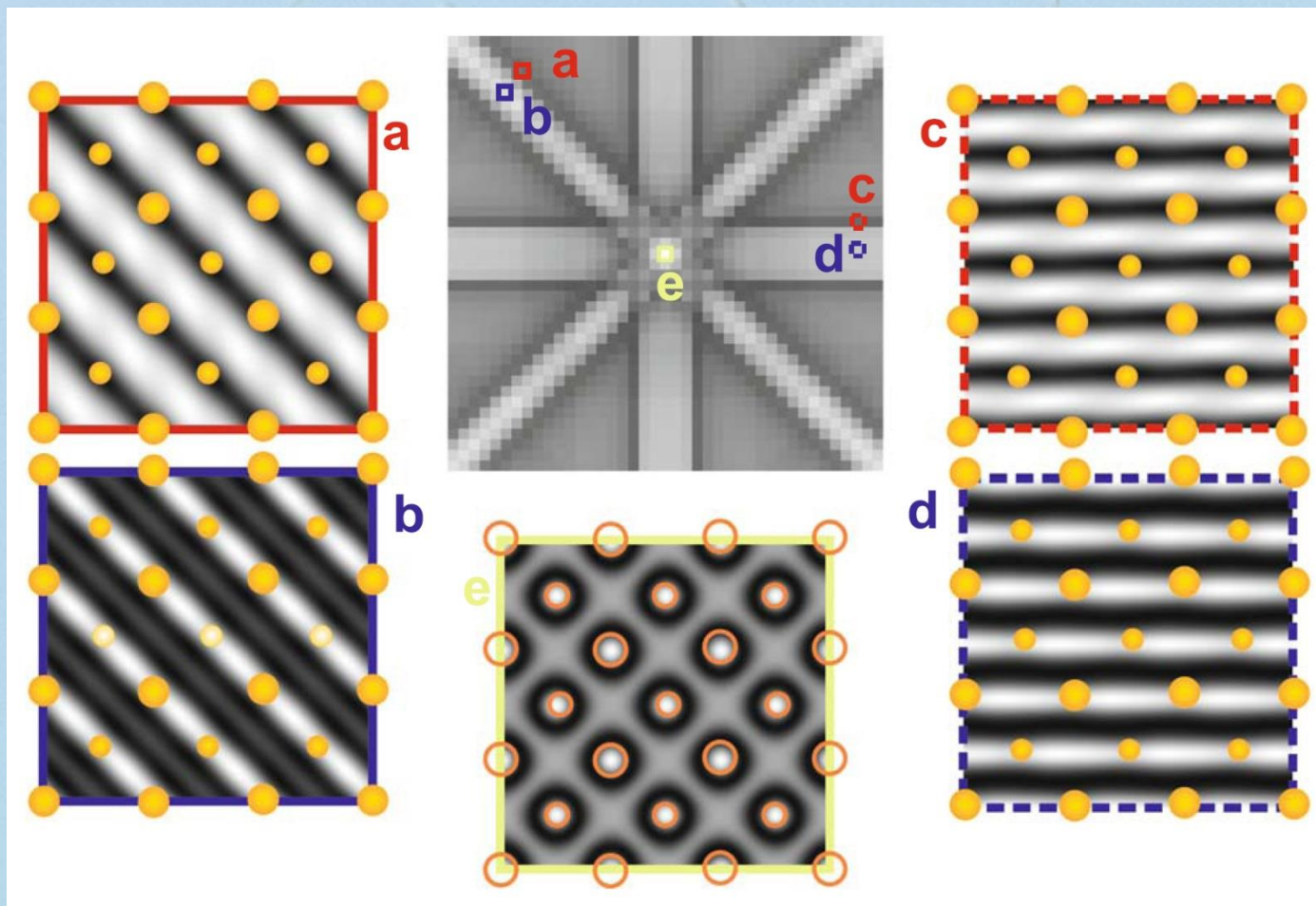
Scanning Microscopy for Nanotechnology Techniques and Applications - Weilie Zhou, Zhong Lin Wang (Eds), Springer Science+Business Media, LLC, 2006

Kikuchiho obrazce



Modelování EBSP obrazců

9-i svazkový model

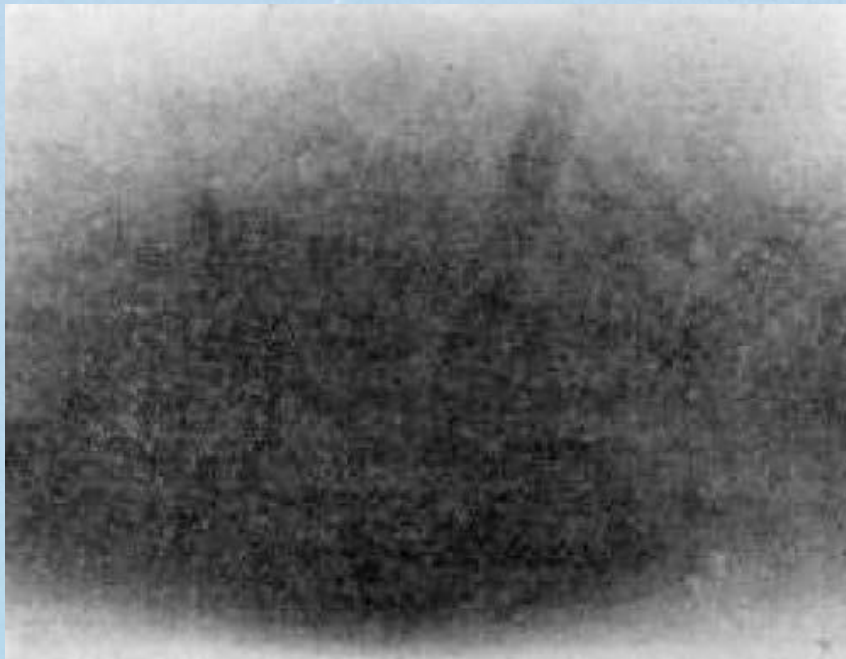


Krátká historie EBSD

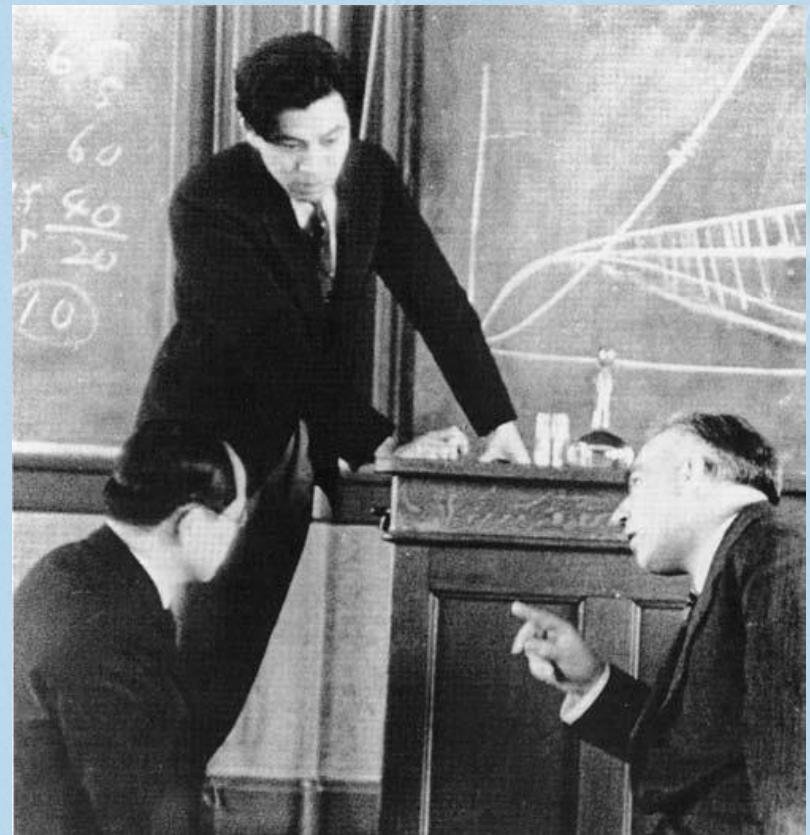
- 1928 Shoji Nishikawa, Seishi Kikuchi – kalcit, 50 KeV elektrony z plynového z výboje
- 1972-1979 John Venables
- 1979-1988 Bristol group – computerisation (D.J. Dingley)
- 1988-2006 OIM (Yale Univ, TSL, HKL)
- 1992 Použití Houghovy transformace pro vyhodnocení Kikuchiho obrazců
- 2006-2012 HR-EBSD (Oxford Univ., BLG, Saint Etienne Univ, Brigham Univ)

Něco z historie metody EBSD

Vůbec první Kikuchiho linie pozorované Kikuchim 1927 v kalcitu.

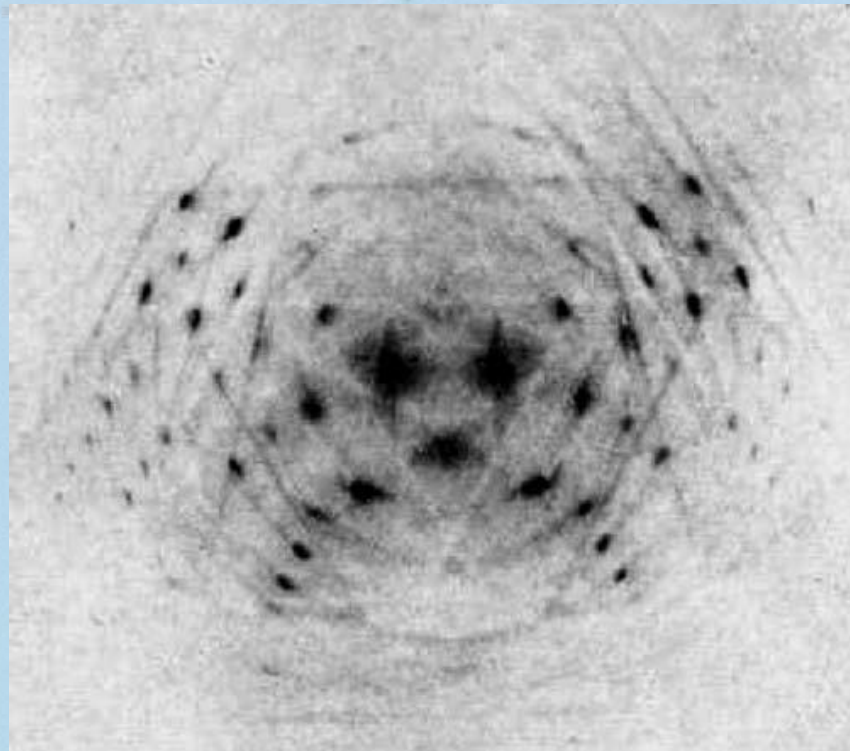


Seishi Kikuchi (*standing*).

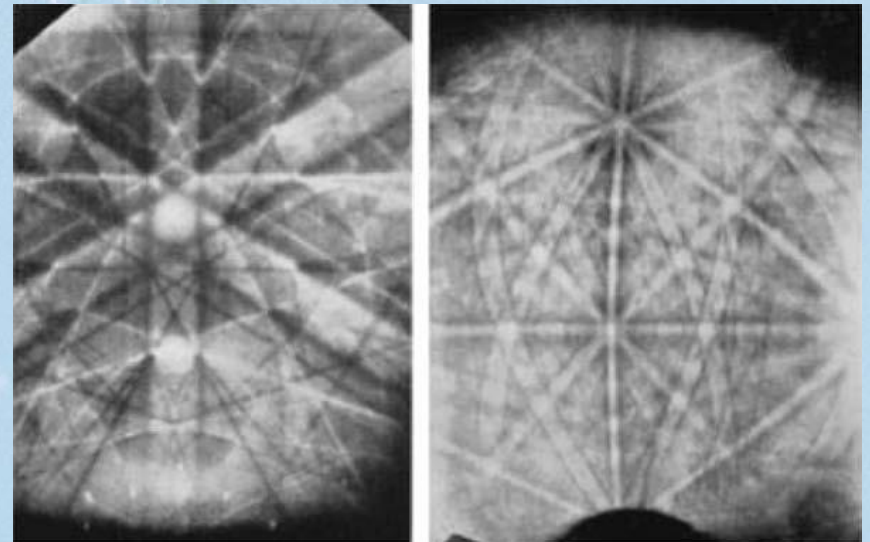


Něco z historie metody EBSD

Kikuchi P-pattern from mica.



Boersch 1937 Iron Kikuchi patterns.



Projekce Kikuchiho linie na kouli

Ferit

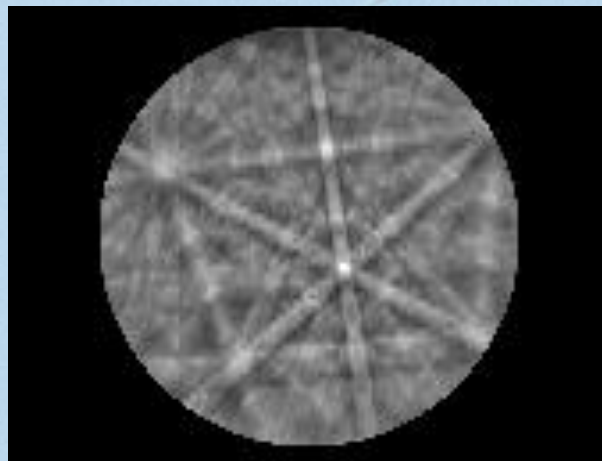
Křemen



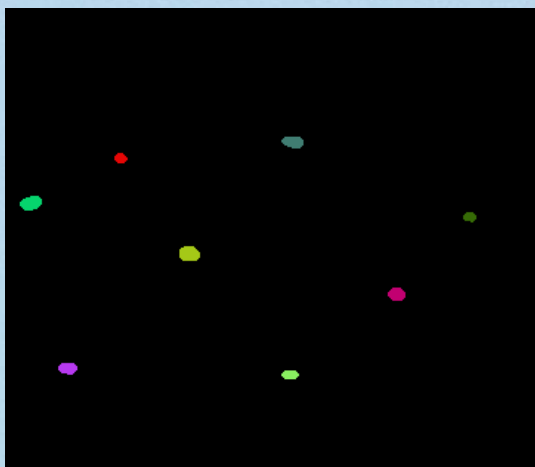
Jak se Kikuchiho linie vyhodnocují?

Body 1 - 2

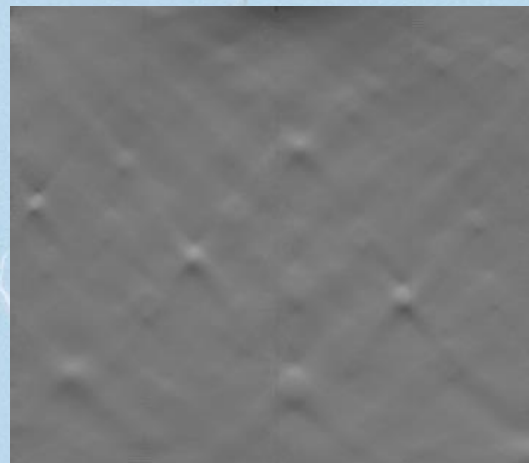
Kikuchiho obrazec



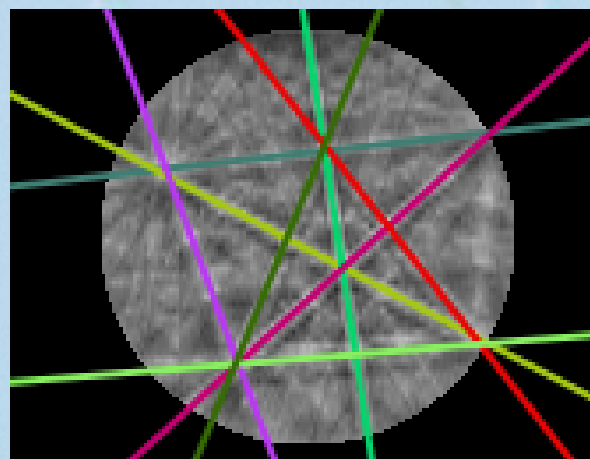
Nalezení píků a stanovení jejich intenzity



Houghova transformace



Nalezení Kikuchiho pásů



Houghova transformace – od 1992

Jensen, Jeppe. "Hough Transform for Straight Lines". *Mini-project in Image Processing, 7th semester 2007*.
http://www.cvmt.dk/education/teaching/e07/MED3/IP/hough_lin.es.pdf.

Retrieved 16 December 2011.

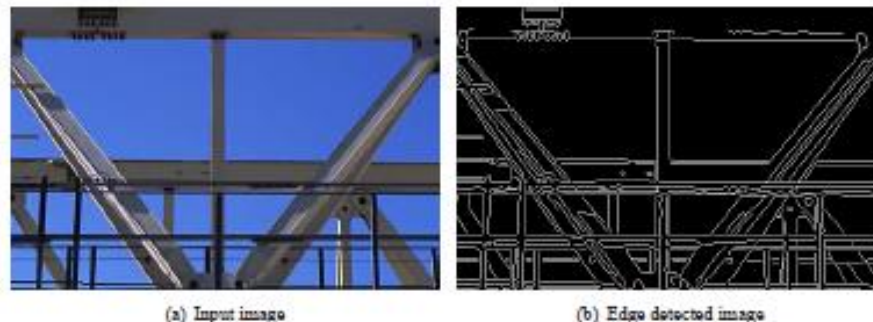


Figure 2: An example with an input image and the result of the edge detection, using the Canny edge detection.

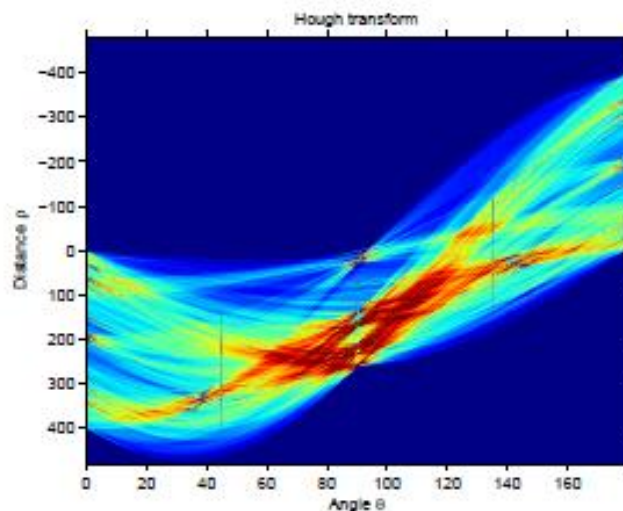
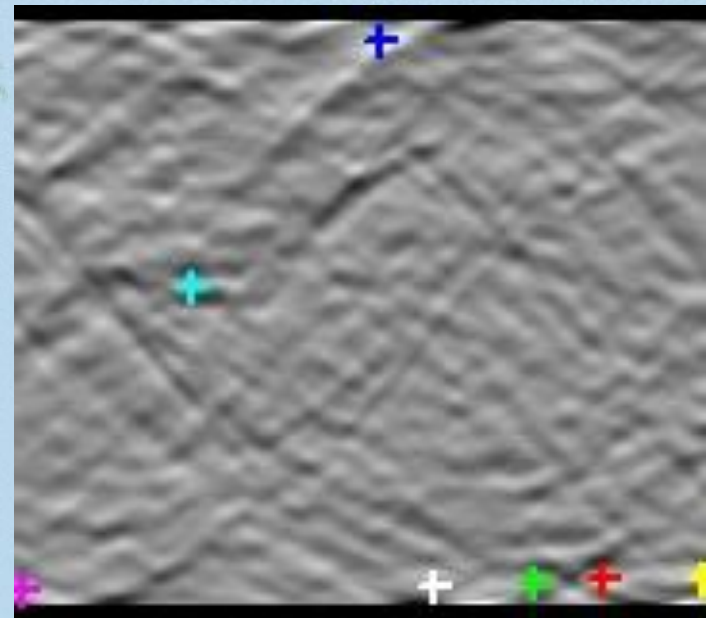


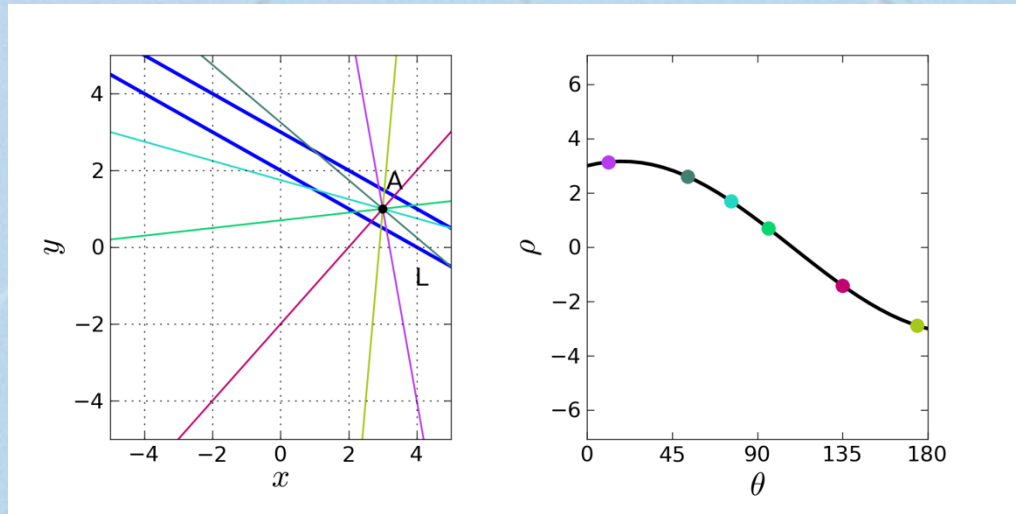
Figure 3: The Hough space of the input image in Figure 2. The dark red points are the points with the highest number of intersections. Many dark red points are around 90 degrees, i.e. that the image has many horizontal lines.

Převádí kartézské souřadnice na polární a tak Kikuchiho pásy na píky, jejichž detekce je snadná. Je speciálním případem Radonovy transformace (tomograf). Dříve probíhalo vyhodnocení každého bodu ručně prokládáním čar.

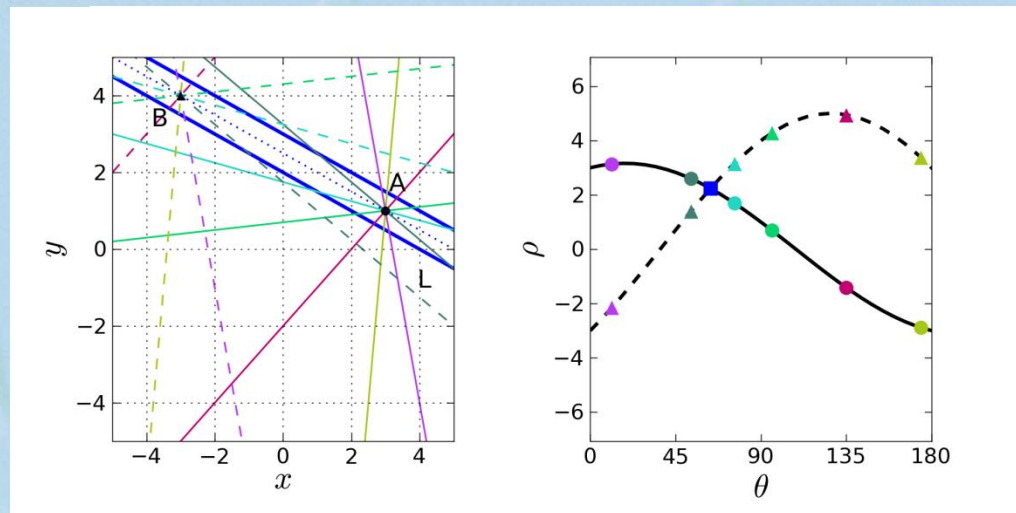
Kikuchiho linie – zpět ke kořenům



Houghova transformace



Houghova transformace – převádí čáry (Kikuchiho linie) na sinusoidy



Houghova transformace

Slouží k transformaci Kikuchiho pásů na píky. Pás – přímku si parametrizujeme v polárních souřadnicích, načež sečteme intenzitu „po přímce“.

$$r = x \cdot \cos \theta + y \cdot \sin \theta$$

$$R(\rho, \theta) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) \cdot \delta(\rho - x \cdot \cos \theta - y \cdot \sin \theta) dx dy$$

δ -funkce zajišťuje nenulovost na přímce.

Houghova transformace

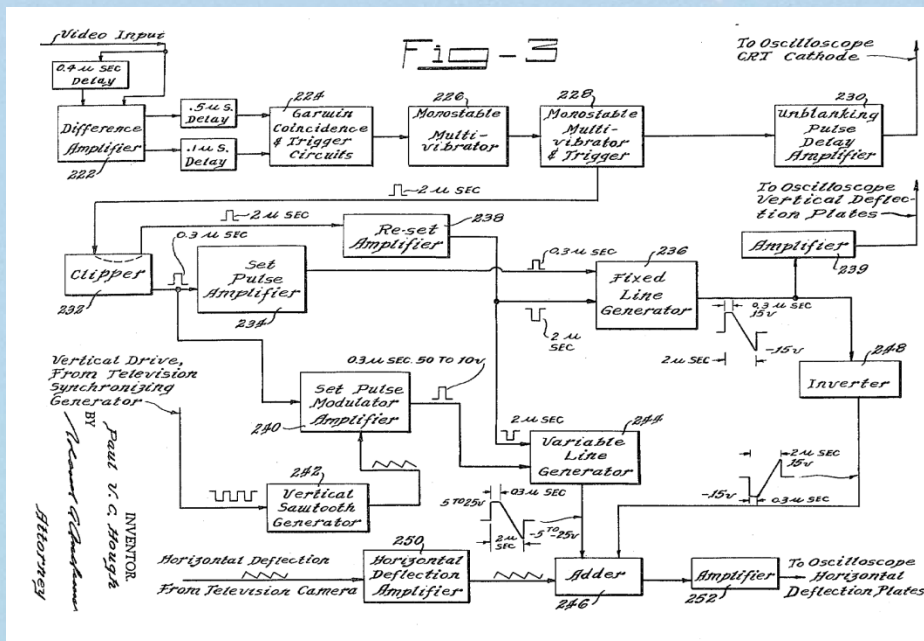
Paul V. C. Hough

Patent US 3069654 A; 18. prosinec 1962

<http://www.google.com/patents/US3069654>

Patentoval až do roku 2004 (metody snímání v AFM – 3 patenty)

John Simon Guggenheim fellow 1959 a 1973



Stanley R. Deans, *Hough Transform from the Radon Transform*, IEEE trans. PAMI3-2-185

Radonova transformace

Je zobecněním Houghovy transformace a také je starší.

Johann Radon se narodil 16. prosince 1887 v Děčíně a v letech 1897-1905 navštěvoval gymnázium v Litoměřicích. Od r. 1946 působil Radon jako profesor na vídeňské univerzitě, kde vykonával krátce funkci děkana a později v r. 1954 rektora. Zemřel 25. května 1956. (PokrokyMFA33-5-5)

Allan MacLeod Cormack (fyzik), Godfrey Hounsfield (elektroinženýr) – Nobelova cena za medicínu 1979 za CT tomograf

(PokrokyMFA29-4-196, A.M. Cormack, JAP34-9-2722)

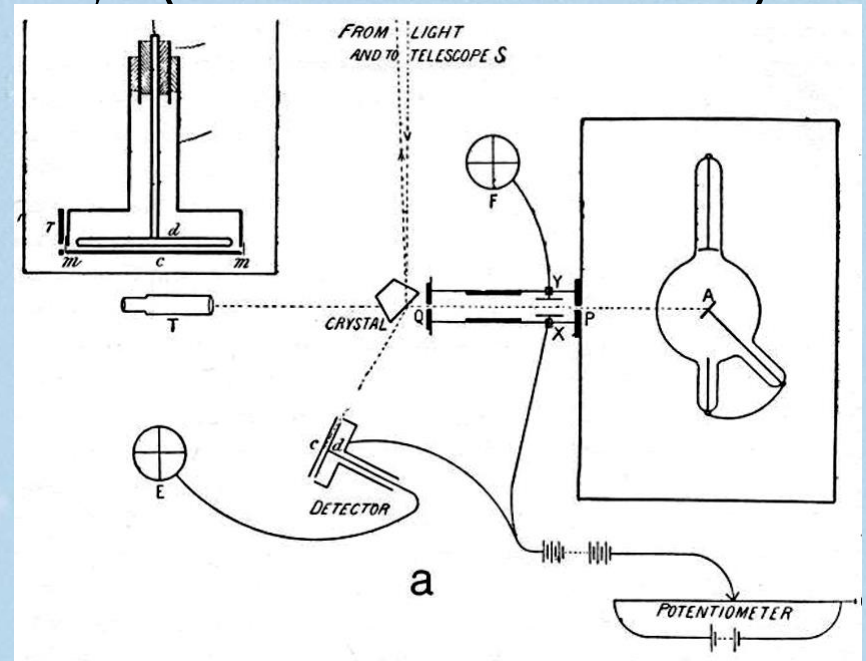
$$I = I_0 \exp \left[- \int_L g(s) ds \right],$$



J. Radon

Prvkové složení zkoumaných materiálů - EDS

Henry G. J. Moseley (1887 – 1915)



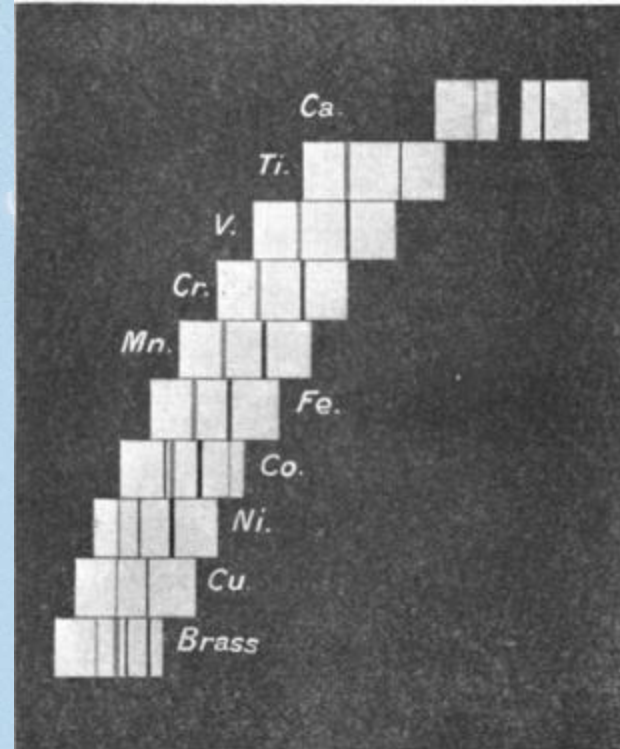
Objev – Moseley 1913

XCIII. *The High-Frequency Spectra of the Elements.*
By H. G. J. MOSELEY, M.A.*

[Plate XXIII.]

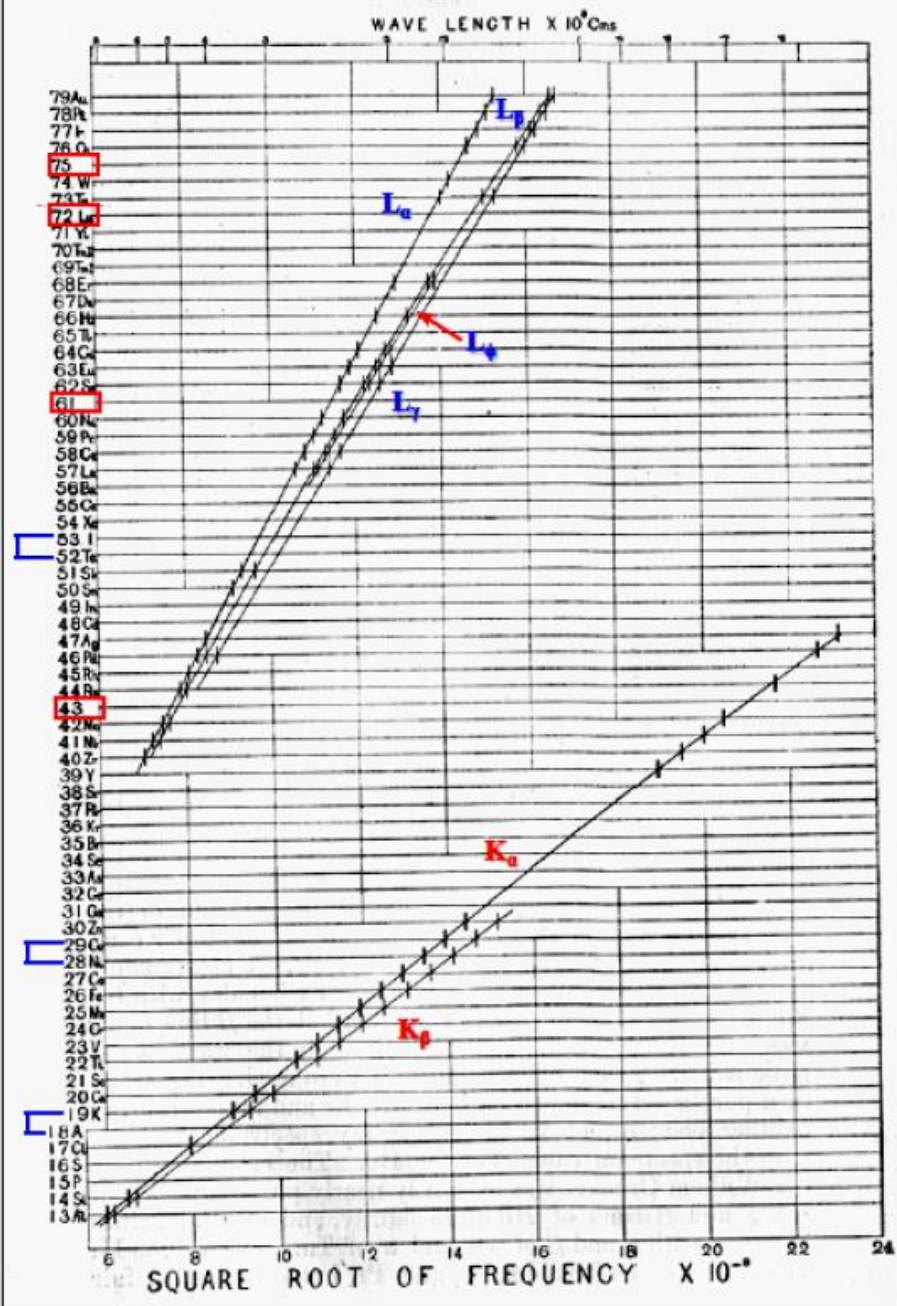
IN the absence of any available method of spectrum analysis, the characteristic types of X radiation, which an atom emits when suitably excited, have hitherto been described in terms of their absorption in aluminium †. The interference phenomena exhibited by X rays when scattered by a crystal have now, however, made possible the accurate determination of the frequencies of the various types of radiation. This was shown by W. H. and W. L. Bragg ‡, who by this method analysed the line spectrum emitted by the platinum target of an X-ray tube. C. G. Darwin and the author § extended this analysis and also examined the continuous spectrum, which in this case constitutes the greater part of the radiation. Recently Prof. Bragg || has also determined the wave-lengths of the strongest lines in the spectra of nickel, tungsten, and rhodium. The electrical methods which have hitherto been employed are, however, only successful where a constant source of radiation is available. The present paper contains a description of a method of photographing these spectra, which makes the analysis of the X rays as simple as any other branch of spectroscopy.

PhilMagSerie6-26-156-1024



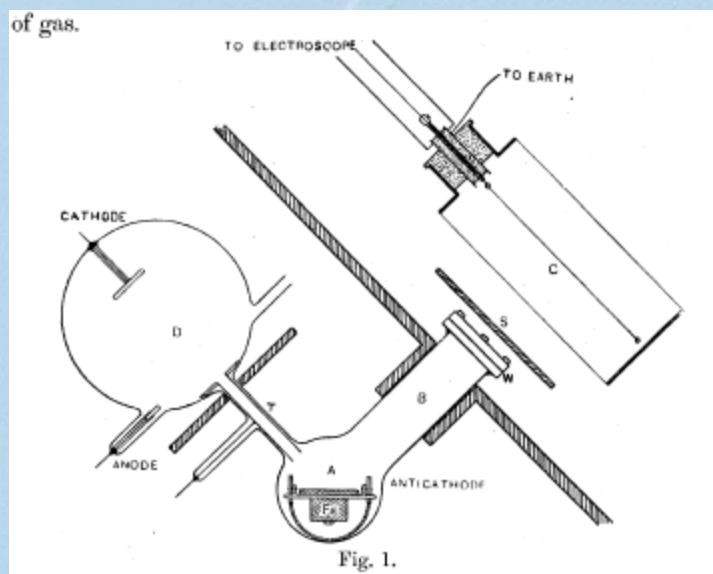
Kaye † has shown that an element excited by a stream of sufficiently fast cathode rays emits its characteristic X radiation. He used as targets a number of substances mounted

Fig. 8.



Objev – G.W.C. Kaye

ptRSLA209-123



VI. *The Emission and Transmission of Röntgen Rays.*

By G. W. C. KAYE, B.A. (Cantab.), B.Sc. (Lond.), A.R.C.Sc., Associate-Member
of the Institution of Electrical Engineers, Trinity College, Cambridge.

Communicated by Prof. J. J. THOMSON, F.R.S.

Received June 17,—Read June 25, 1908.

Literatura

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- Doporučená literatura:
- *Scanning Electron Microscopy and X-Ray Microanalysis*, J. I. Goldstein, D. E. Newbury, P. Echlin, D. C. Joy, A. D. Romig Jr., Ch. E. Lifshin, ISBN-13: 978-0306472923, Plenum Press, New York, 1992, 1981
- *Handbook of Sample Preparation for Scanning Electron Microscopy and X-Ray Microanalysis* , Patrick Echlin, ISBN: 0387857303, Springer Science+Business Media, LLC 2009
- *Electron Backscatter Diffraction in Materials Science*, Adam J. Schwartz, Mukul Kumar, Brent L. Adams, David P. Field, 2nd Edition, ISBN 978-0-387-88135-5, Springer Science+Business Media, LLC 2009
- *Introduction to Focused Ion Beams Instrumentation, Theory, Techniques and Practice*, Lucille A. Giannuzzi , Fred A. Stevie, ISBN: 0-387-23116-1, Springer Science + Business Media, Inc., 2005
- *Zkoumání látek elektronovým paprskem*, V. Hulínský, K. Jurek, SNTL, Praha 1982
- *Úvod do transmisní elektronové mikroskopie*, Miroslav Karlík, ISBN: 978-80-0104-729-3, ČVUT, Praha, 2011

Děkuji za pozornost!