

Theory: Interaction of electrons with matter



Periodensystem der Elemente



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| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|----------------------------|---------------------------|--------------------------|--------------------------------|--------------------------|-----------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------------|------------------------------|-----------------------------|---|---|----|----|----|----|---------------------------|----------------------------|-----------------------------|----------------------------|-----------------------------|----------------------------|-------------------------|----|------------|----|-------------|
| 1 | IA 1 | 2 | IIA 2 | 3 | IIIB 3 | 4 | IVB 4 | 5 | VB 5 | 6 | VIIB 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | IIIA 13 | 14 | IVA 14 | 15 | V 15 | 16 | VIA 16 | 17 | VIIA 17 | 18 | VIIIA 18 |
| 1 | H Wasserstoff 1,0079 | | | | | | | | | | | | | | | | | | B Bor 10,811 | C Kohlenstoff 12,011 | N Stickstoff 14,007 | O Sauerstoff 15,999 | F Fluor 18,998 | | Ne Neon 20,18 | | | | |
| 2 | Li Lithium 6,941 | Be Beryllium 9,0122 | | | | | | | | | | | | | | | | | Al Aluminium 26,982 | Si Silicium 28,086 | P Phosphor 30,974 | S Schwefel 32,065 | Cl Chlor 35,453 | | Ar Argon 39,948 | | | | |
| 3 | Na Natrium 22,99 | Mg Magnesium 24,305 | | | | | | | | | | | | | | | | | Ga Gallium 69,723 | Ge Germanium 72,64 | As Arsen 74,922 | Se Selen 78,96 | Br Brom 79,904 | | Kr Krypton 83,798 | | | | |
| 4 | K Kalium 39,098 | Ca Calcium 40,078 | Sc Scandium 44,956 | Ti Titan 47,887 | V Vanadium 50,942 | Cr Chrom 51,996 | Mn Mangan 54,938 | Fe Eisen 55,845 | Co Cobalt 58,933 | Ni Nickel 58,693 | Cu Kupfer 63,546 | Zn Zink 65,38 | | | | | | | Ga Gallium 69,723 | Ge Germanium 72,64 | As Arsen 74,922 | Se Selen 78,96 | Br Brom 79,904 | | Kr Krypton 83,798 | | | | |
| 5 | Rb Rubidium 85,468 | Sr Strontium 87,62 | Y Yttrium 88,906 | Zr Zirkon 91,224 | Nb Niobium 92,906 | Mo Molybdän 95,96 | Tc Technetium (97,90) | Ru Ruthenium 101,07 | Rh Rhodium 102,91 | Pd Palladium 106,42 | Ag Silber 107,87 | Cd Cadmium 112,41 | | | | | | | In Indium 114,82 | Sn Zinn 118,71 | Sb Antimon 121,76 | Te Tellur 127,6 | I Iod 126,9 | | Xe Xenon 131,29 | | | | |
| 6 | Cs Cäsium 132,91 | Ba Barium 137,33 | La - Lu 57 - 71 | Hf Hafnium 178,49 | Ta Tantal 180,95 | W Wolfram 183,84 | Re Rhenium 186,21 | Os Osmium 190,23 | Ir Iridium 192,22 | Pt Platin 195,08 | Au Gold 196,97 | Hg Quecksilber 200,59 | | | | | | | Tl Thallium 204,38 | Pb Blei 207,2 | Bi Bismut 208,98 | Po Polonium (209,0) | At Astat (209,0) | | Rn Radon (222) | | | | |
| 7 | Fr Francium (223,0) | Ra Radium (226,0) | Ac - Lr 89 - 103 | Rf Rutherfordium (261,1) | Db Dubnium (262,1) | Sg Seaborgium (266,1) | Bh Bohrium (264,1) | Hs Hassium (269,1) | Mt Meitnerium (268,1) | Ds Darmstadtium (272,1) | Rg Roentgenium (272,1) | Cn Copernicium (277) | | | | | | | Uut Ununtrium (284) | Fl Flerovium (289) | Uup Ununpentium (288) | Lv Livermorium (293) | Uus Ununseptium (292) | Uuo Ununoctium (294) | | | | | |

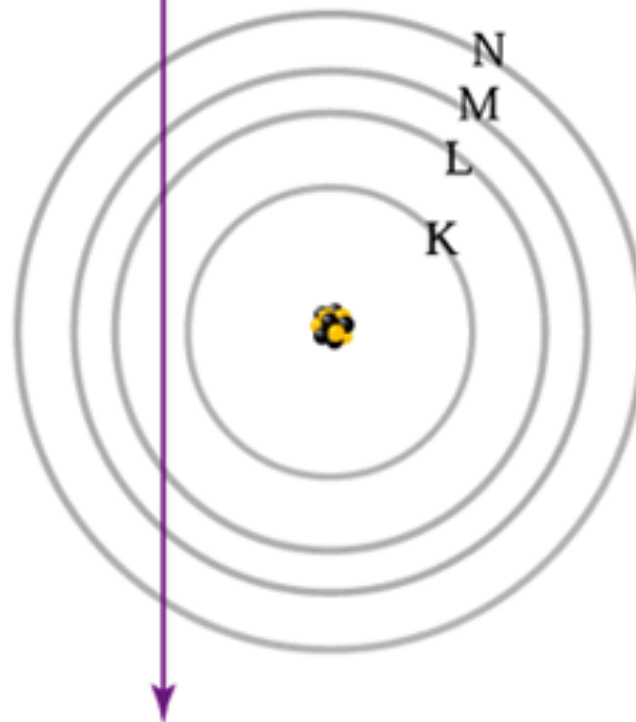
innere Übergangsmetalle

| | | | | | | | | | | | | | | |
|---------------------------|-------------------------|------------------------------|------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|------------------------------|------------------------------|--------------------------|------------------------------|---------------------------|-----------------------------|
| 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 |
| La Lanthan 138,91 | Ce Cer 140,12 | Pr Praseodym 140,91 | Nd Neodym 144,24 | Pm Promethium 144,91 | Sm Samarium 150,36 | Eu Europium 151,96 | Gd Gadolinium 157,25 | Tb Terbium 158,93 | Dy Dysprosium 162,5 | Ho Holmium 164,93 | Er Erbium 167,26 | Tm Thulium 168,93 | Yb Ytterbium 173,05 | Lu Lutetium 174,97 |
| 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 |
| Ac Actinium (227,0) | Th Thorium 232,04 | Pa Protactinium 231,04 | U Uran 238,03 | Np Neptunium (237,0) | Pu Plutonium (244,0) | Am Americium (243,0) | Cm Curium (247,0) | Bk Berkelium (247,0) | Cf Californium (251,0) | Es Einsteinium (252,0) | Fm Fermium (257,0) | Md Mendelevium (258,0) | No Nobelium (259,0) | Lr Lawrencium (260,1) |

<http://www.dentilux.com/services/services.htm>

Primary beam

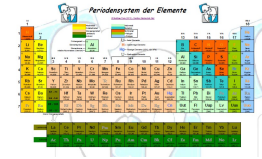
15 keV



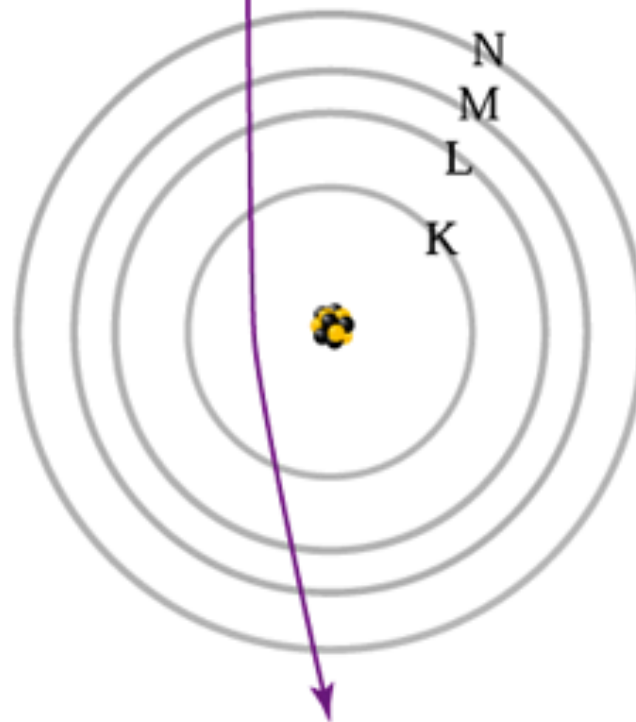
Periodensystem der Elemente

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 |
|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|

Primary beam
15 keV

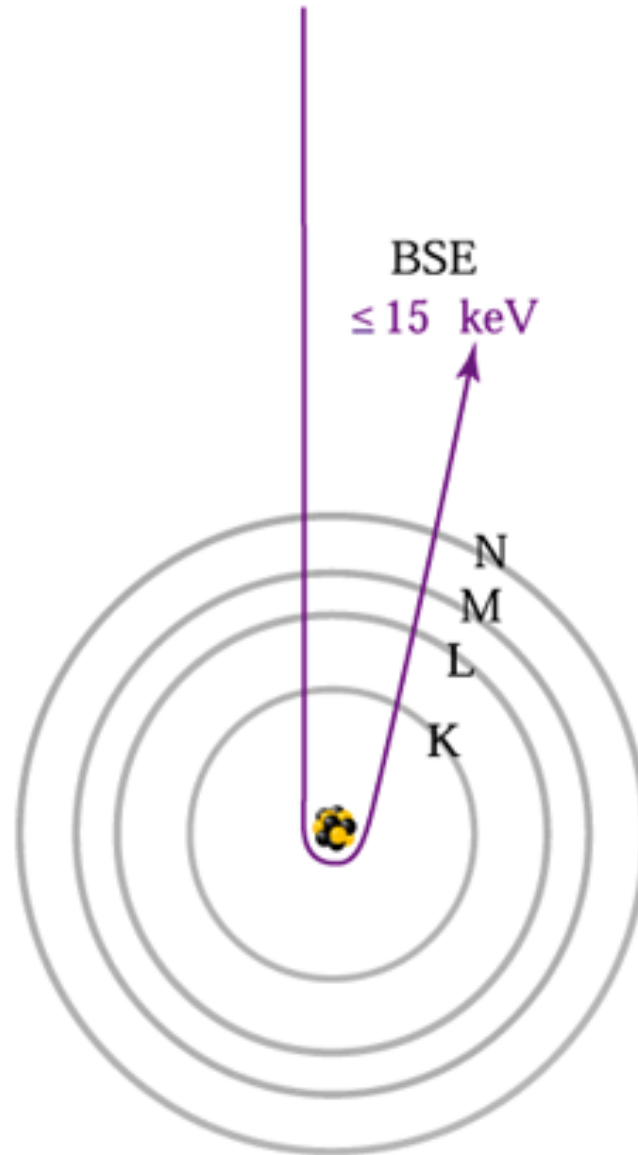
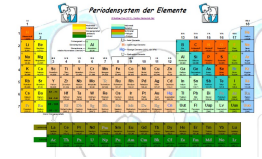


A small, colorful periodic table of elements, titled "Periodensystem der Elemente". It shows the standard layout of elements with their symbols and atomic numbers.

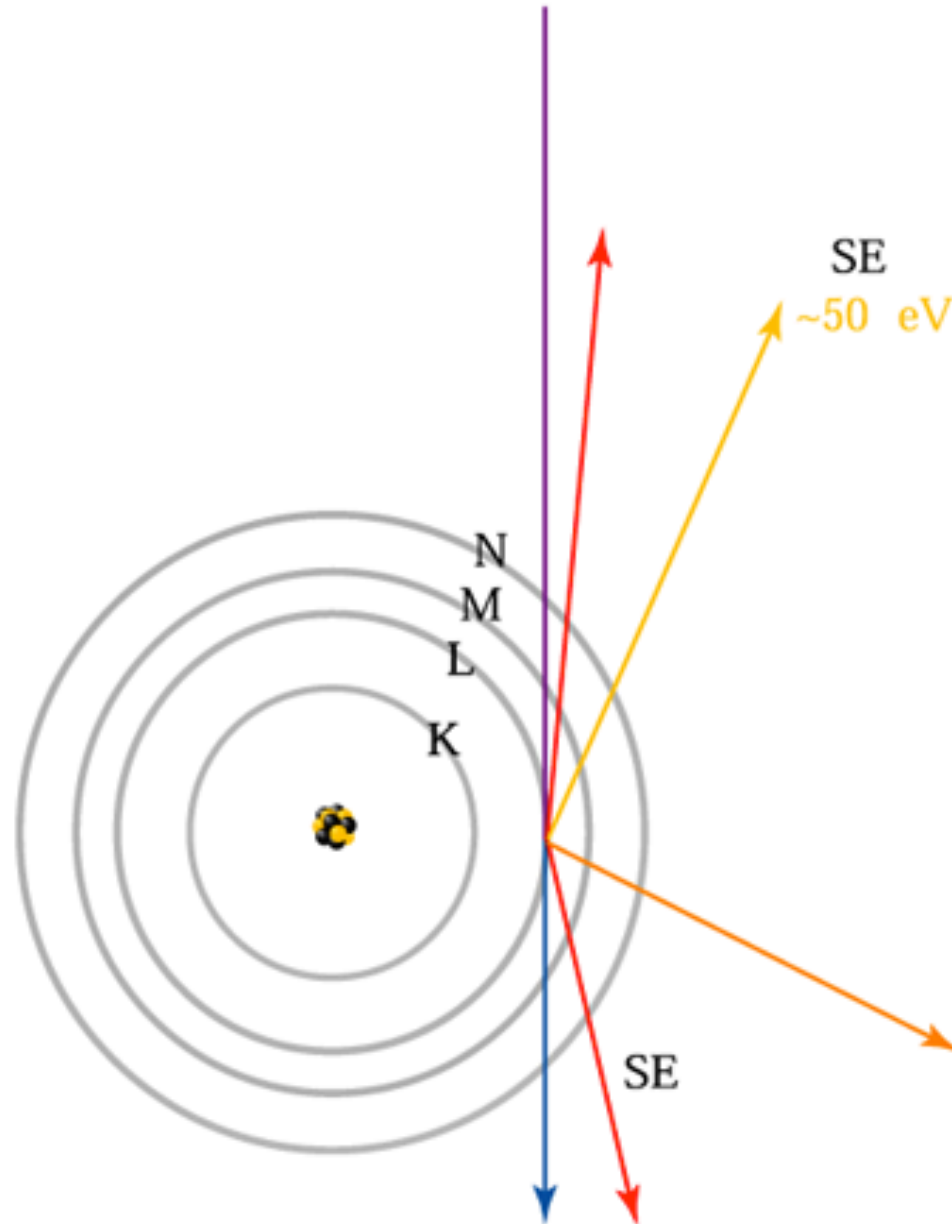
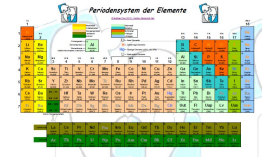


Primary beam

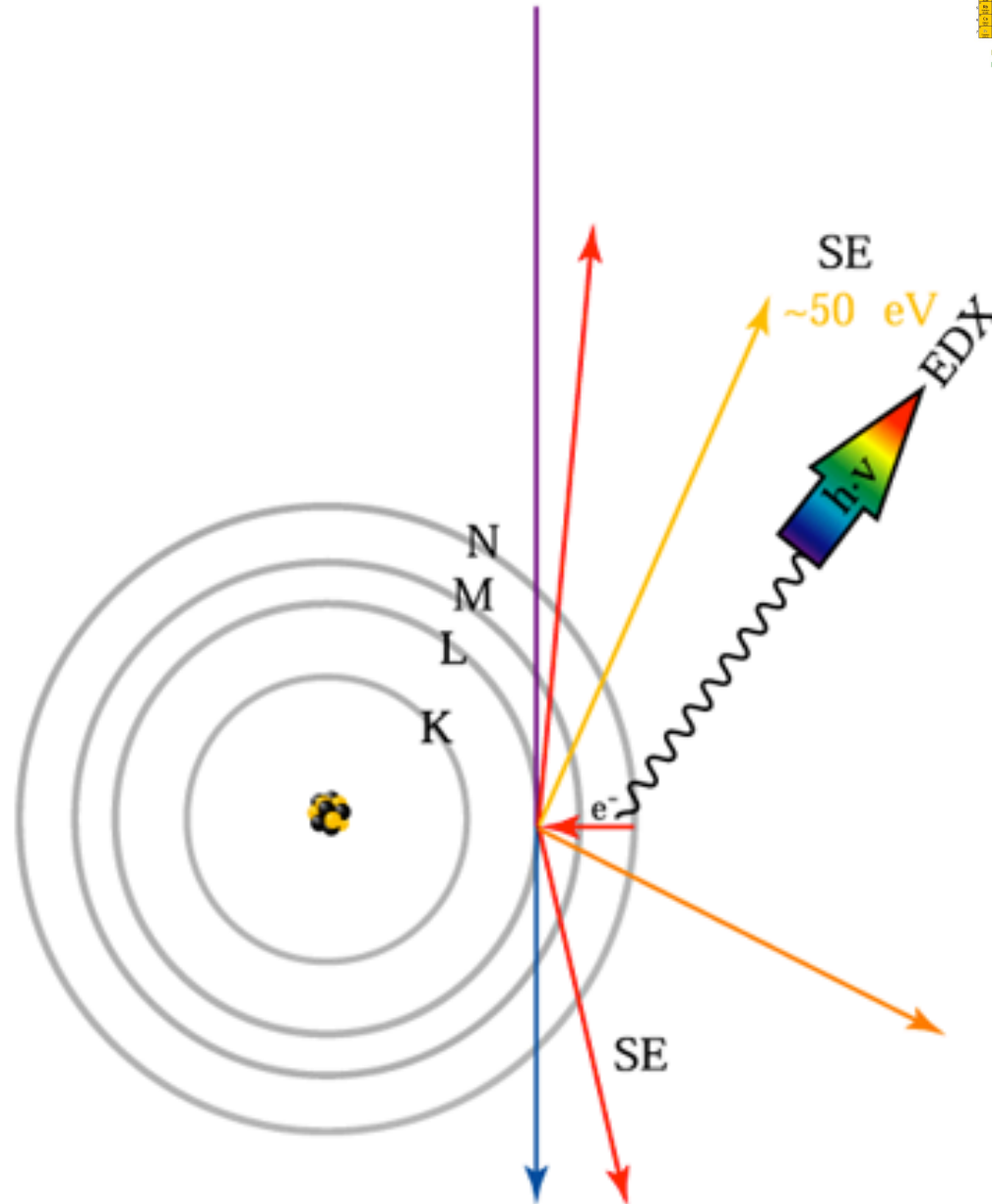
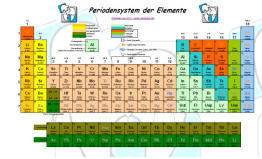
15 keV



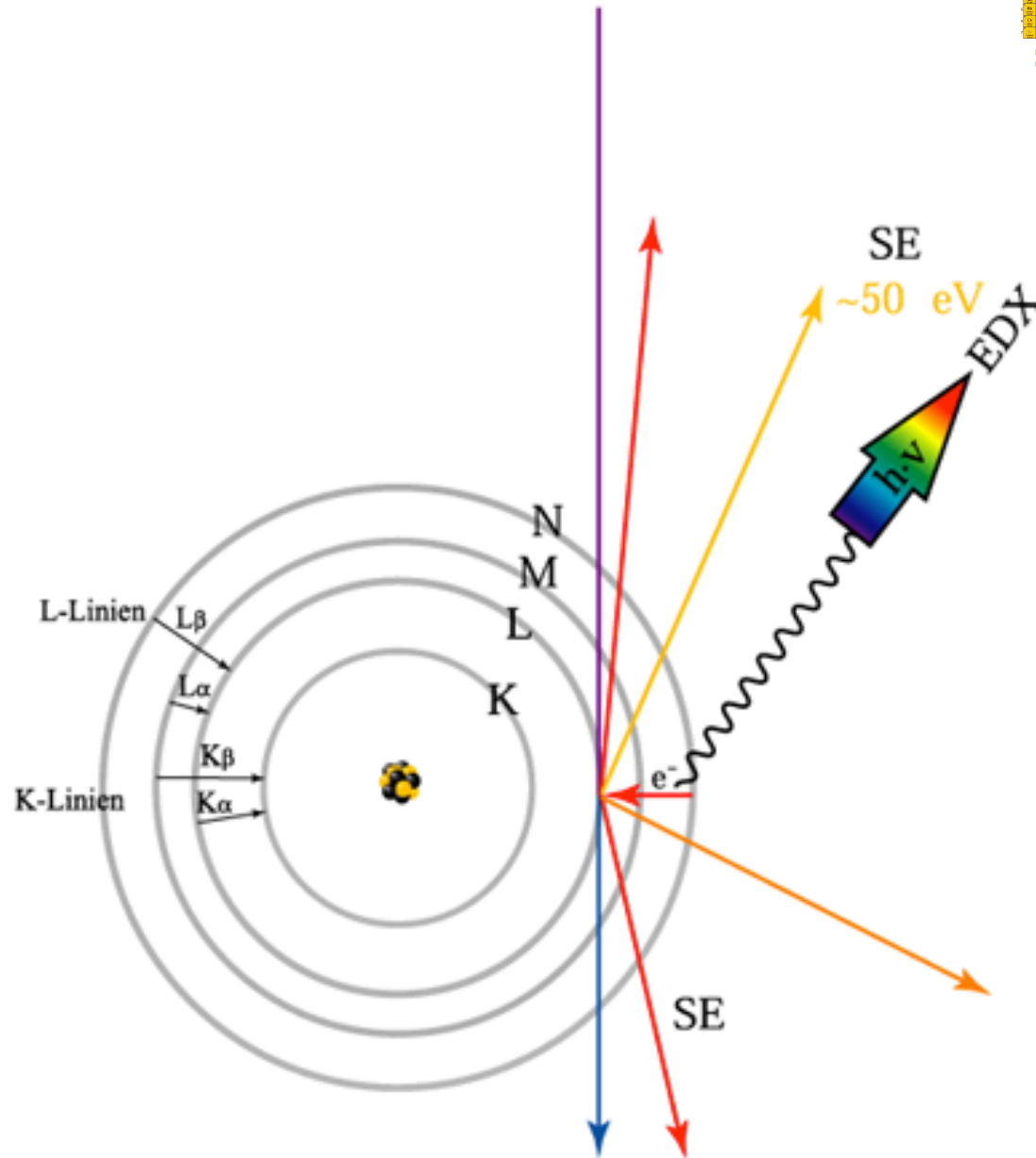
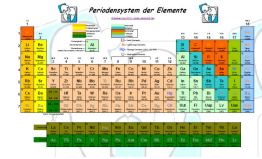
Primary beam
15 keV



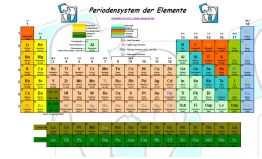
Primary beam
15 keV



Primary beam
15 keV



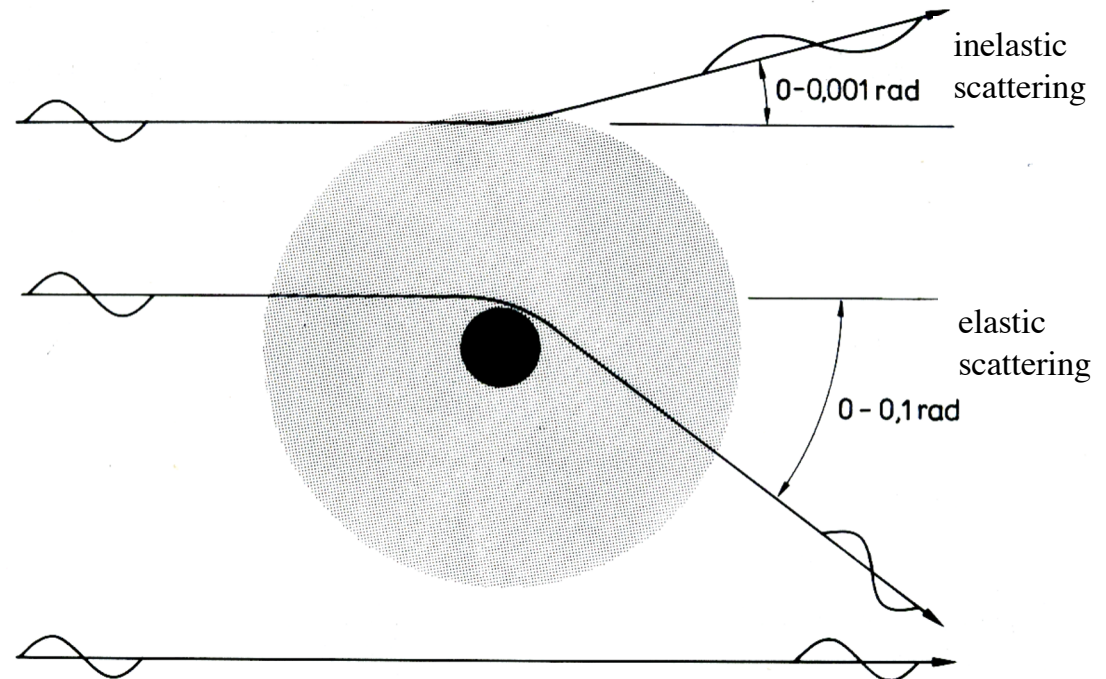
Scattering: With or without energy loss

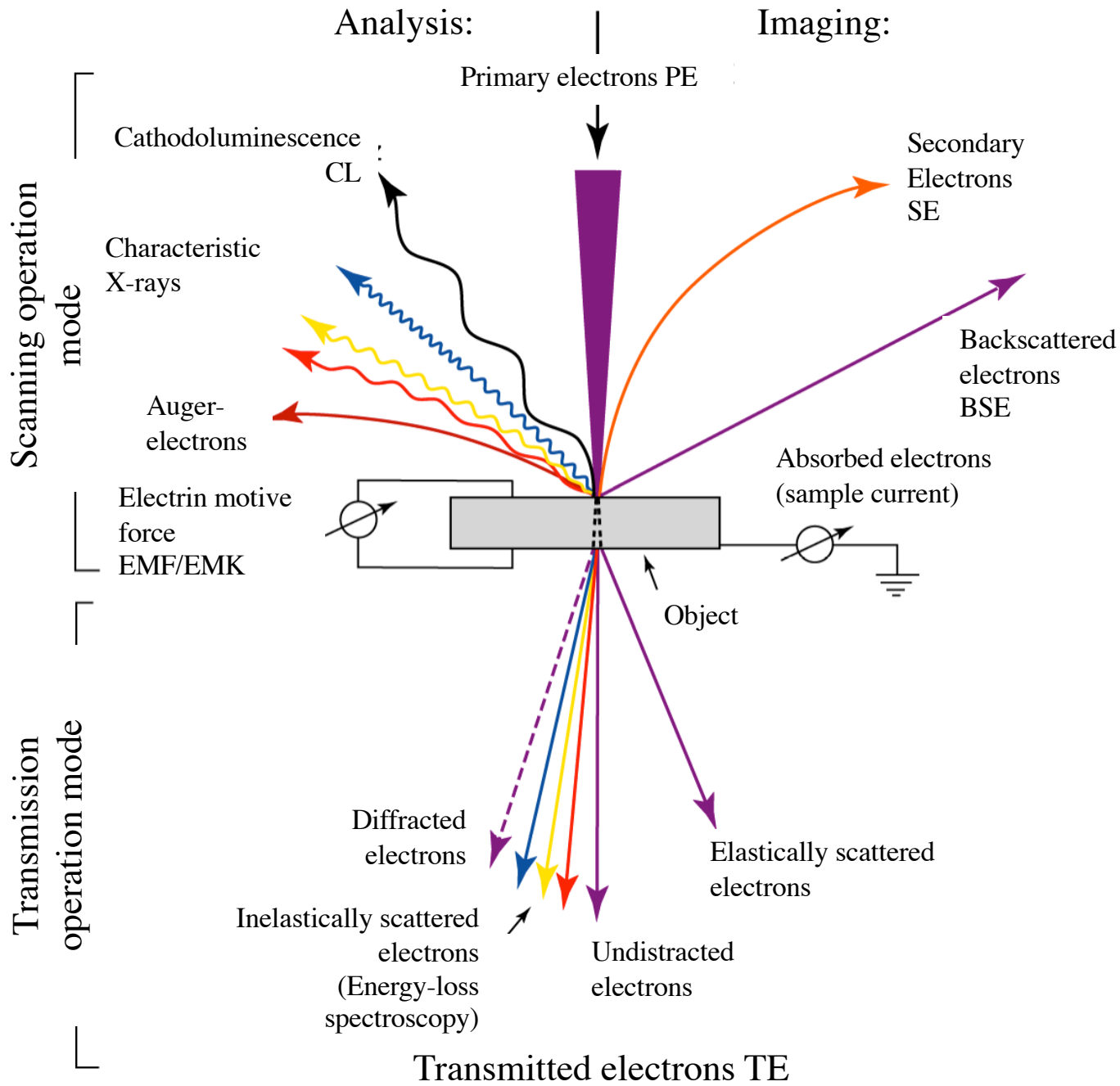


- Interaction of electrons with sample atoms

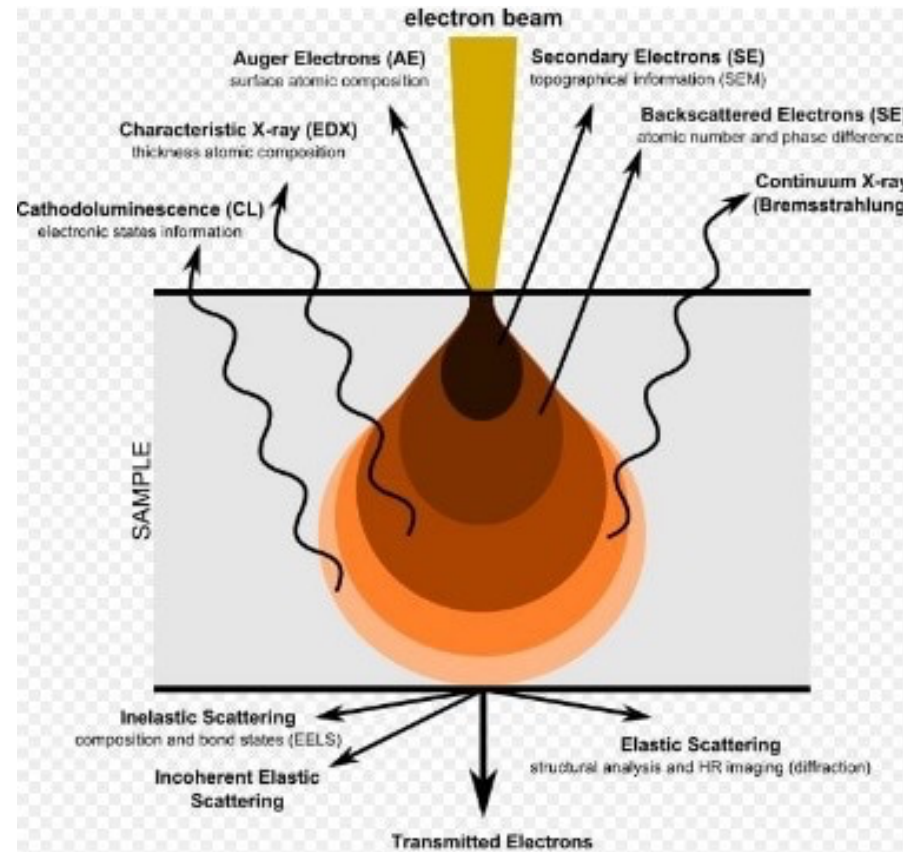
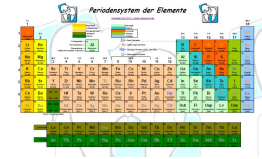
- elastic scattering
(nucleus – electron)
no energy exchange
scattering angle $> 10^{-1}$

- inelastic scattering
(electron – electron)
energy loss
scattering angle very small : $10^{-3} - 10^{-5}$



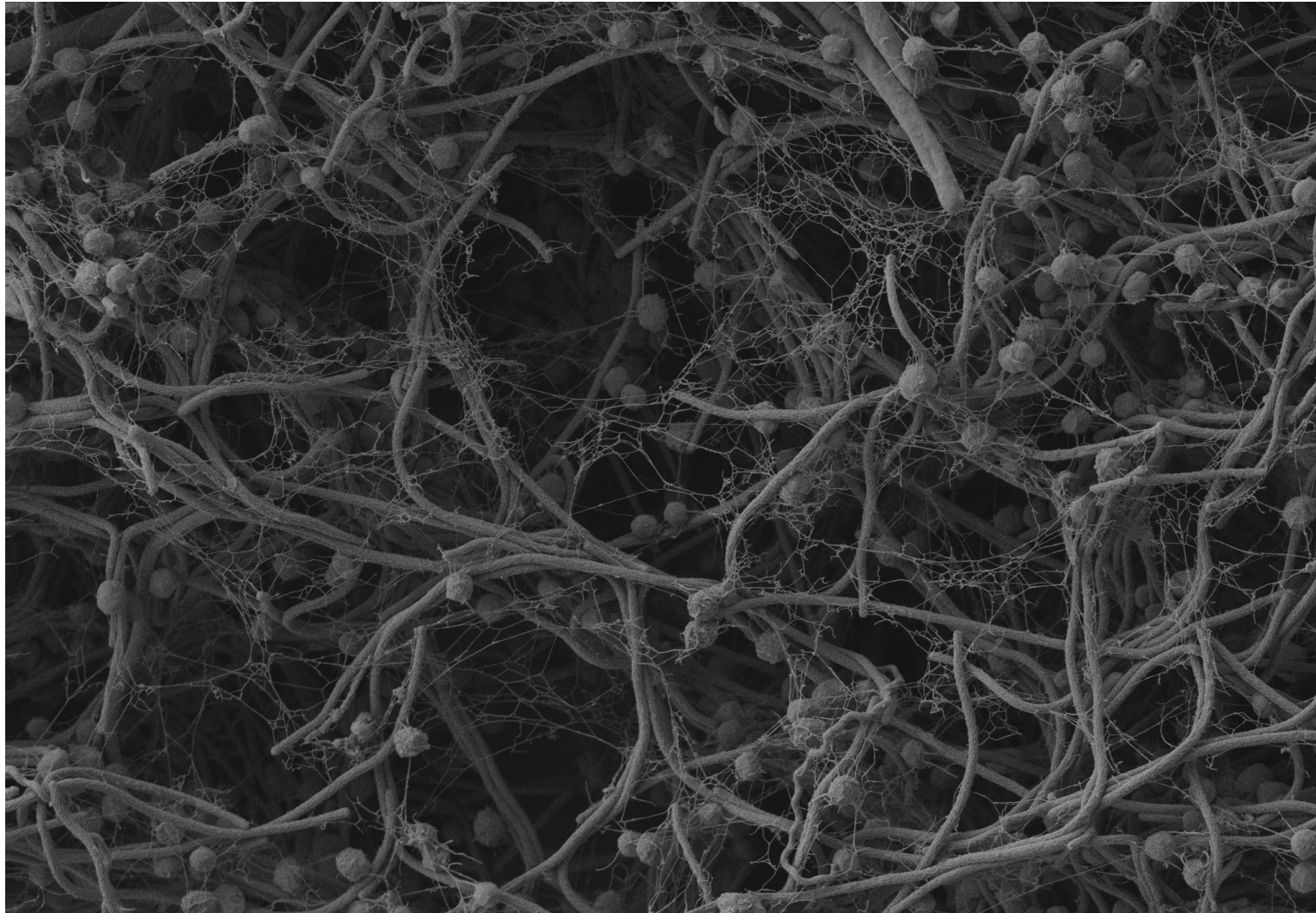
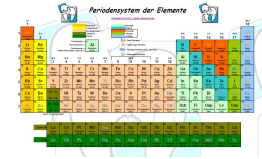


Origin of signals in the SEM



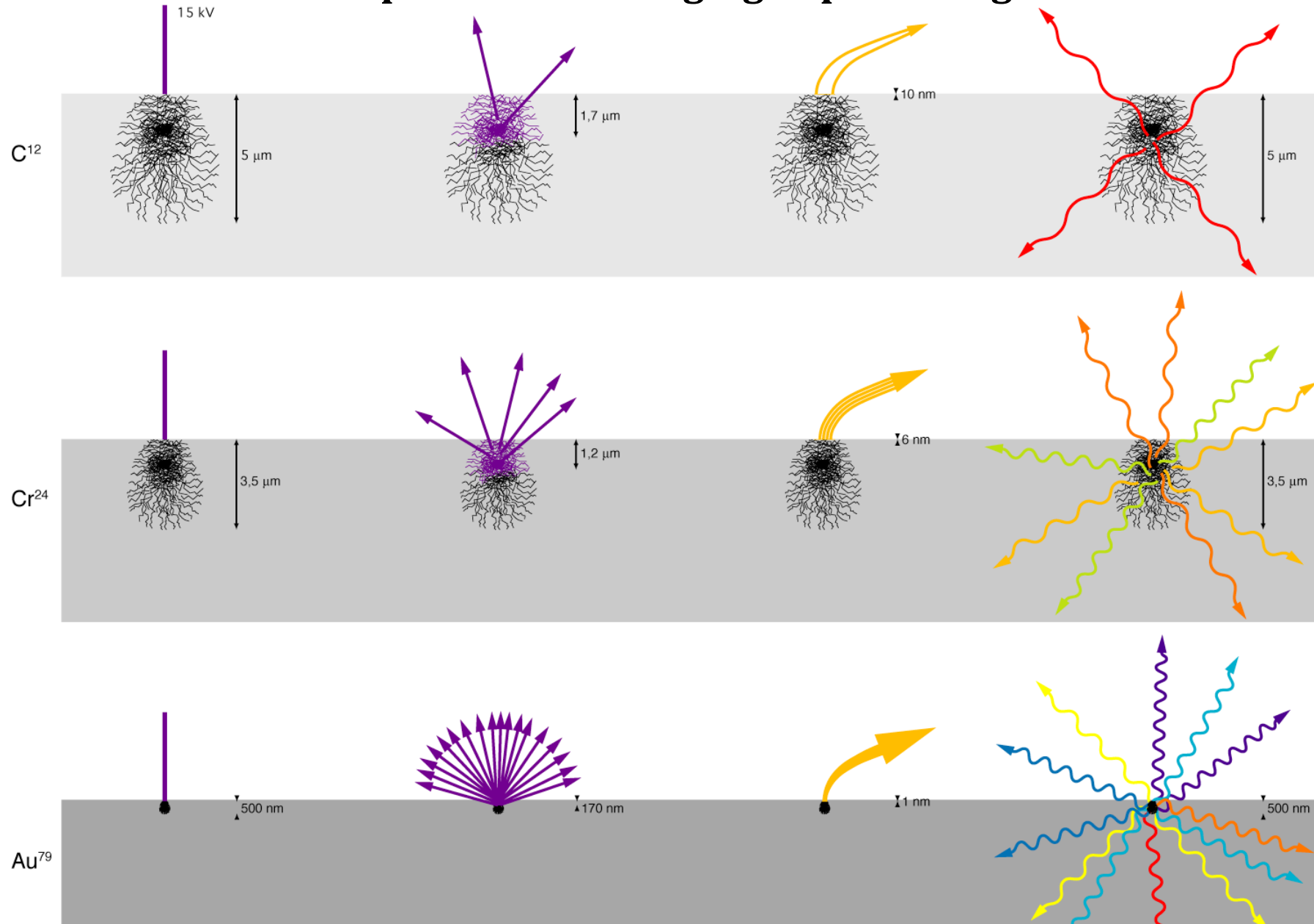
<https://www.thermofisher.com/blog/microscopy/wp-content/uploads/sites/12/2019/11/electron-matter-interaction-volume.jpeg>

„Image formation“ in the SEM

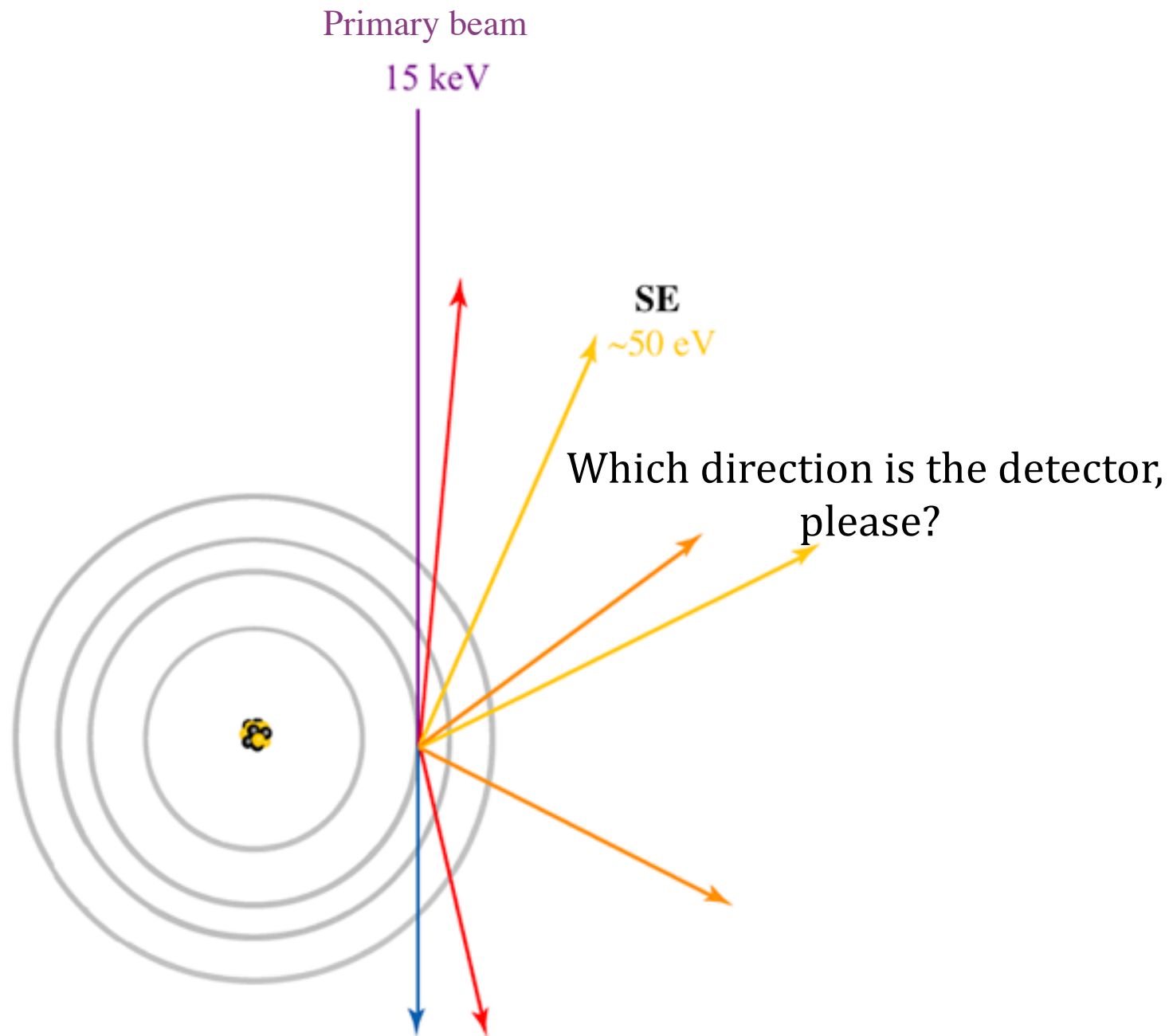


FIB Imaging = SEM Mag = 4.63 K X Stage at R = 347.8 ° ESB Grid = 500 V Signal A = SE2 Noise Reduction = Pixel Avg. FIB Probe = 30KV:50 pA
Aperture Size = 10.00 µm Scan Speed = 9 EHT = 1.50 kV Mixing = Off Tilt Angle = 36.0 ° FIB Tracking WD = Off
High Current = Off 1 µm WD = 5.1 mm Mix Signal = 0.5461 Stage at T = 0.0 ° FIB Track WD Delta = 0.00 nm
Date :27 Mar 2018

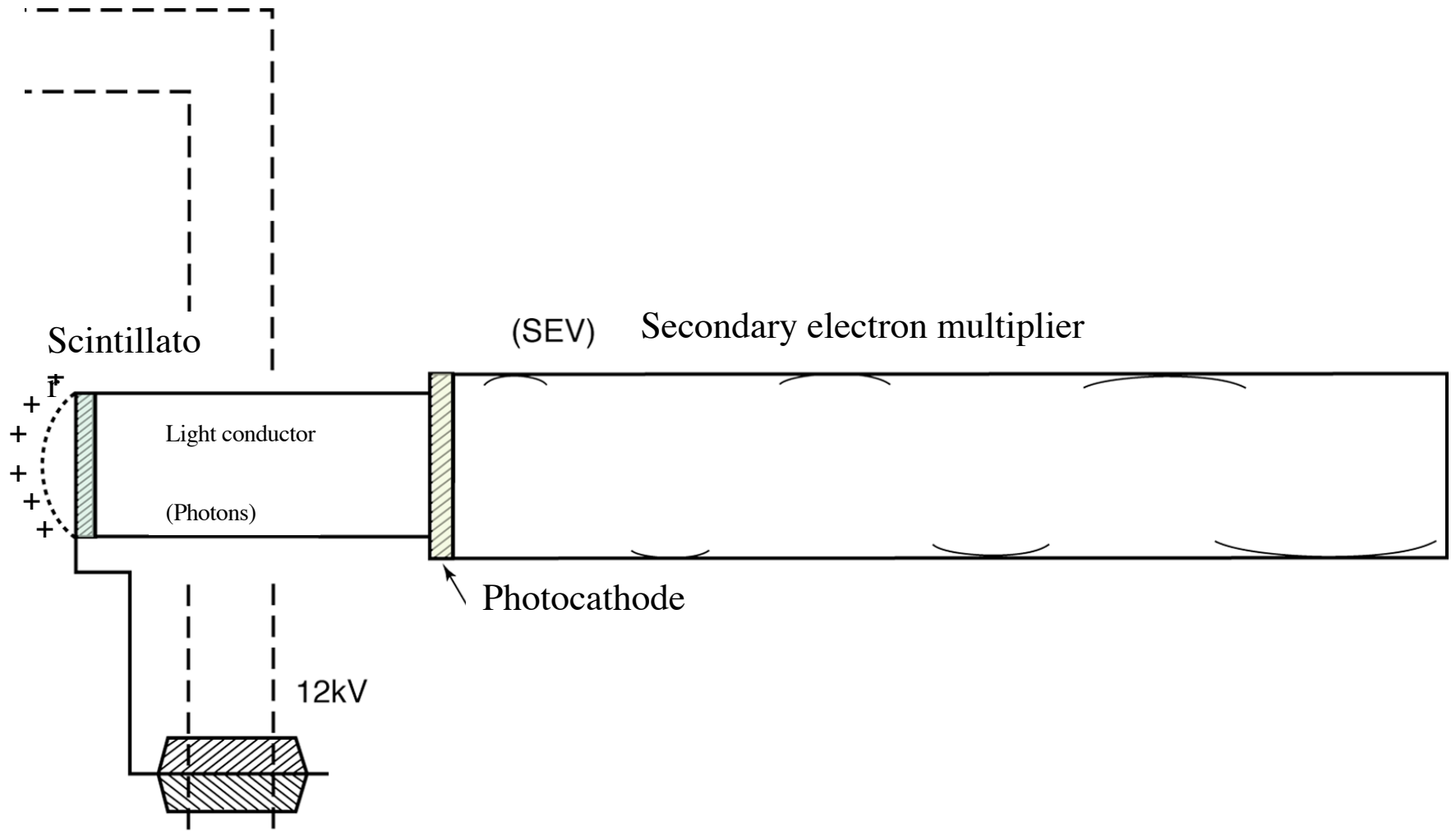
Comparison of emerging depths of signals

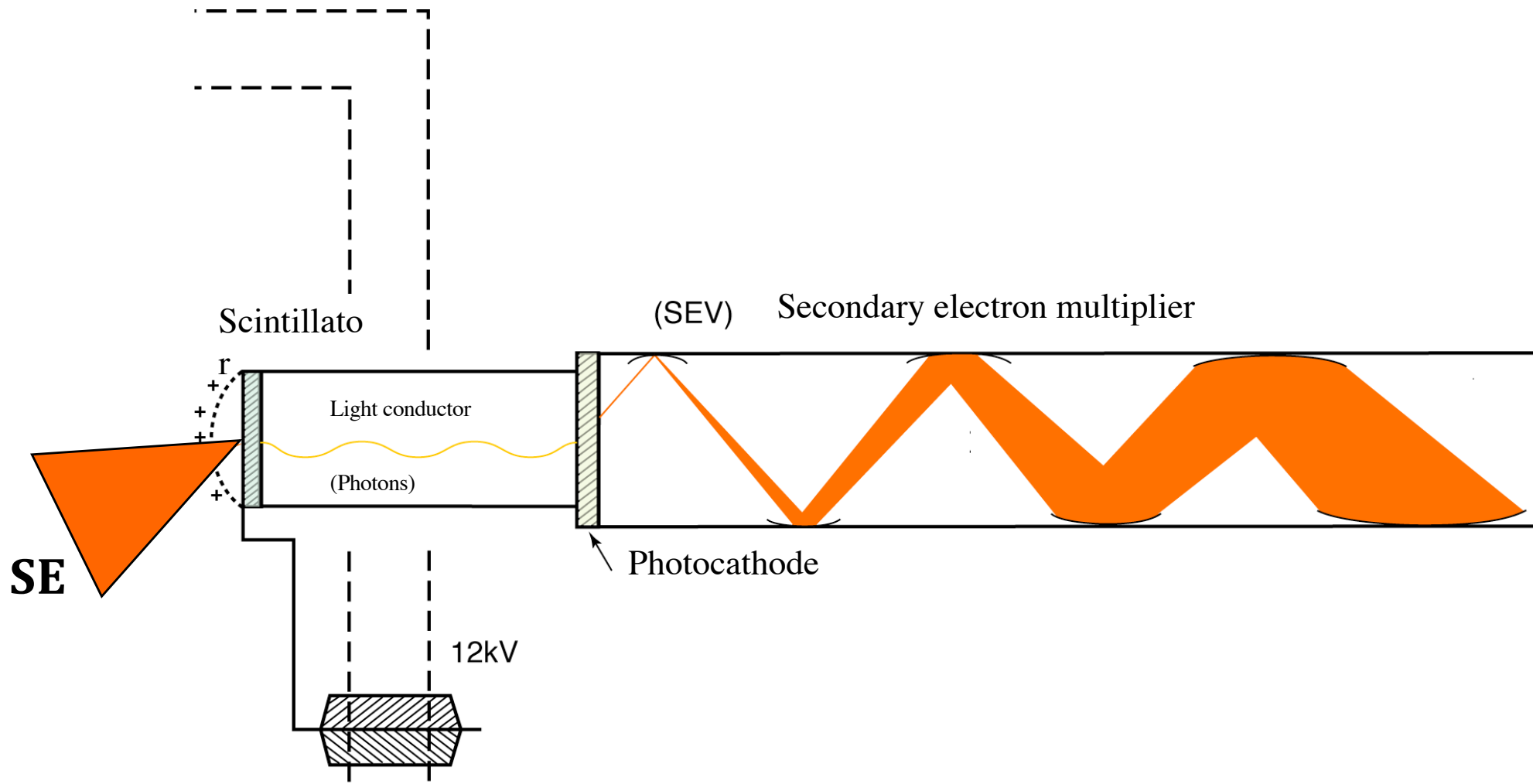


From the electron beam to the SE-image

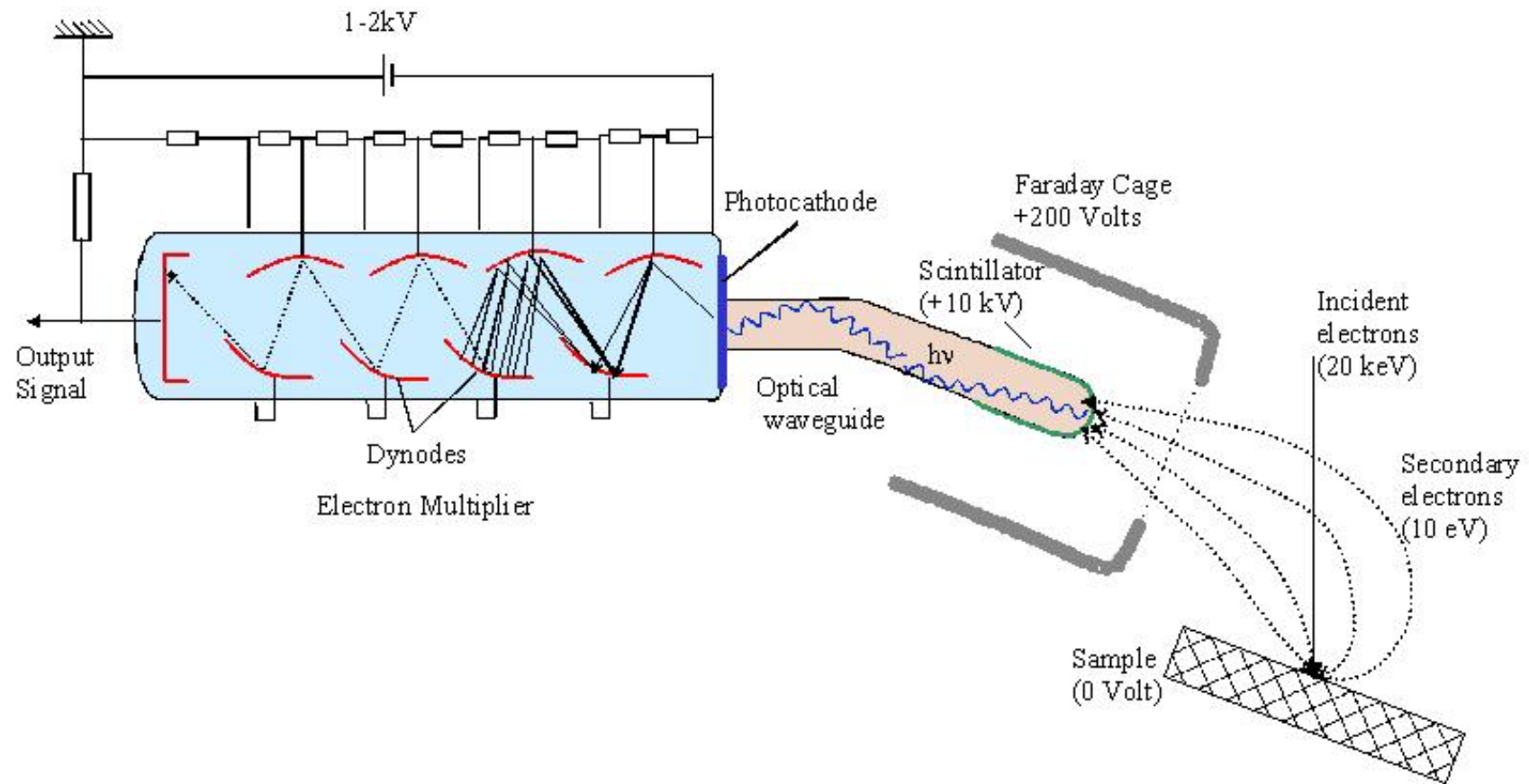


Secondary electron detector

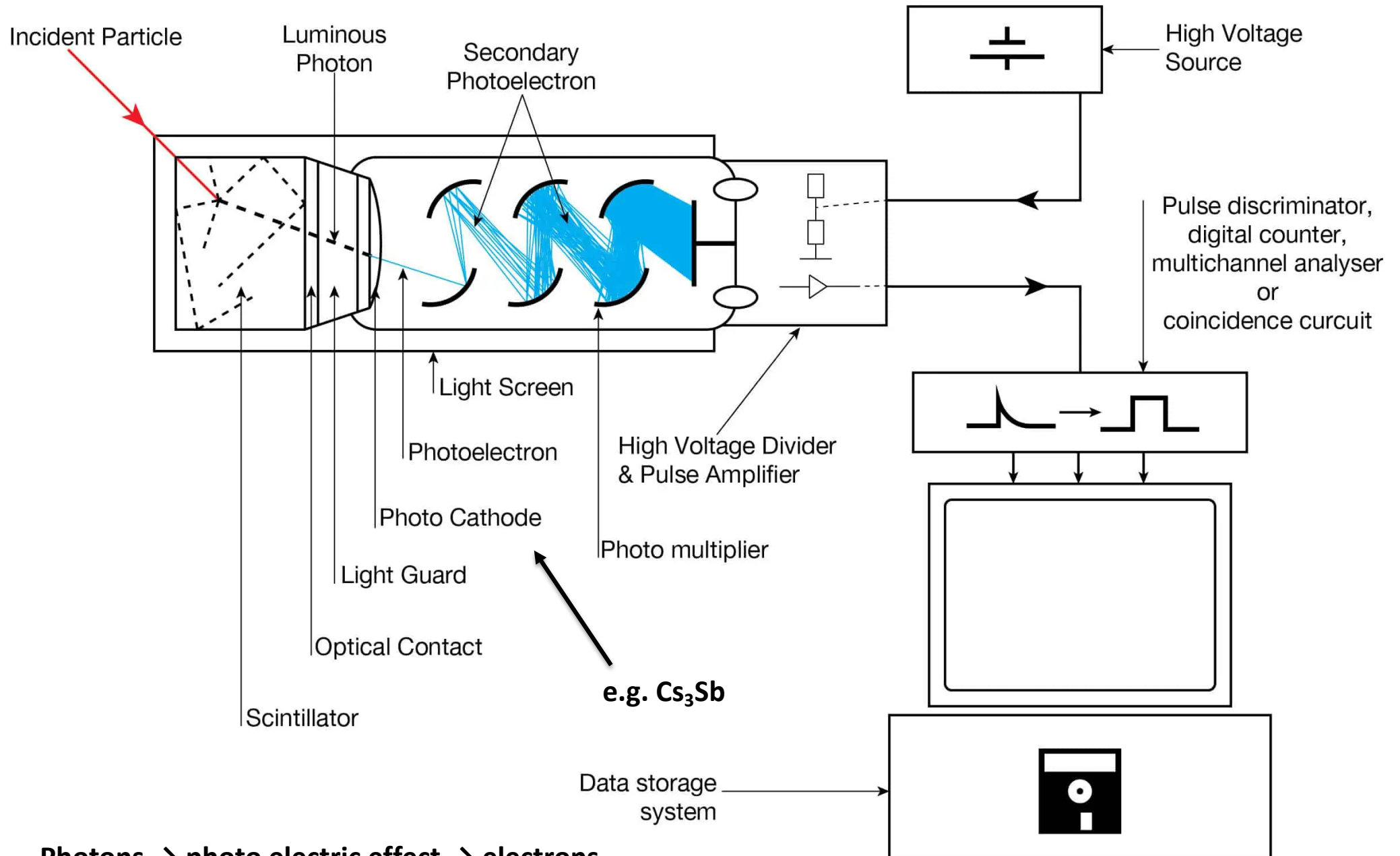




Everhart-Thornley-detector

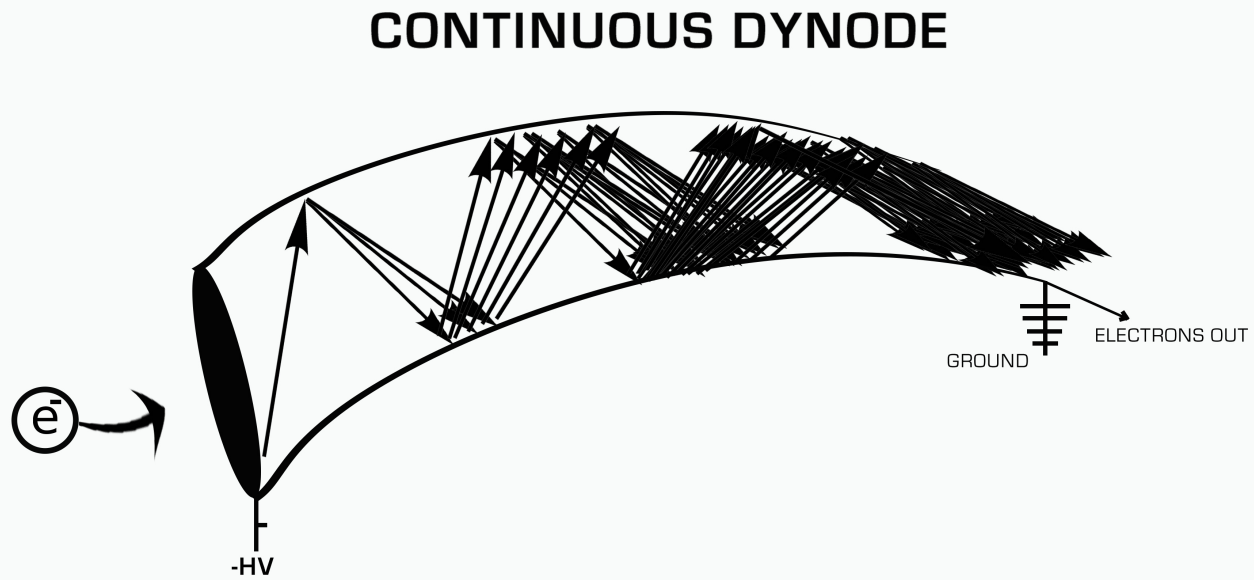
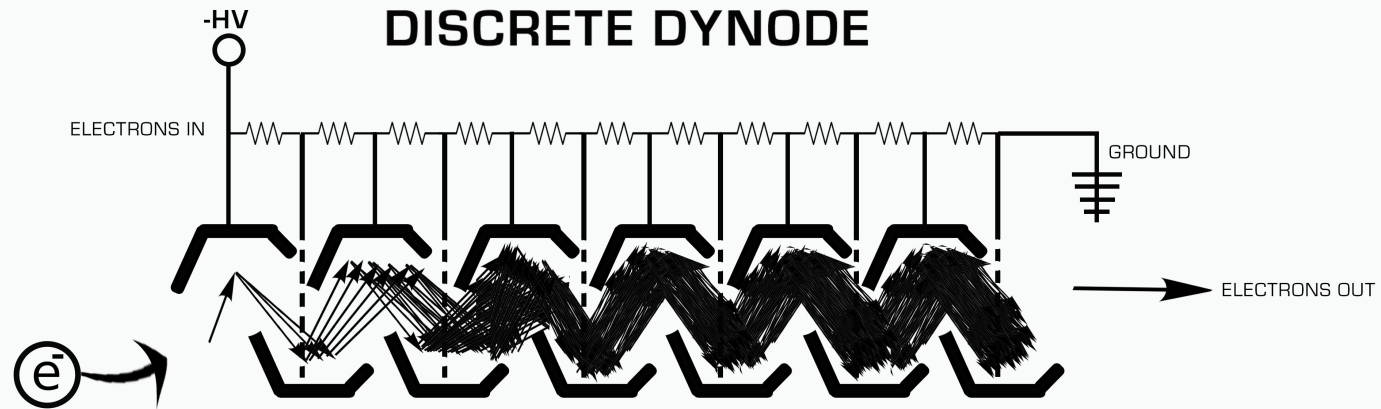


SE-detector: photo cathode

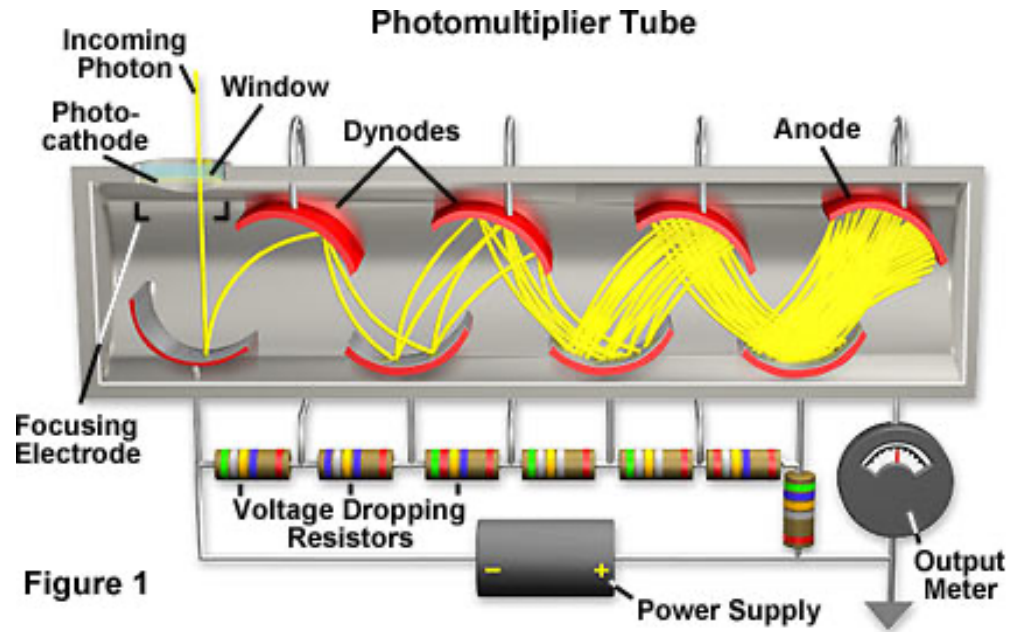


Photons → photo electric effect → electrons

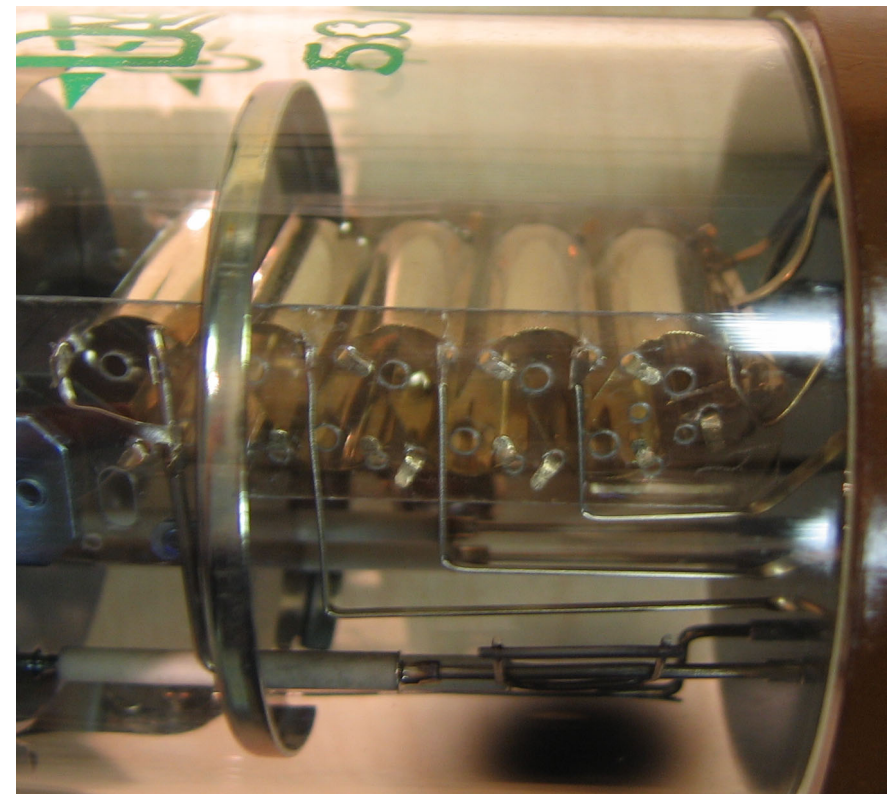
Dynodes



Dynodes

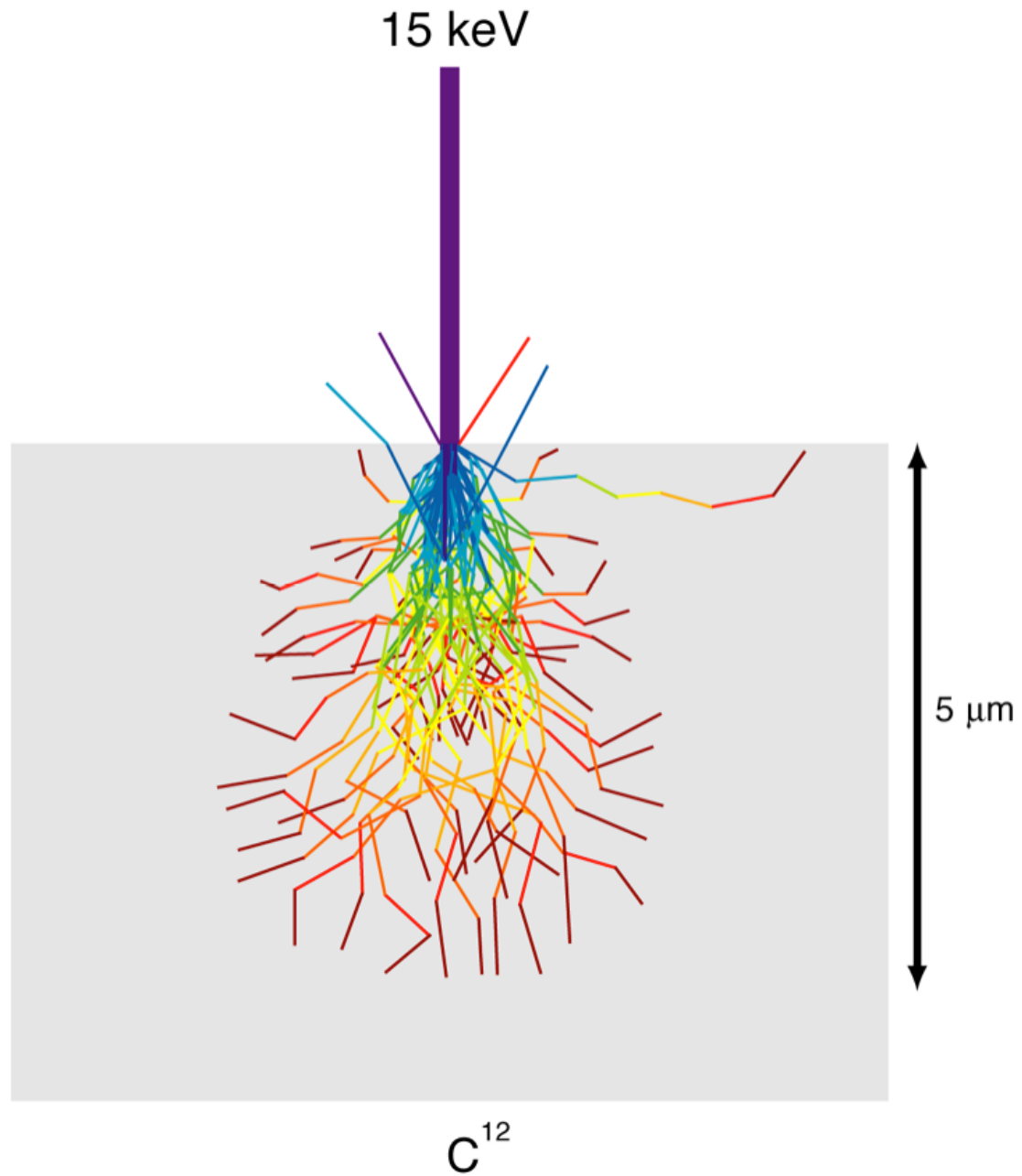


<https://www.olympus-lifescience.com/de/microscope-resource/primer/digitalimaging/concepts/photomultipliers/>

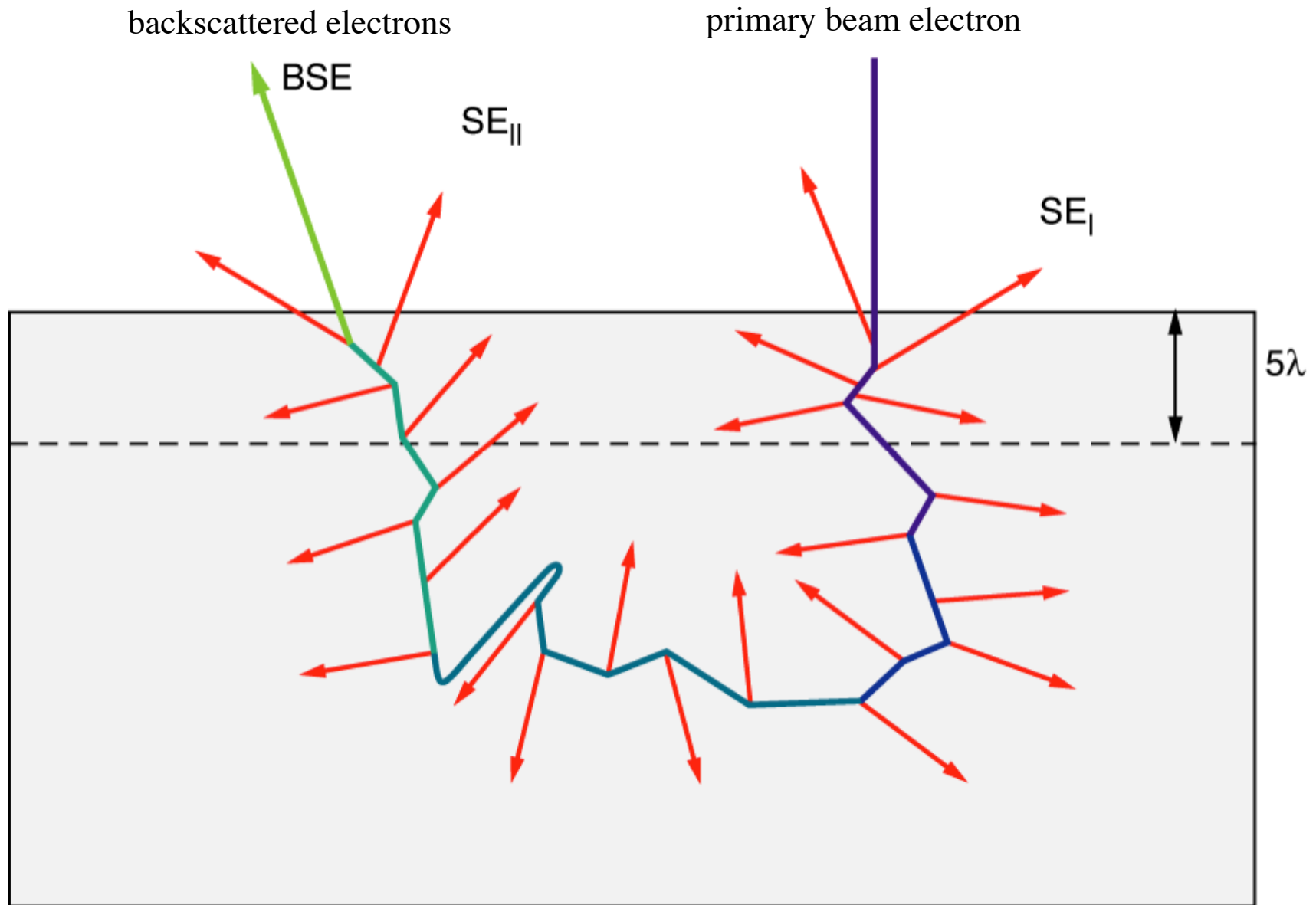


<https://de.wikipedia.org/wiki/Dynode>

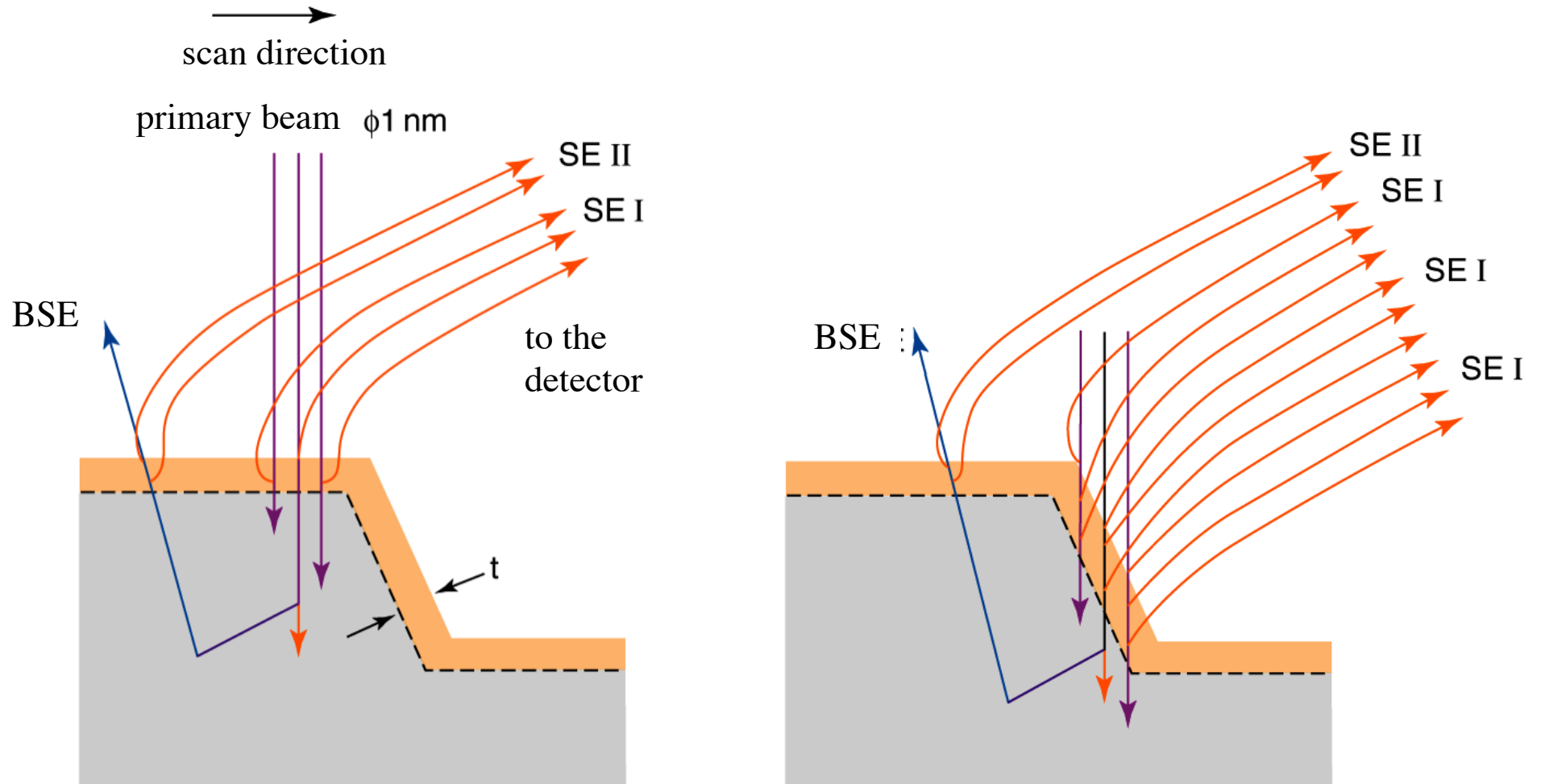
The path of primary/secondary electrons



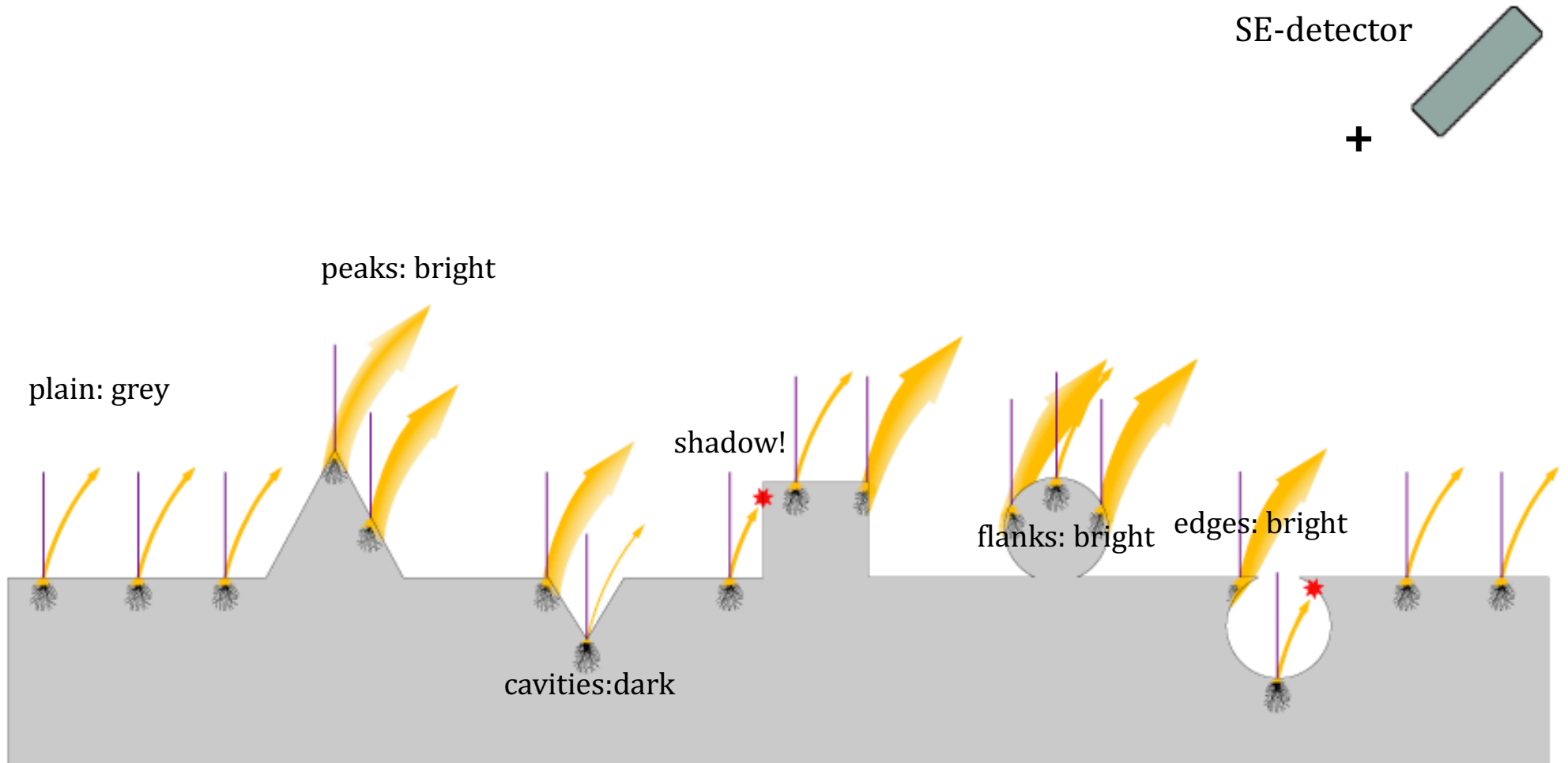
SE I - SE II - BSE



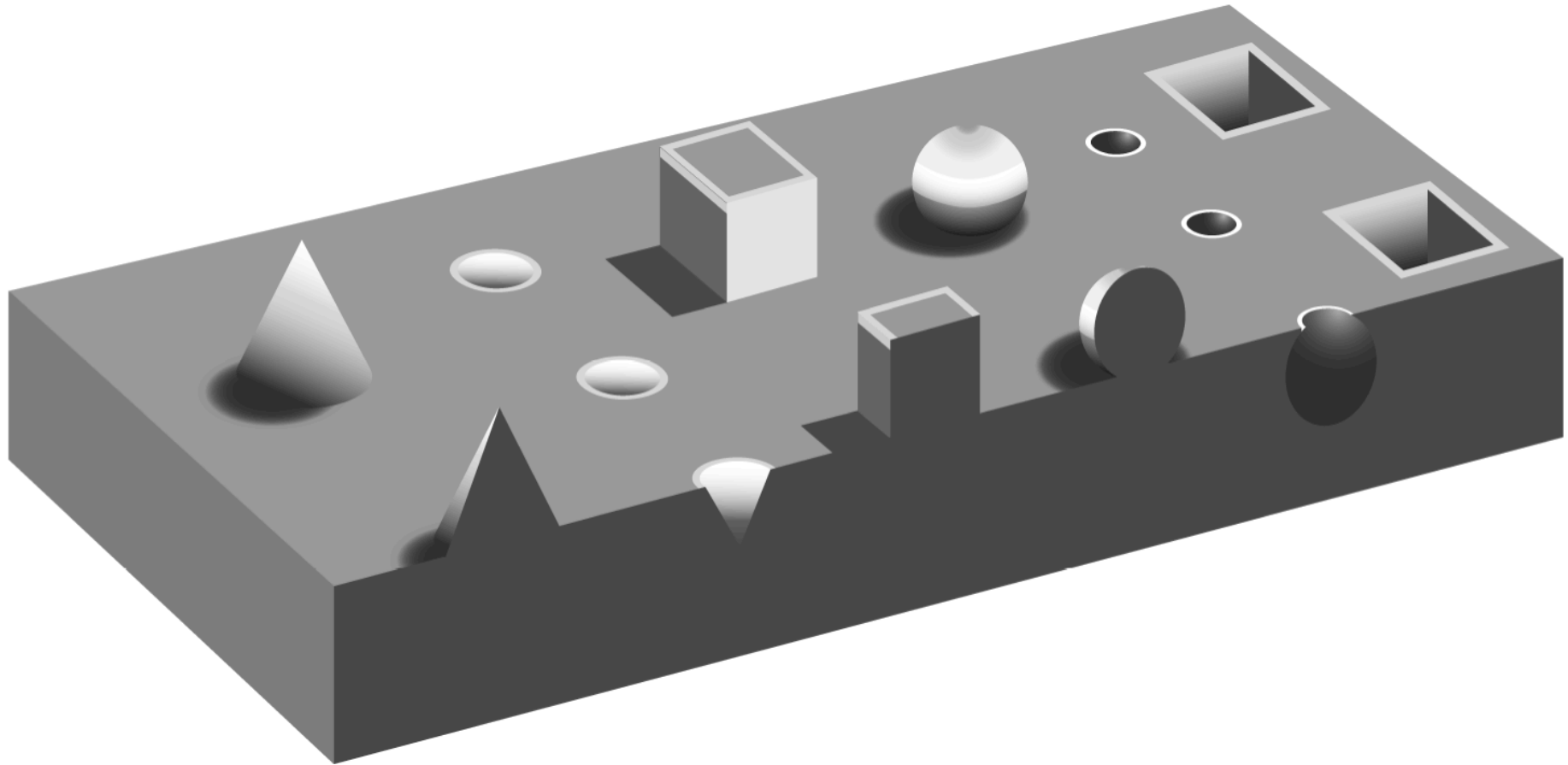
SE: „from plain to incline“



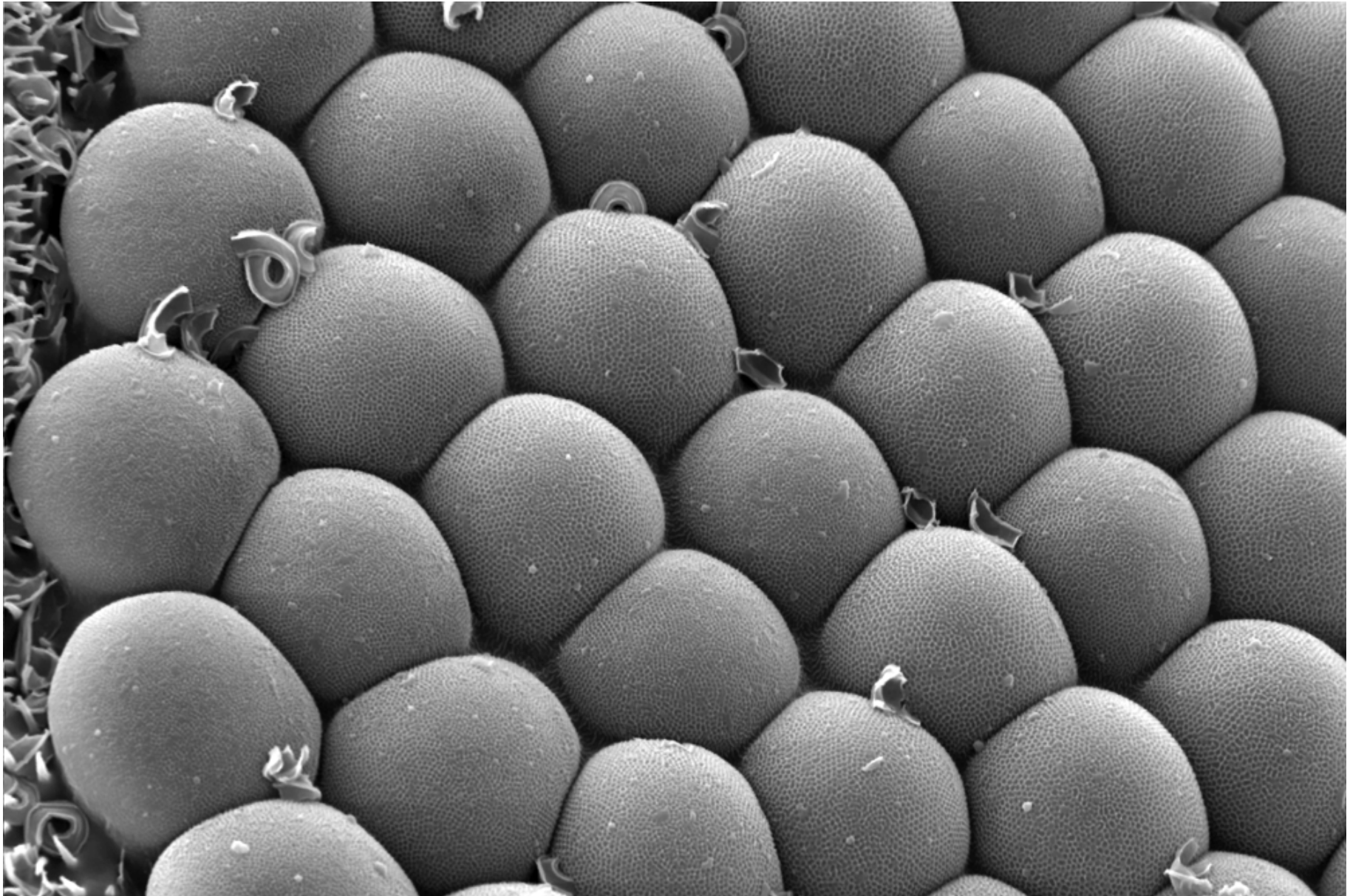
Getting into the 3rd dimension using the “topography contrast”



Topography contrast



Topography contrast



Resolution: why is the cathode type and beam diameter so important?



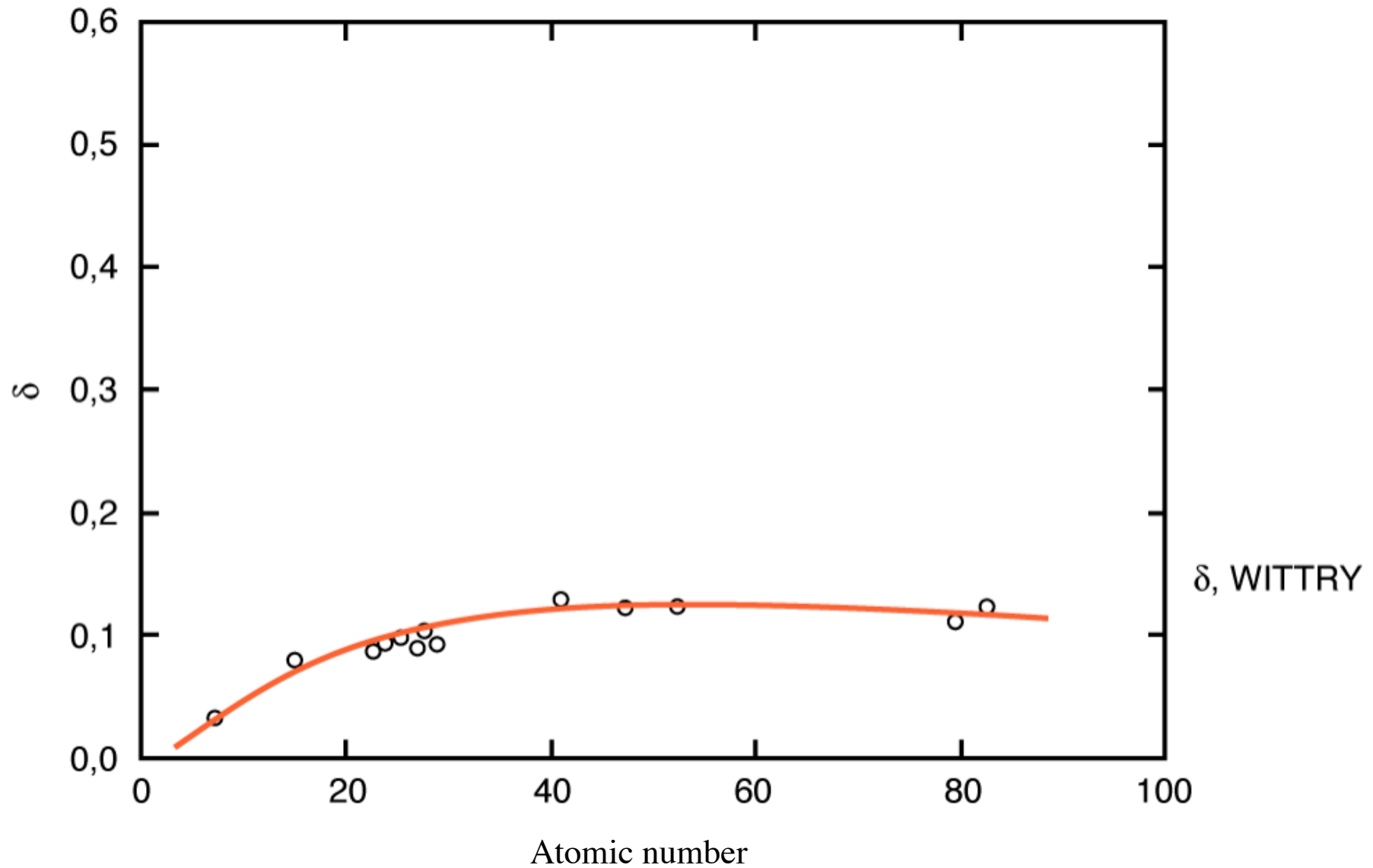
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Resolution: why is the cathode type and beam diameter so important?

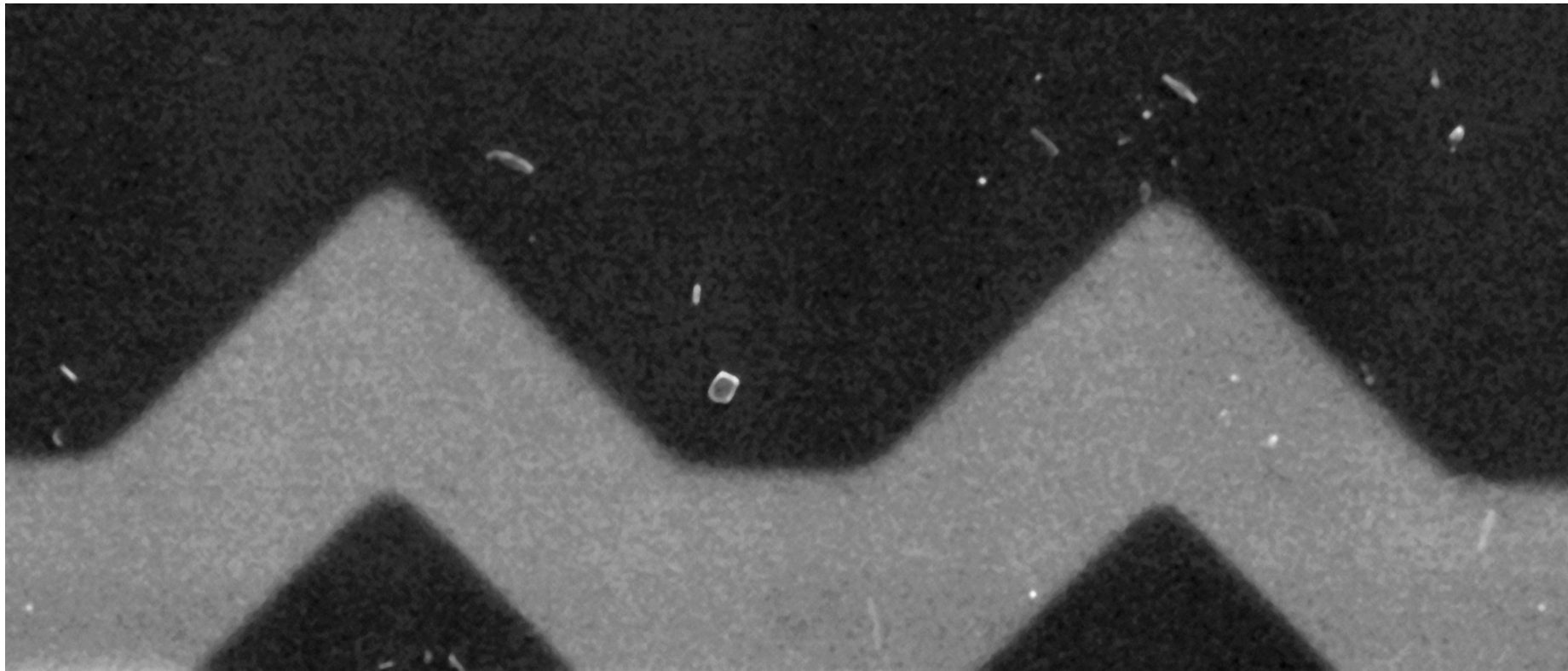
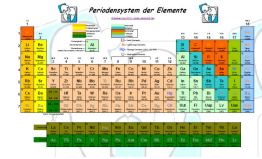


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Atomic number and SE-yield

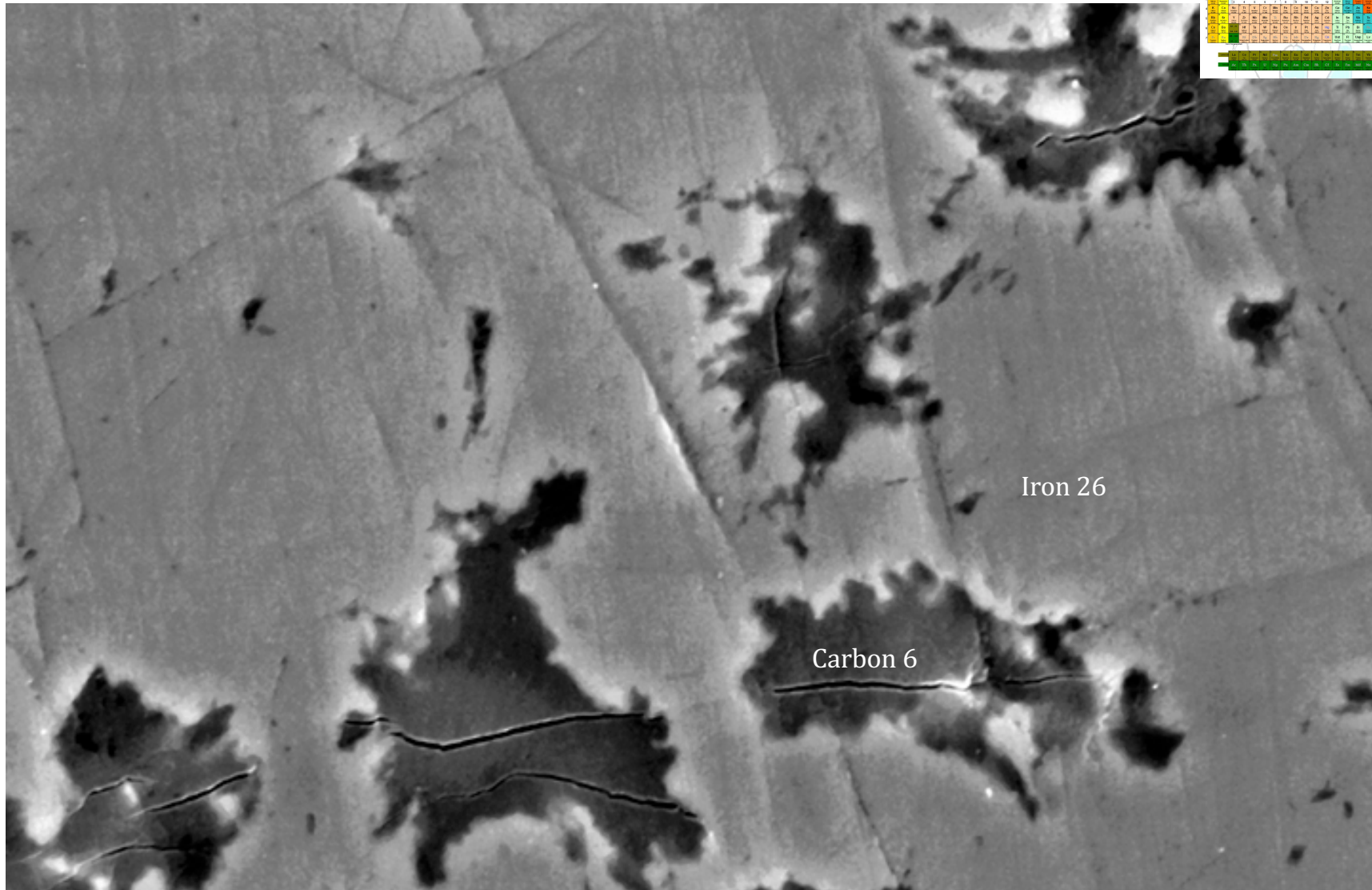
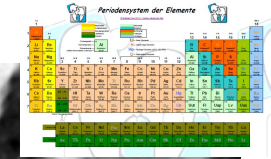


Material contrast



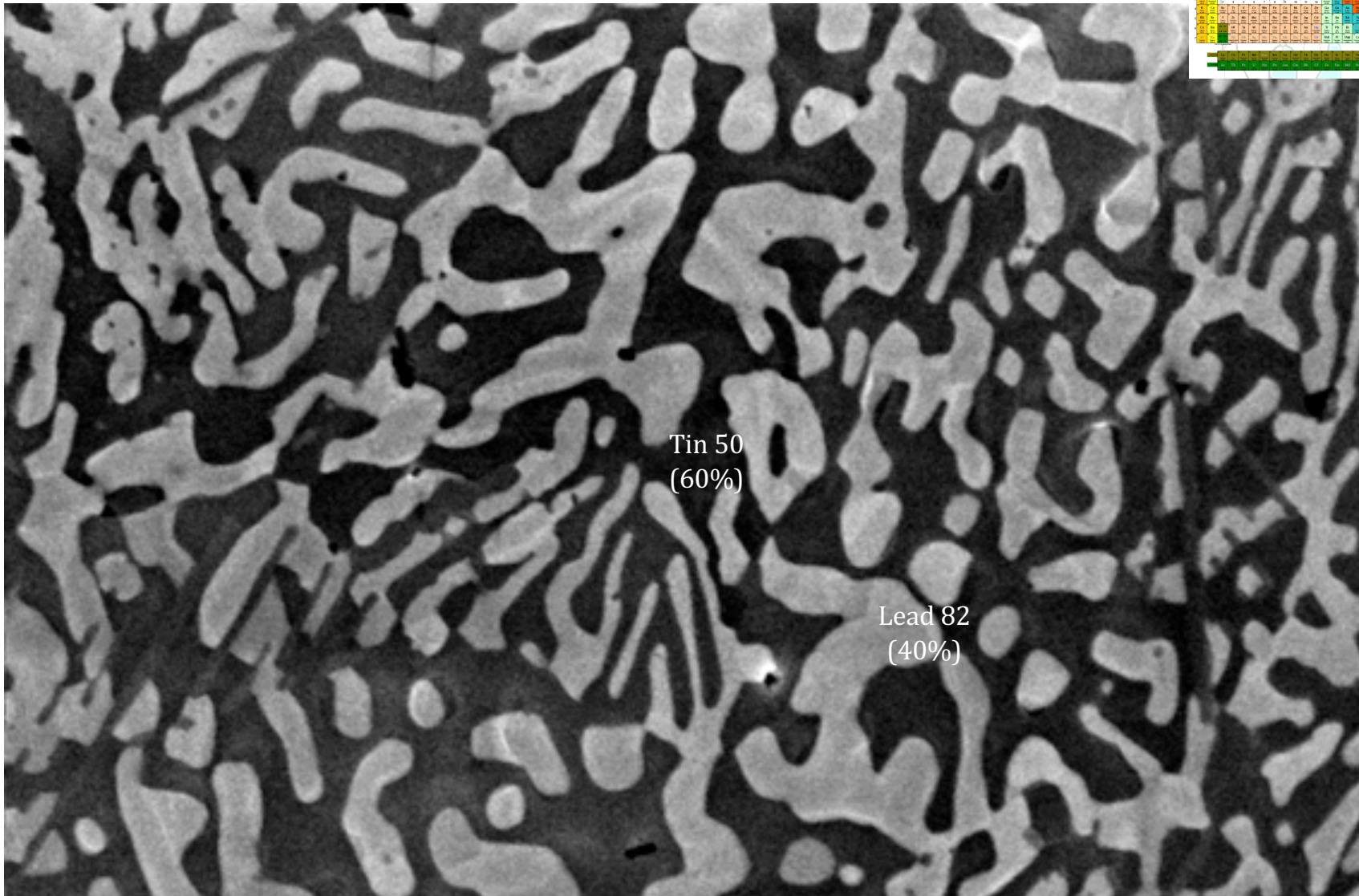
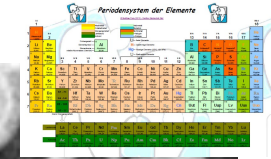
SE-image (8 kV) smooth surface of a semiconductor

Material contrast



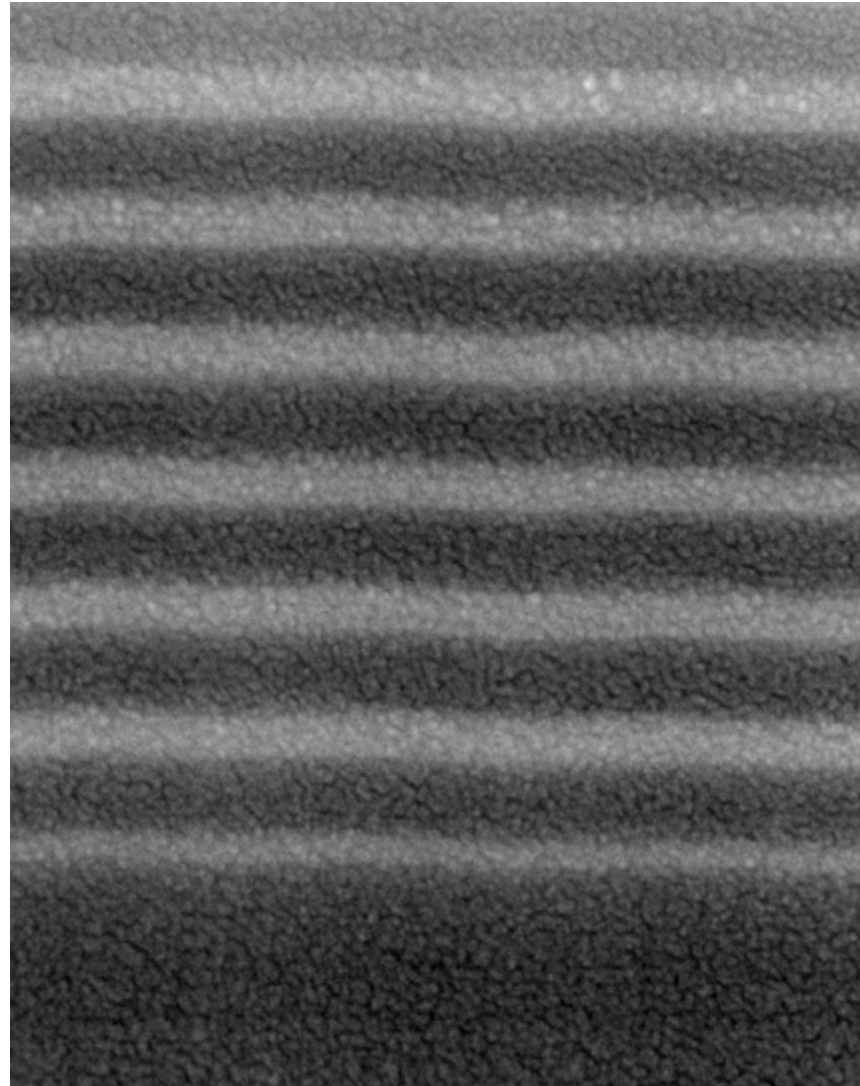
SE-image (10 kV) smooth surface of an old kitchen knife

Material contrast



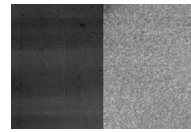
SE-image (8 kV) smooth surface of tin-solder/brazing solder

Material contrast



SE-image (20 kV) fracture surface from glass with blooming in a layer sequence

Material contrast or „micro roughness“



2 different materials?

