Pozytony - narzędzie badań strukturalnych

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Positron identity

e^+ is antiparticle of e^- :

- mass 511.003 keV/c^2
- spin ½
- opposite Q
- opposite μ_B
- stable in vacuum ($>2\times10^{21}$y)

Ps is light H :

- Energy E= ½ Ry
- p-Ps: τ=125 ps, 2γ
- o-Ps: τ=142 ns, 3γ

One of Anderson's (1933) original photographs illustrating the historic discovery of the positron. In the cloud chamber, there is a lead plate 6 mm thick and a magnetic field oriented in the page. The change of energy (63 MeV below the plate to 23 MeV above) with the known thickness of lead and magnitude of the field proves that the particle is positive and of the same mass as the electron.

Rev. Mod. Phys., Vol. 60, No. 3, July 1988

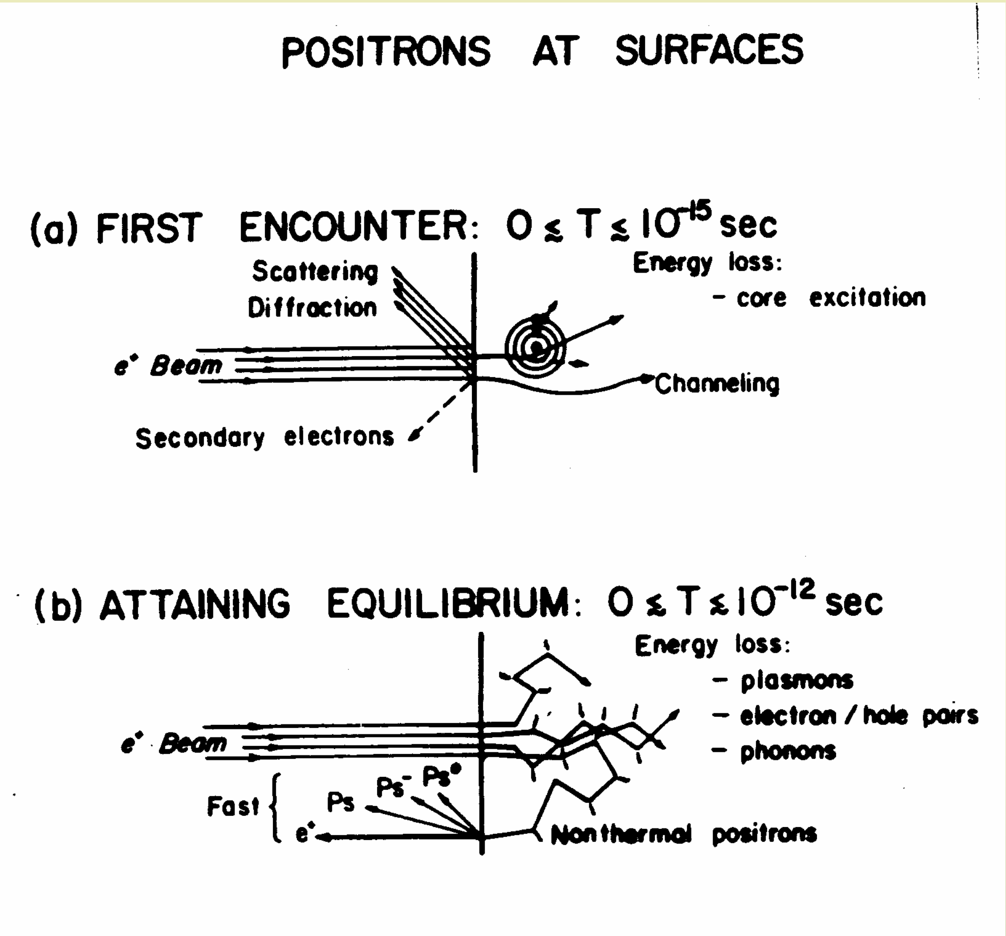
Positron history

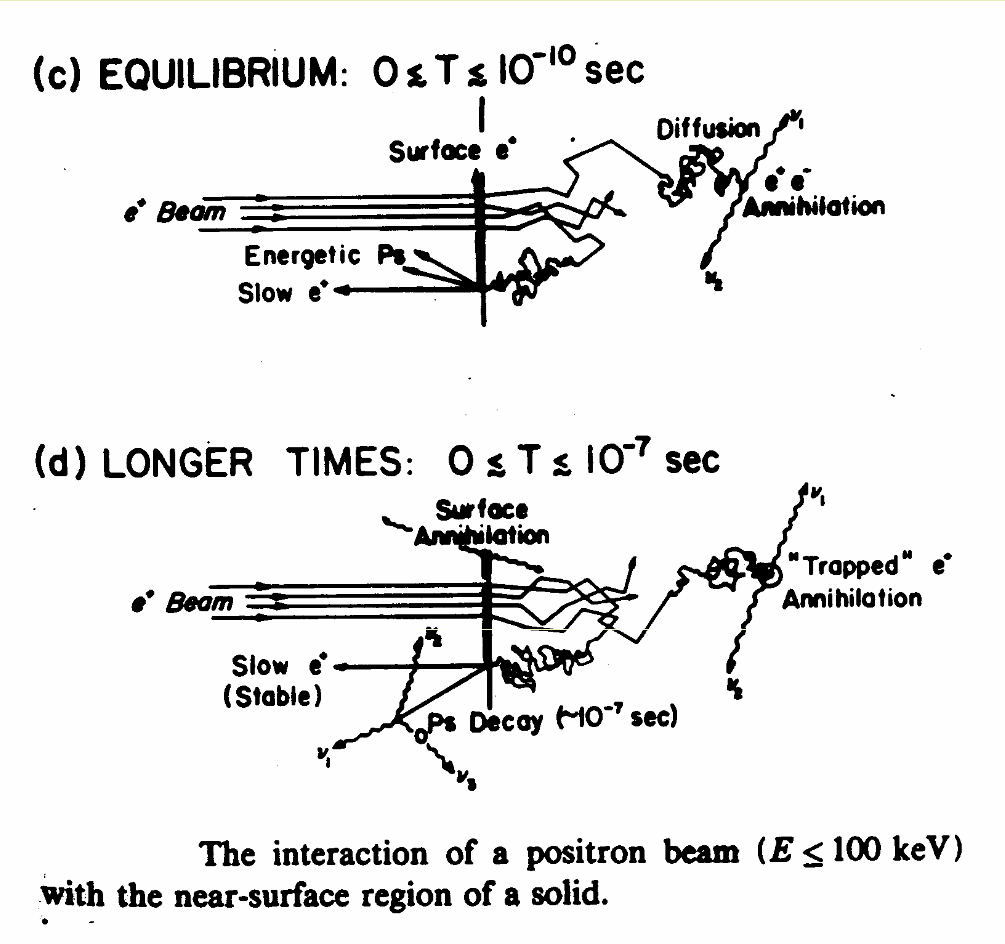
History of "slow" positrons

1930 – e^+ postulated by Dirac
1932 – discovered in cosmic rays
by Anderson
"out of 1300 photographs of cosmic tracks,
15 were od positive particles which could not
have a mass greater as that of the proton"

1950 – Madanski-Rasetti try to moderate
1951 – evidence of Ps atom (Deutsch)
1958 – moderated e^+ , $\varepsilon=3\text{x}10^{-8}$ (Cherry)
1979 – single crystal moderator (Mills)
1980 – brightness enhancement (Mills)

Positron slowing down

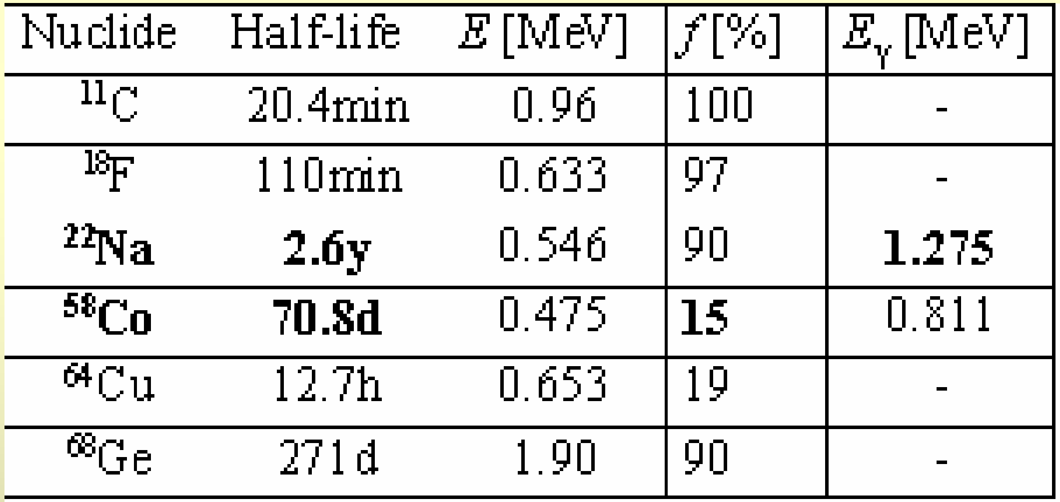




The interaction of a positron beam ($E \lesssim 100$ keV) with the near-surface region of a solid.

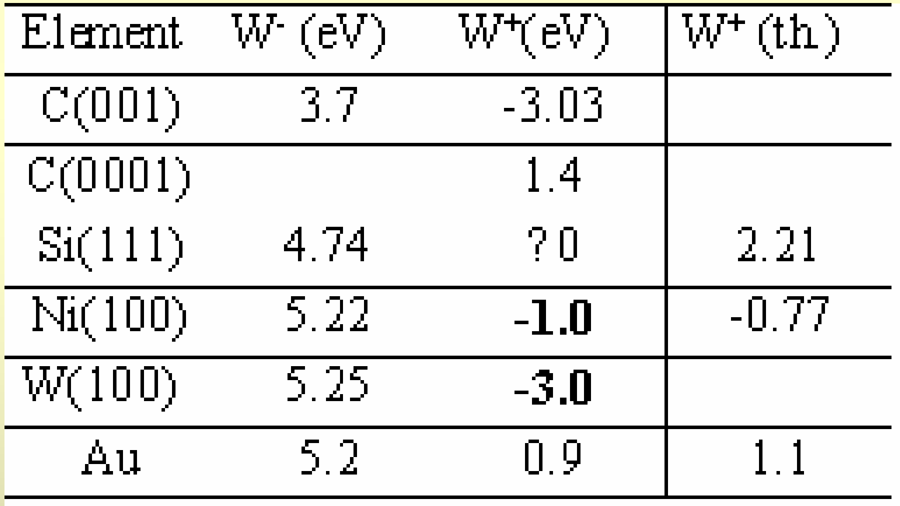
Positron sources

Radioactive nuclides



Nuclide	Half-life	E [MeV]	f [%]	E_γ [MeV]
^{11}C	20.4min	0.96	100	-
^{18}F	110min	0.633	97	-
^{22}Na	**2.6y**	0.546	90	**1.275**
^{58}Co	**70.8d**	0.475	**15**	0.811
^{64}Cu	12.7h	0.653	19	-
^{68}Ge	271d	1.90	90	-

Moderators

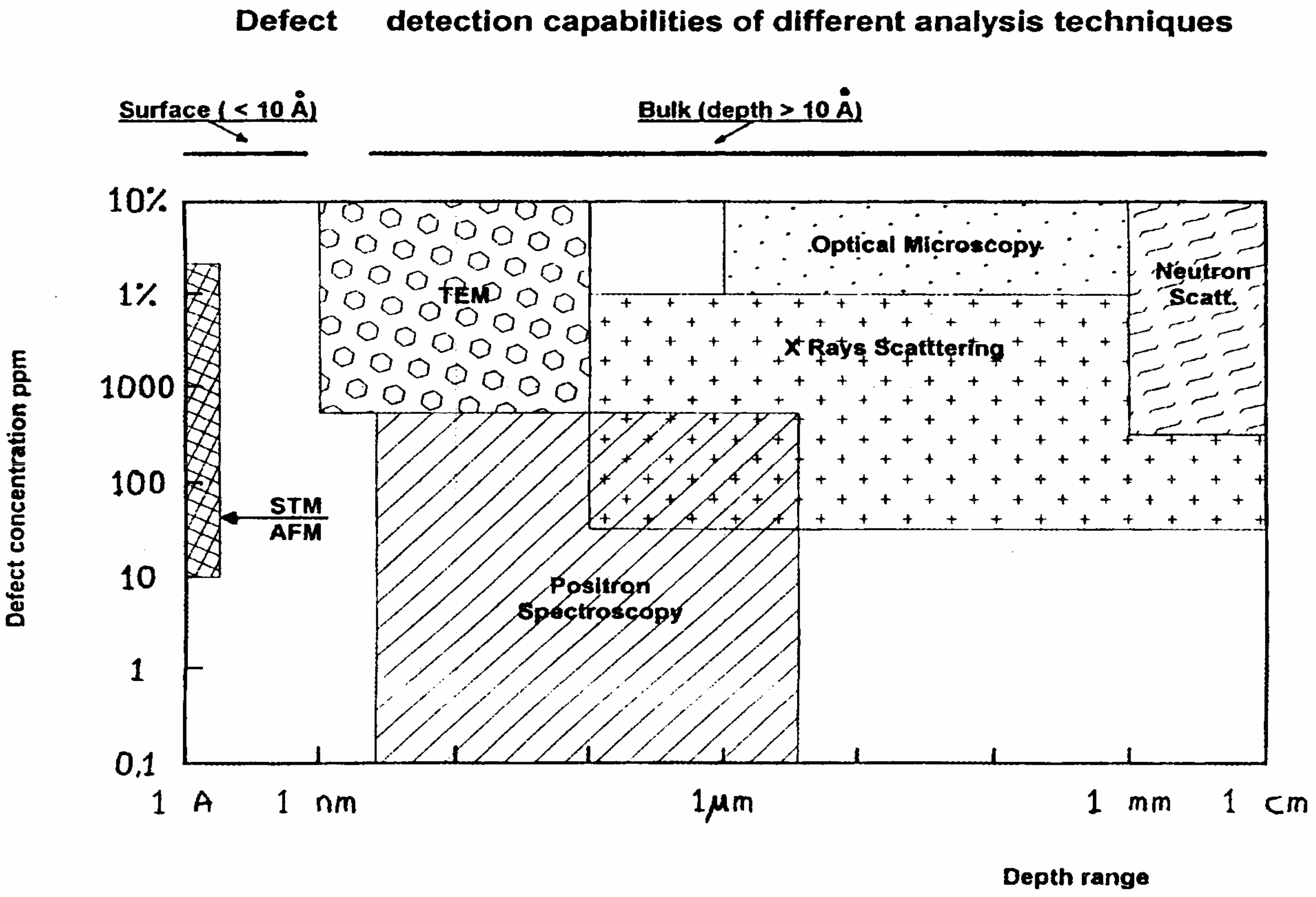


Element	W^- (eV)	W^+(eV)	W^+ (th)
C(001)	3.7	-3.03	
C(0001)		1.4	
Si(111)	4.74	? 0	2.21
Ni(100)	5.22	**-1.0**	-0.77
W(100)	5.25	**-3.0**	
Au	5.2	0.9	1.1

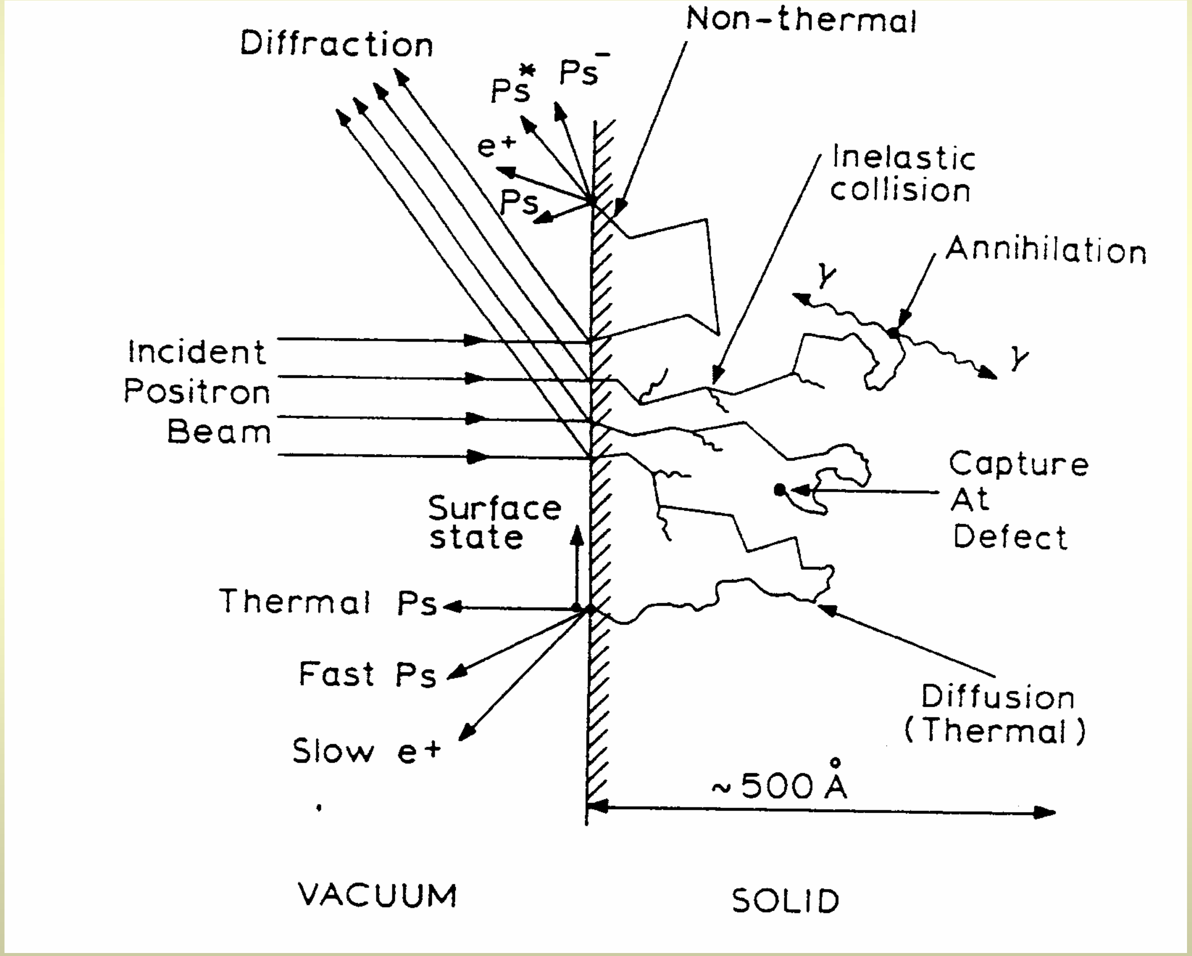
W (100): $\varepsilon = 4\times10^{-4}$

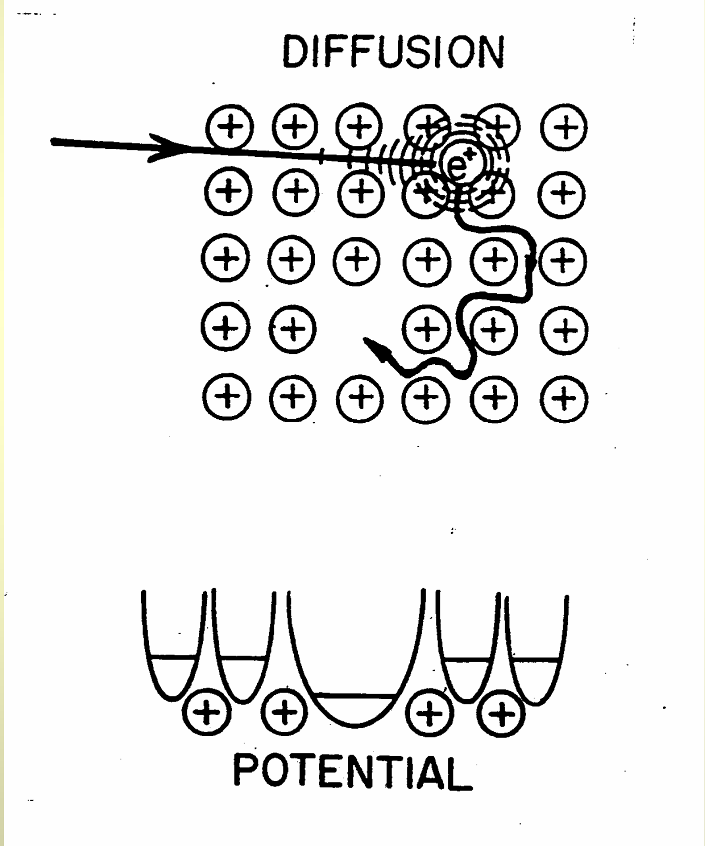
Solid Ne: ε=1% ?

Positrons in Solid State Physics

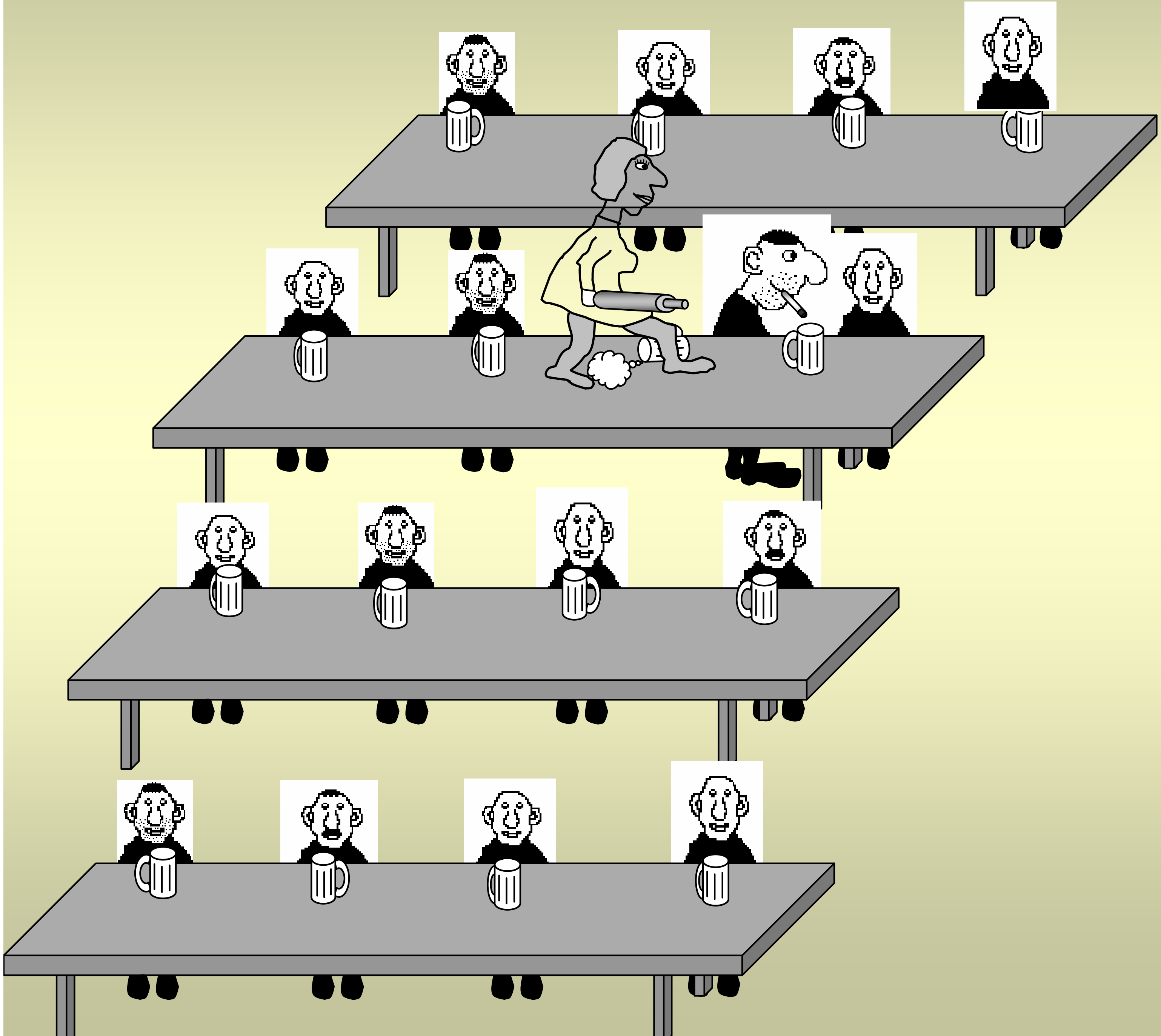


Positron walking





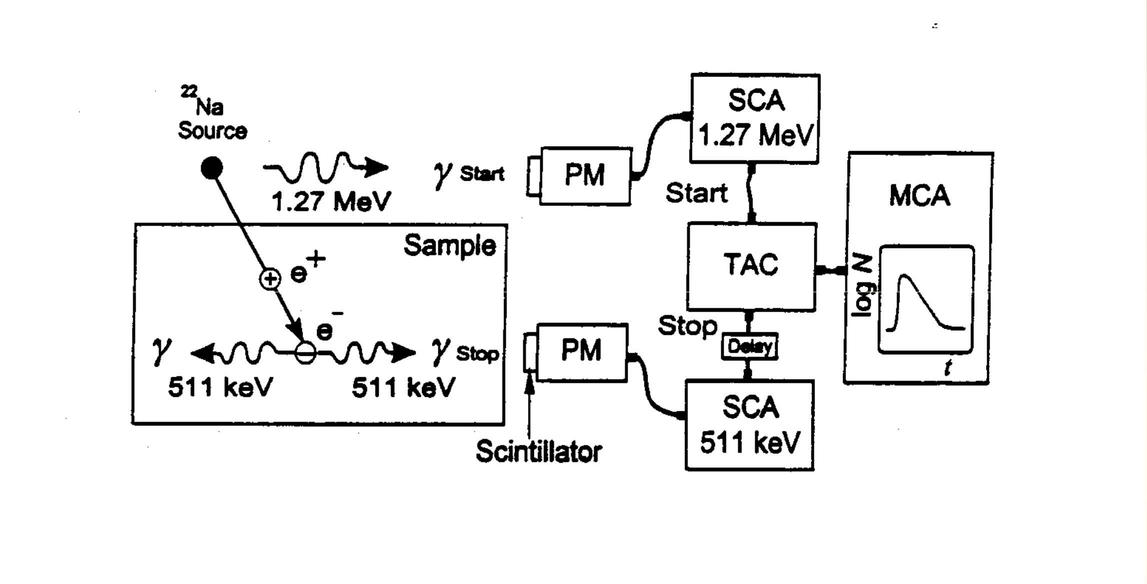
Positron in a crystal

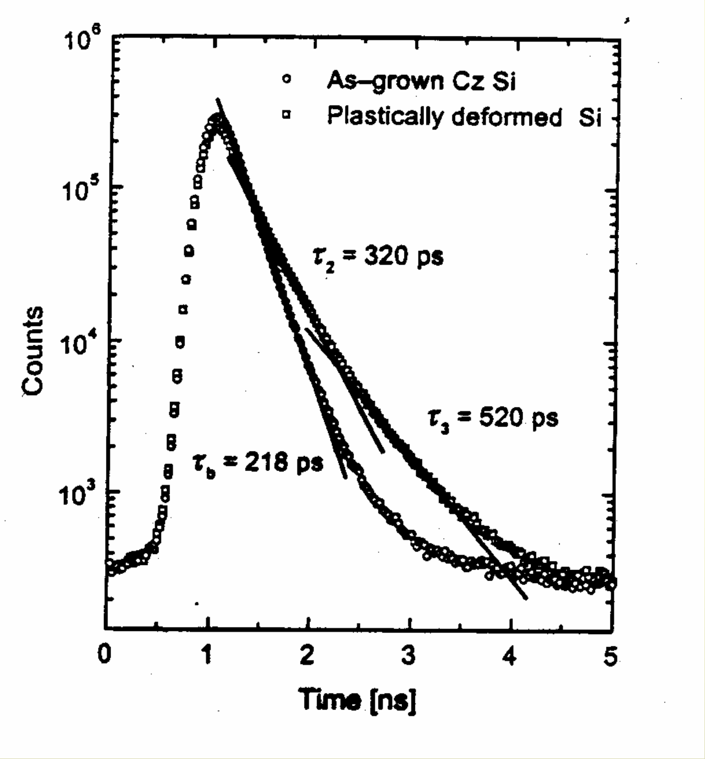


Techniques:
- Doppler broadening (depth profile)
- lifetime (in bulk)
- coincidence (in bulk)

Samples:
- semiconductors
- metal-doped glasses
- pure metals and alloys

1. Positron lifetime technique

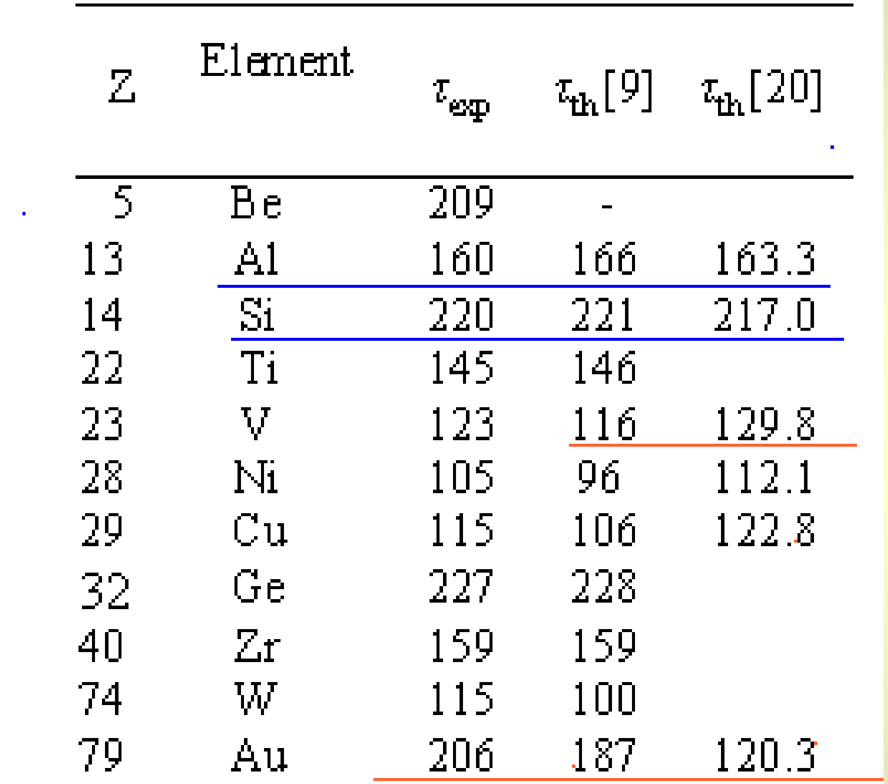




$$\tau_{\text{defect}} > \tau_{\text{bulk}}$$

1. Life-time technique

High-purity metals (monocrystals)

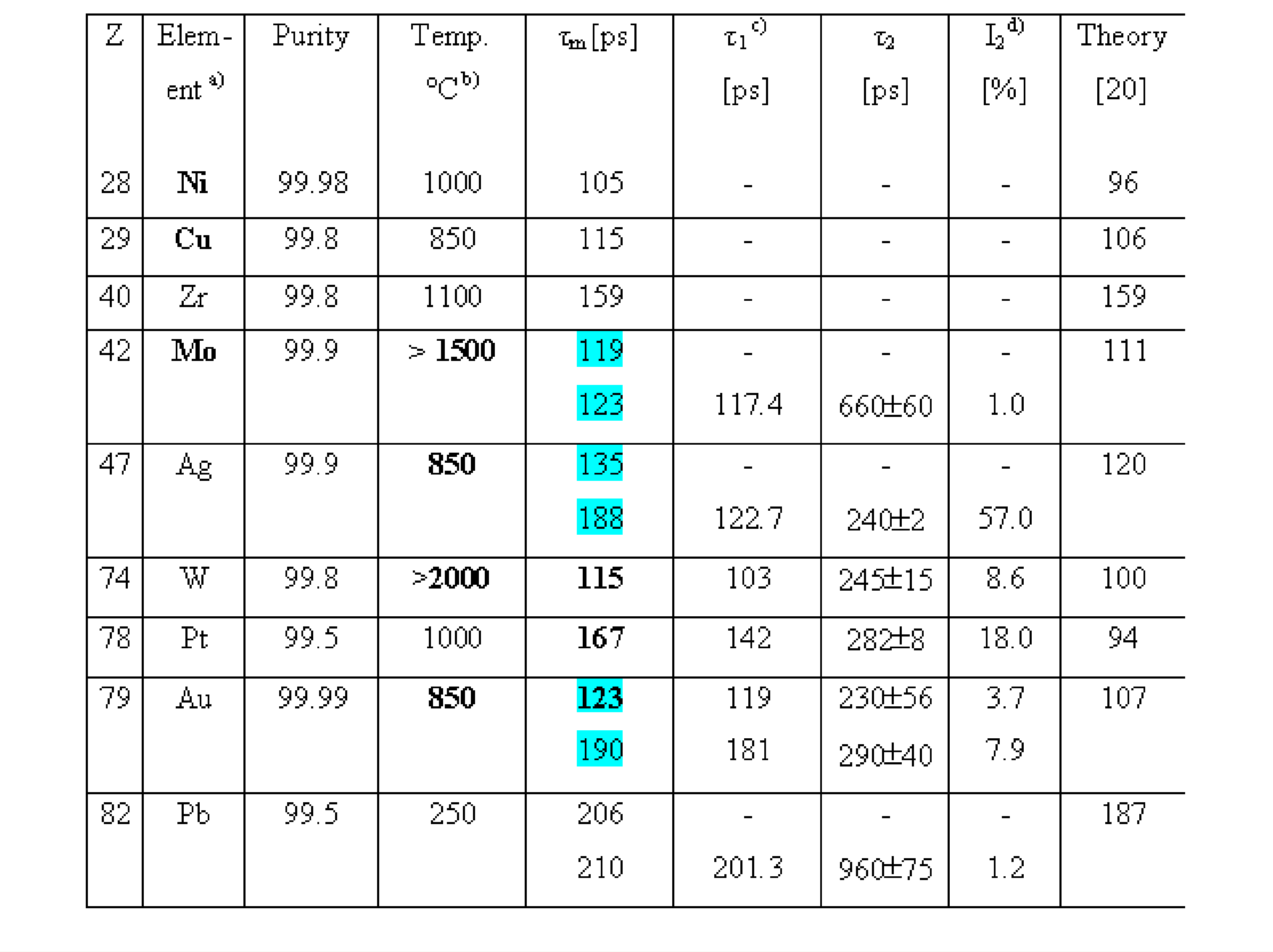


Z	Element	τ_{exp}	τ_{th}[9]	τ_{th}[20]
5	Be	209	-	
13	Al	160	166	163.3
14	Si	220	221	217.0
22	Ti	145	146	
23	V	123	116	129.8
28	Ni	105	96	112.1
29	Cu	115	106	122.8
32	Ge	227	228	
40	Zr	159	159	
74	W	115	100	
79	Au	206	187	120.3

[20] A. Rubaszek, Z. Szotek, W. M. Temmerman, Phys. Rev. B 58 (1998) 11285

1. Life-time technique

High-purity metals (annealing)



Z	Element [a]	Purity	Temp. °C [b]	τ_m [ps]	τ_1 [c] [ps]	τ_2 [ps]	I_2 [d] [%]	Theory [20]
28	**Ni**	99.98	1000	105	-	-	-	96
29	**Cu**	99.8	850	115	-	-	-	106
40	Zr	99.8	1100	159	-	-	-	159
42	**Mo**	99.9	**> 1500**	119 123	- 117.4	- 660±60	- 1.0	111
47	Ag	99.9	**850**	135 188	- 122.7	- 240±2	- 57.0	120
74	W	99.8	**>2000**	**115**	103	245±15	8.6	100
78	Pt	99.5	1000	**167**	142	282±8	18.0	94
79	Au	99.99	**850**	**123** 190	119 181	230±56 290±40	3.7 7.9	107
82	Pb	99.5	250	206 210	- 201.3	- 960±75	- 1.2	187

Trento-München Positron Microscope

E=500 eV – 25 keV
spot = 2 µm

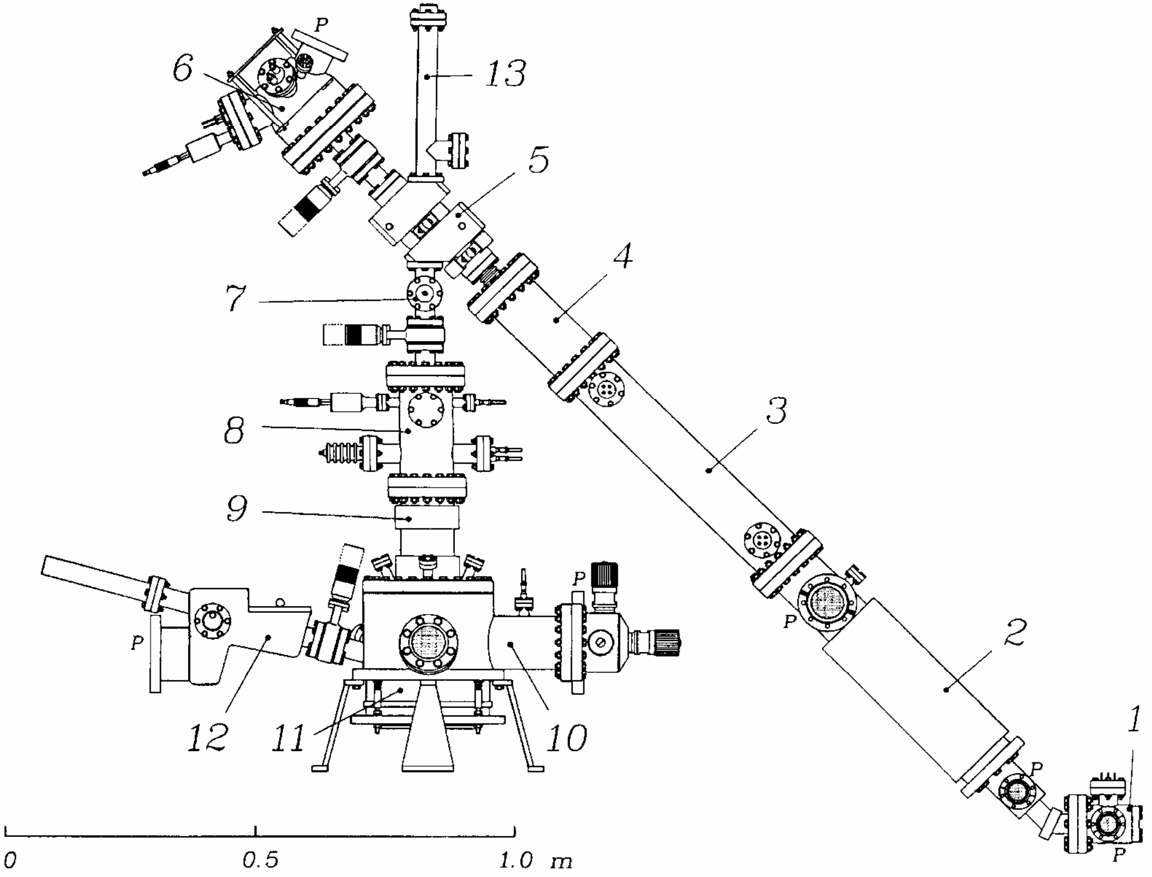
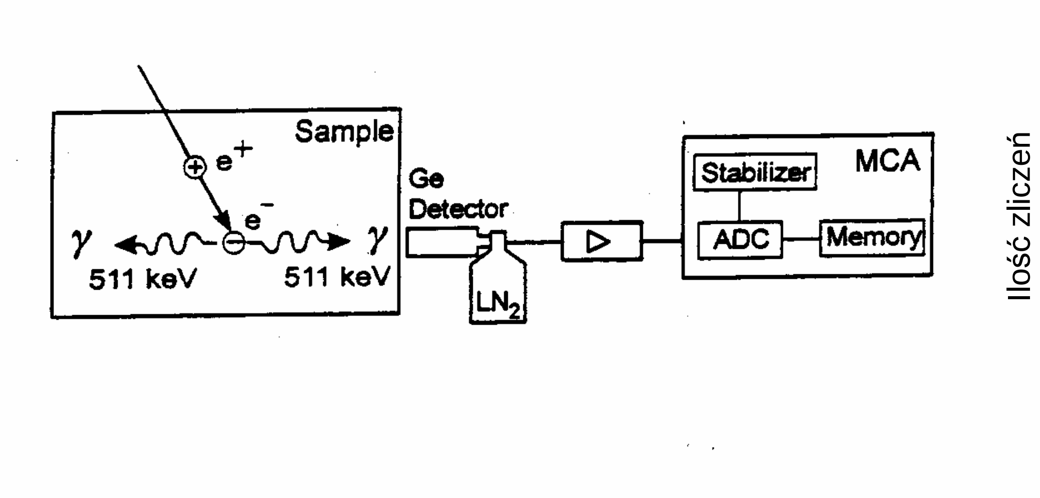
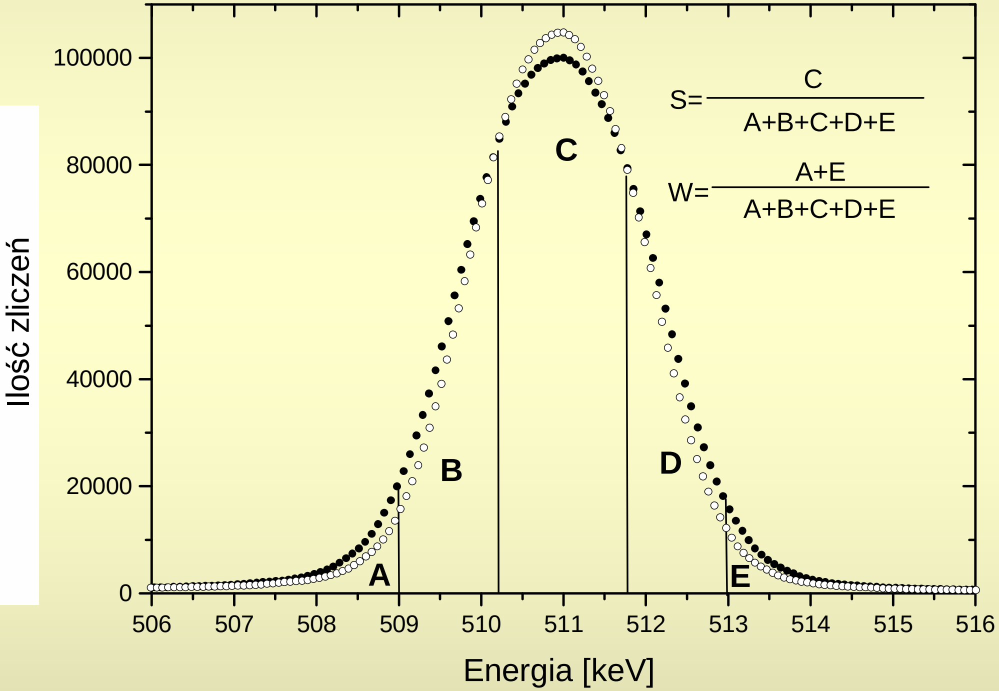


Fig. 1. Overview of the scanning positron microscope – vacuum vessel with attachments: *1* – radioactive source and moderator; *2* – drift tube for pulse forming (sawtooth buncher); *3* – resonance buncher; *4* – accelerator; *5* – beam switch; *6* – remoderator unit; *7* – postbuncher; *8* – main accelerator; *9* – deflector coils; *10* – specimen chamber with manipulator; *11* – probe forming lens with detector in the central bore; *12* – load lock; *13* – electron gun; *P* – pumping port. Some components have been rotated into the plane of the drawing

2. Doppler broadening technique

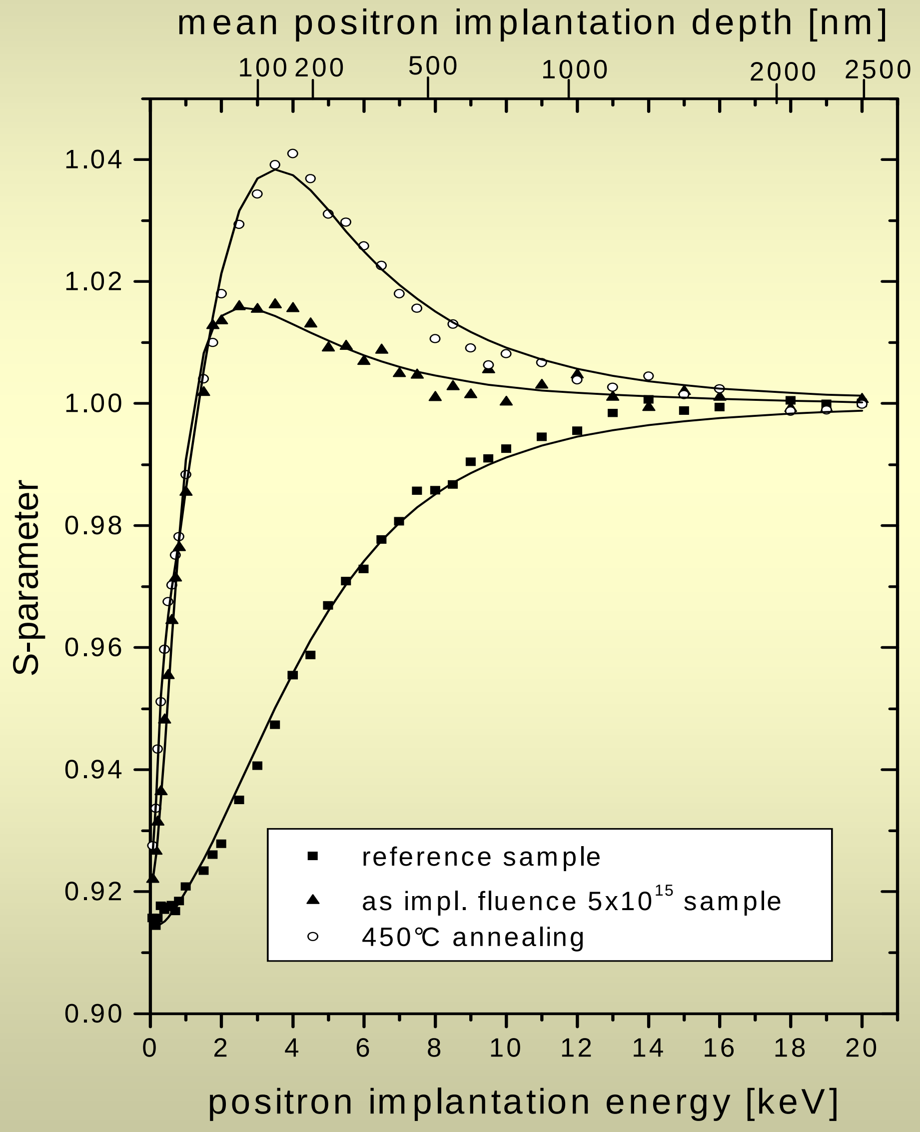
$\mathbf{p}_{tot}=\mathbf{p}_e+\mathbf{p}_p$ $\Delta E = cp_z / 2$





S=(E$_0$±0.85keV)/(E$_0$±4.25keV)

2. Doppler-broadening: normalization



Trento Positron Annihilation Set-up

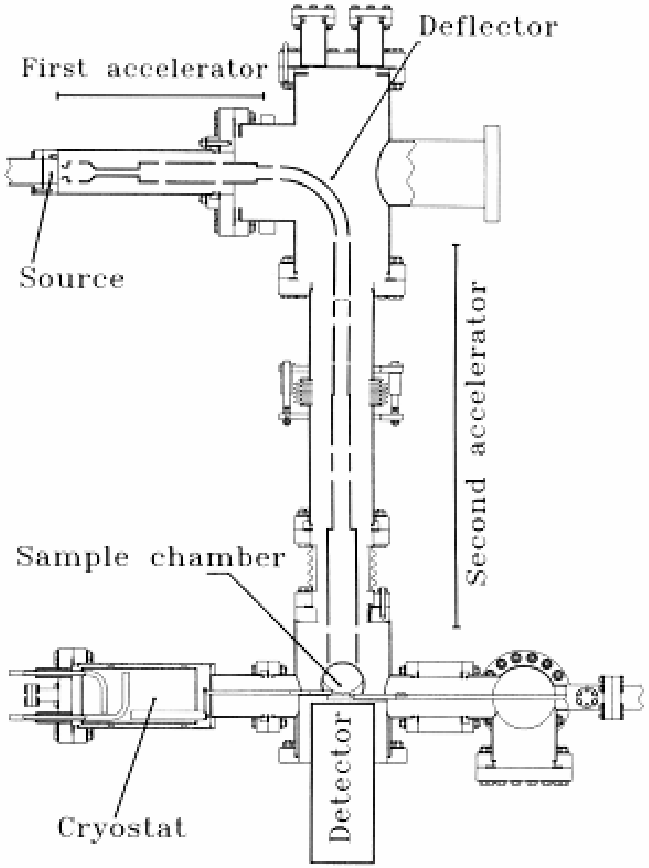


Fig. 1. A schematic layout of the electrostatic positron beam constructed in the Trento laboratory.

E=100 eV – 25 keV (down to 2μm)
spot < 1 mm

He bubbles in Si

He – implantation

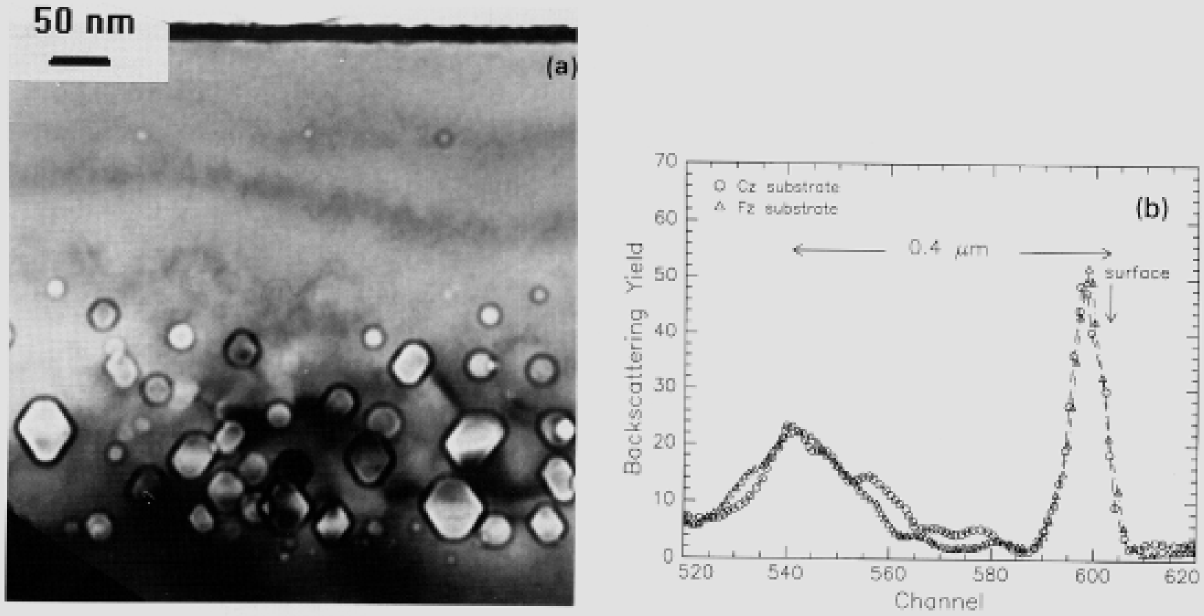
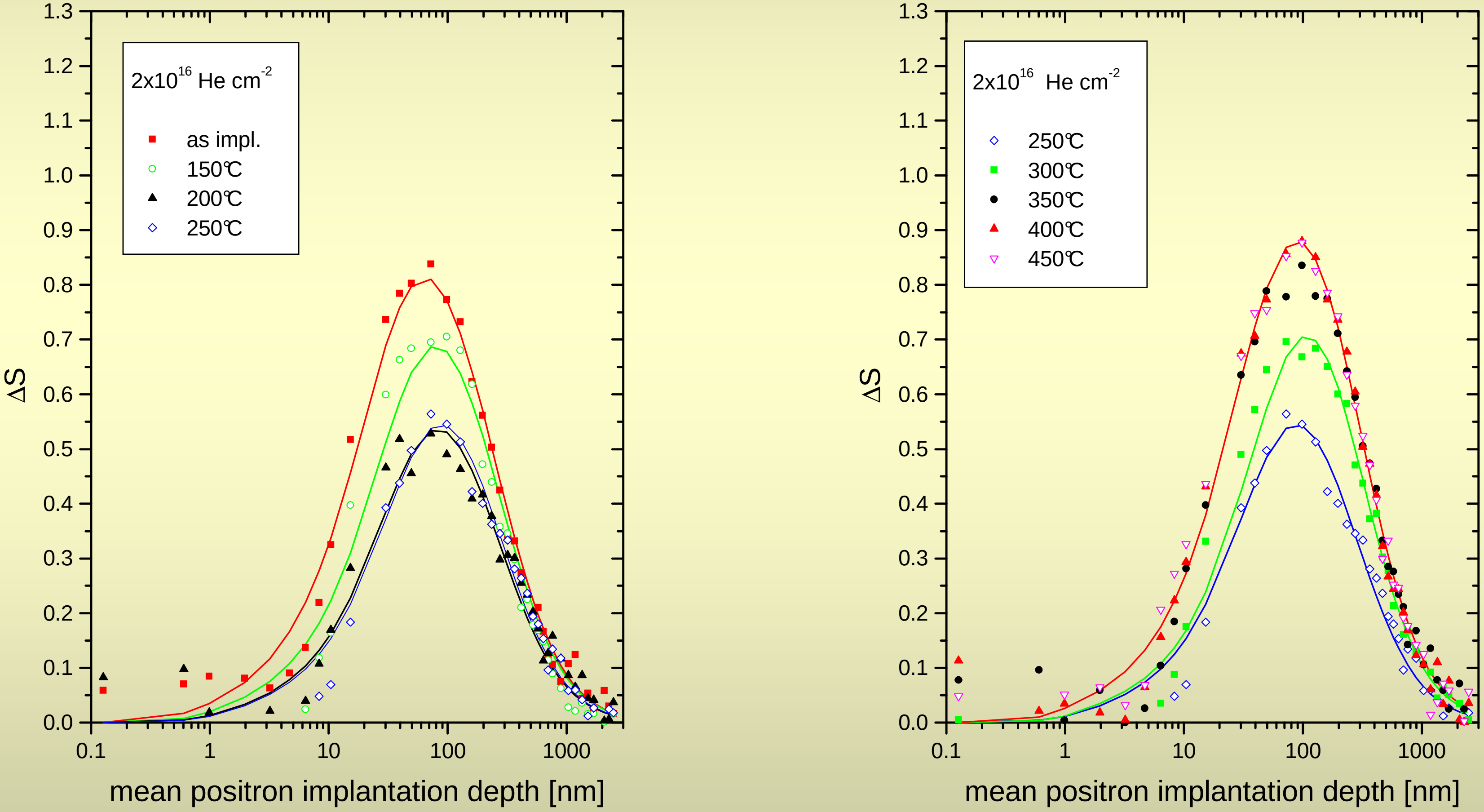


Fig. 3. (a) XTEM image of a double polished sample implanted with $1 \times 10^{17}/\text{cm}^2$ He at 40 keV and thermal processed at 700°C for 1 h. Then it was implanted in the opposite side with $5 \times 10^{14}/\text{cm}^2$ Pt at 1 MeV and diffused at 1000°C for 2 h. In this case the He implanted side is shown. (b) RBS spectra of the same sample as in (a) of the He implanted side.

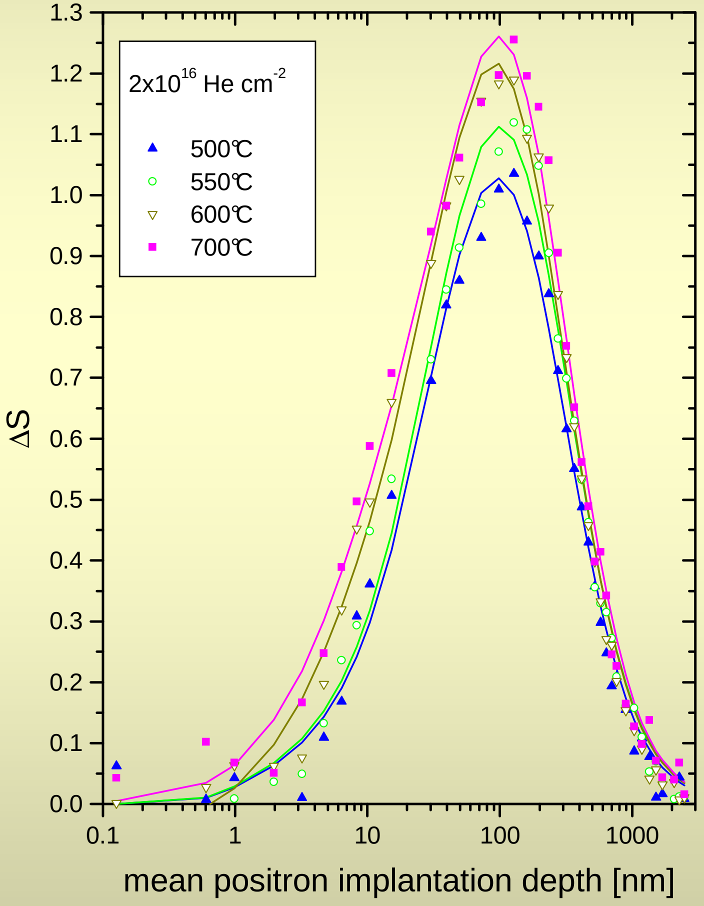
$n=0.5\text{x}10^{16}\text{cm}^2$ **NO!**

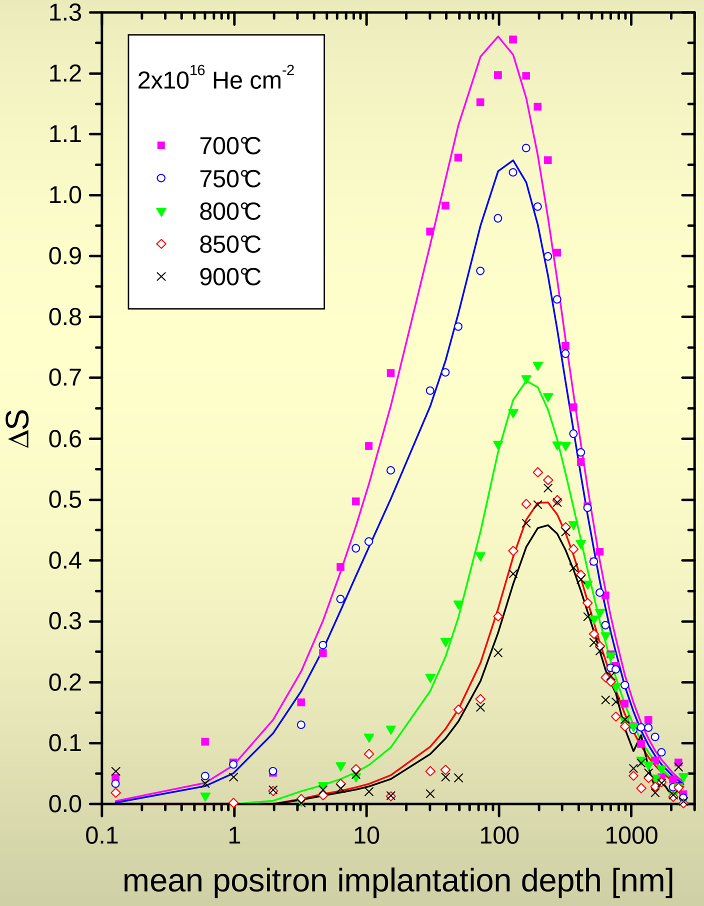
$n=2\text{x}10^{16}\text{cm}^2$ **YES!**

He bubbles in Si

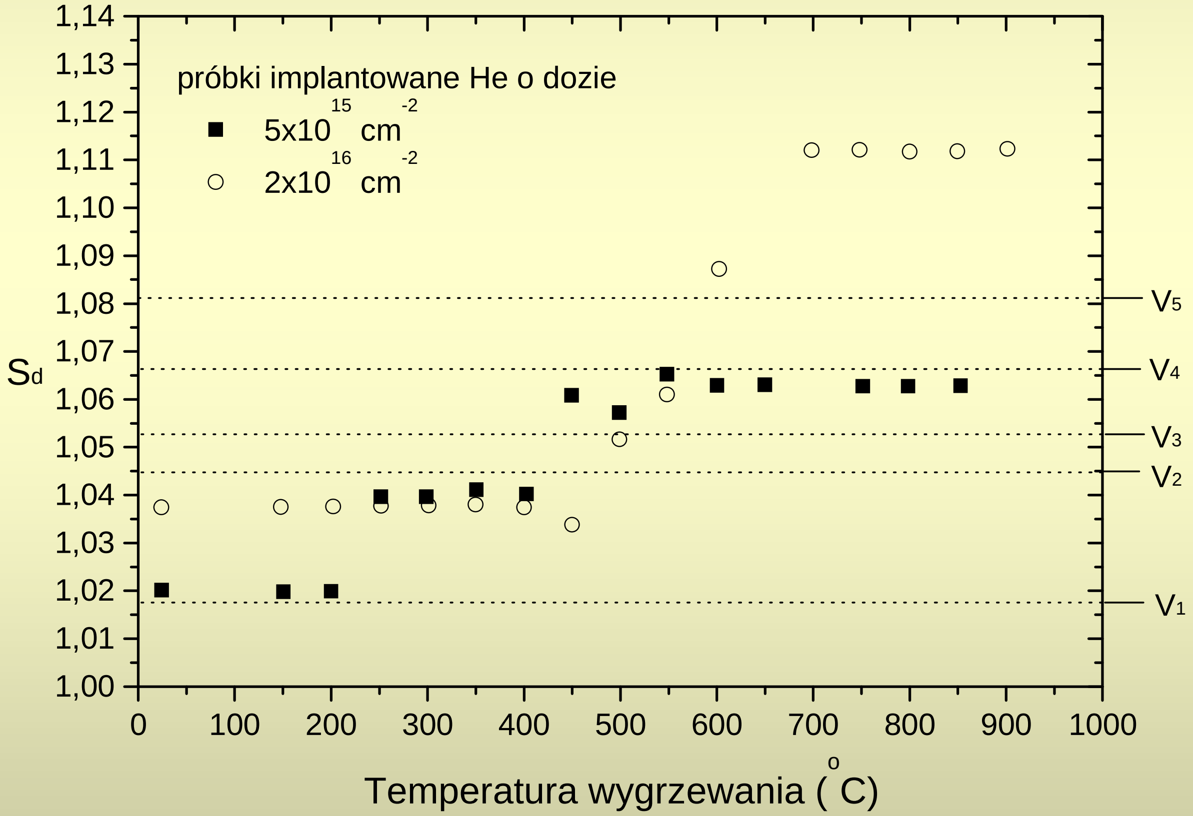


He bubbles in Si

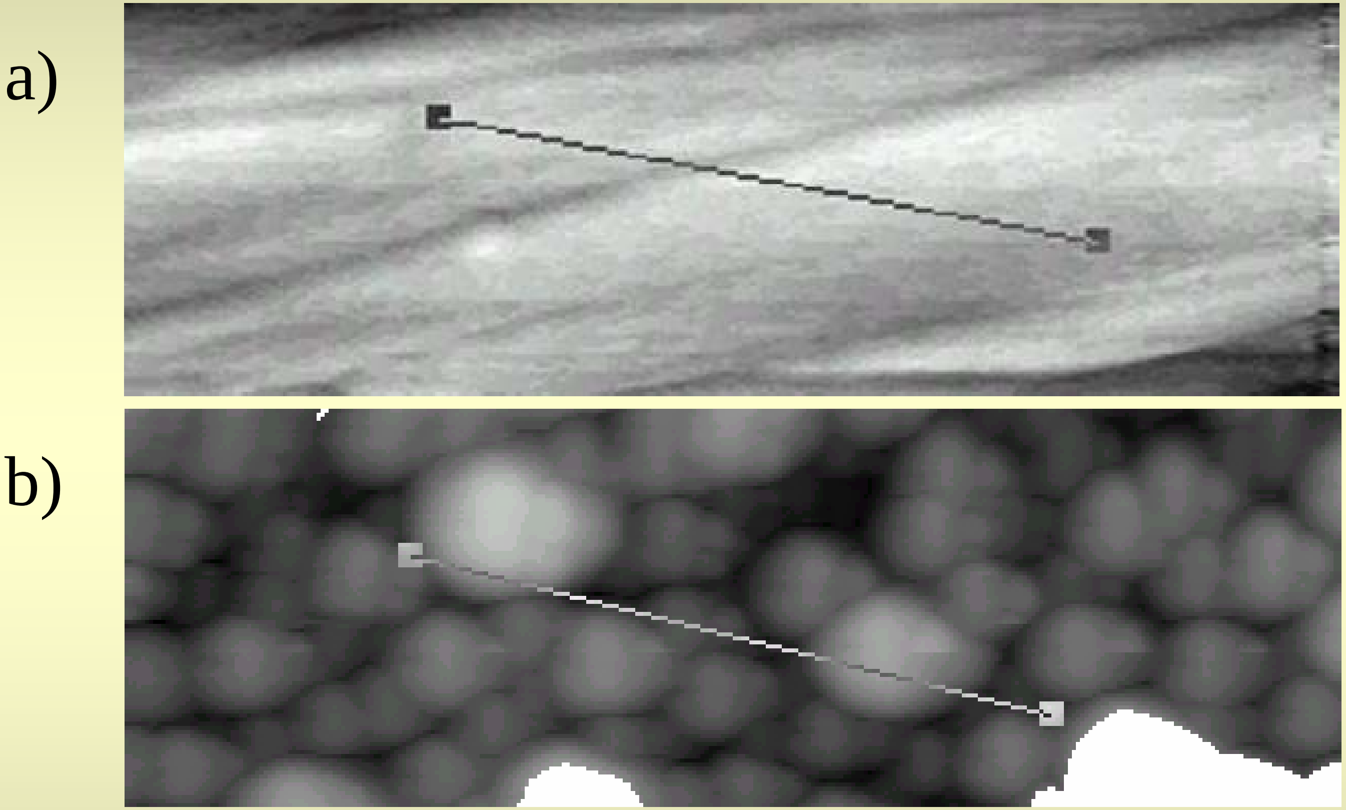




He bubbles in Si
quantization of S - values



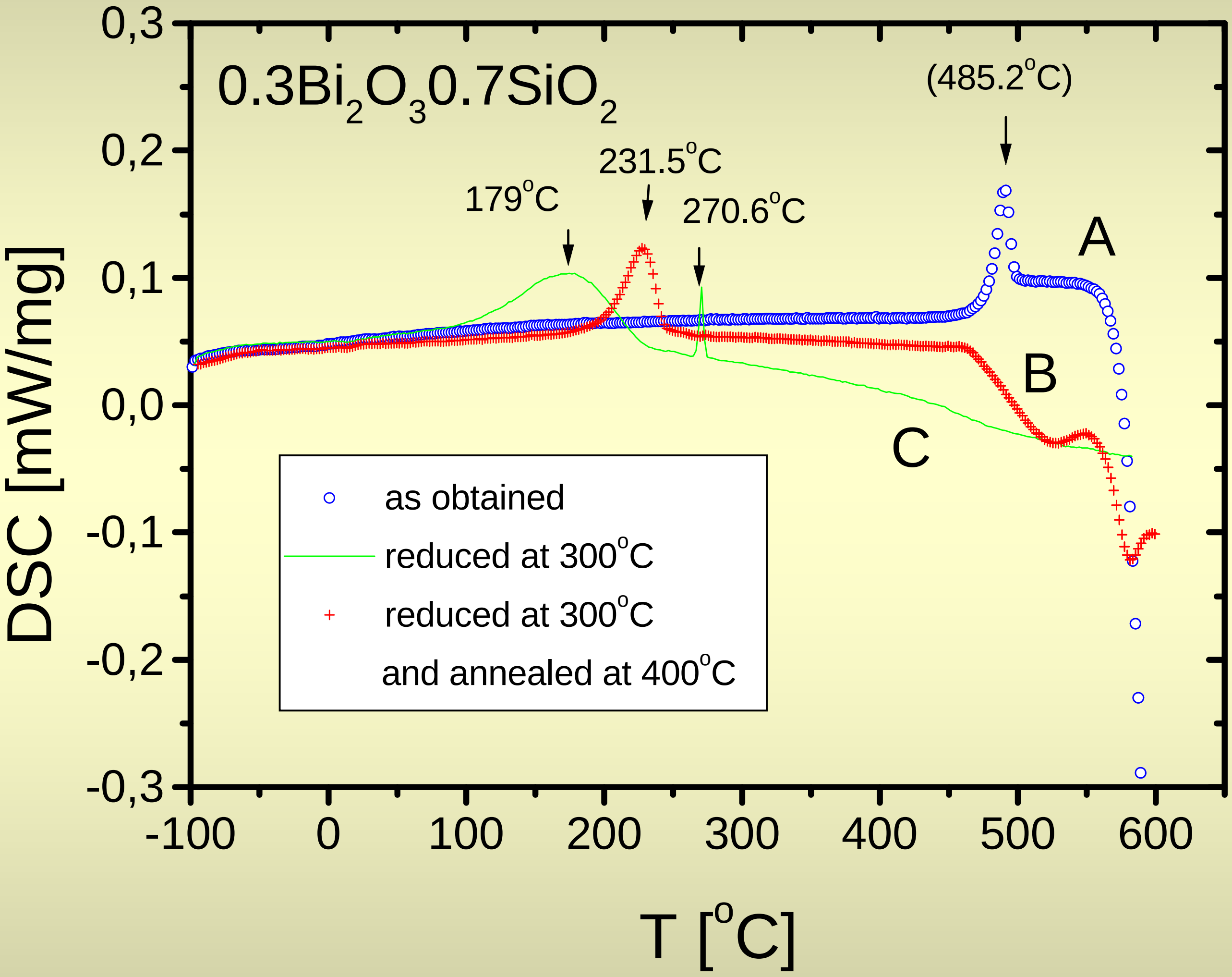
Metal-doped glasses (Pb, Bi)



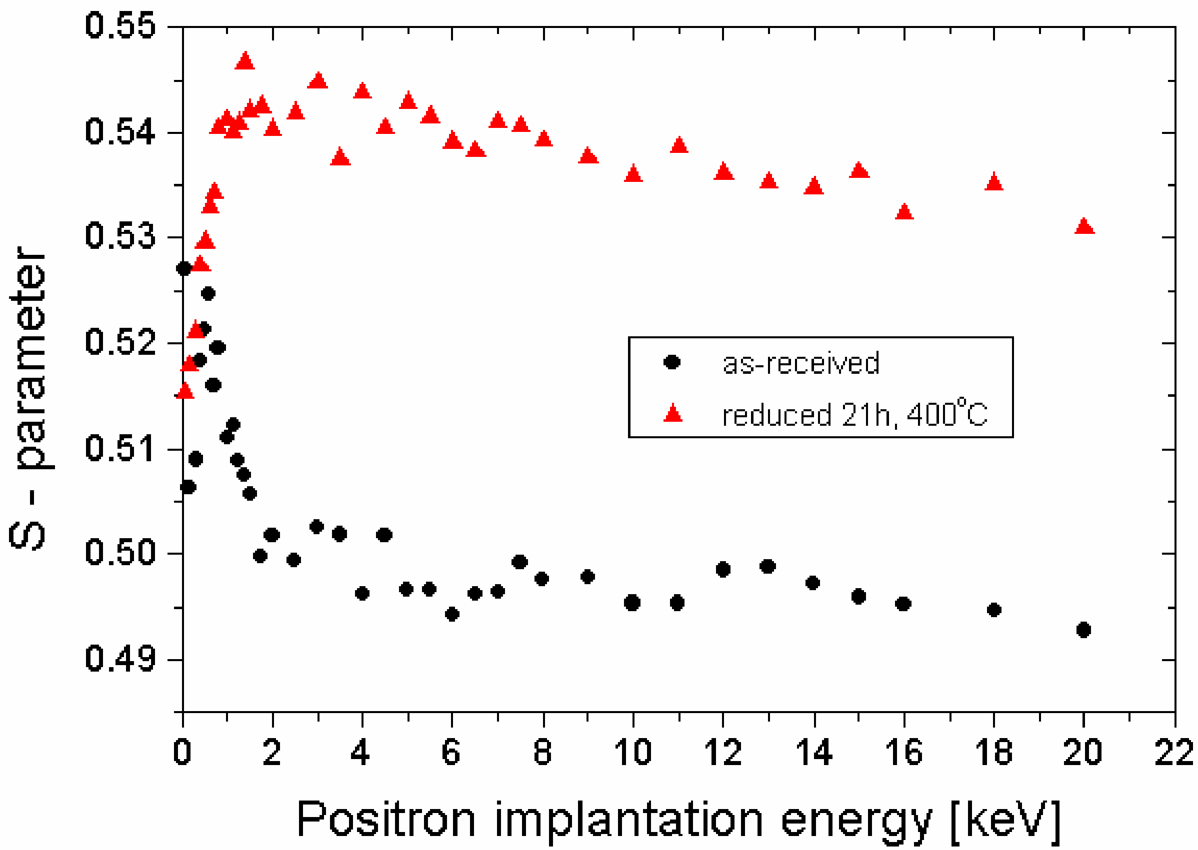
AFM picture of Si-Pb glass; a) freshly broken;

b) Annealed at 580°C for 21h

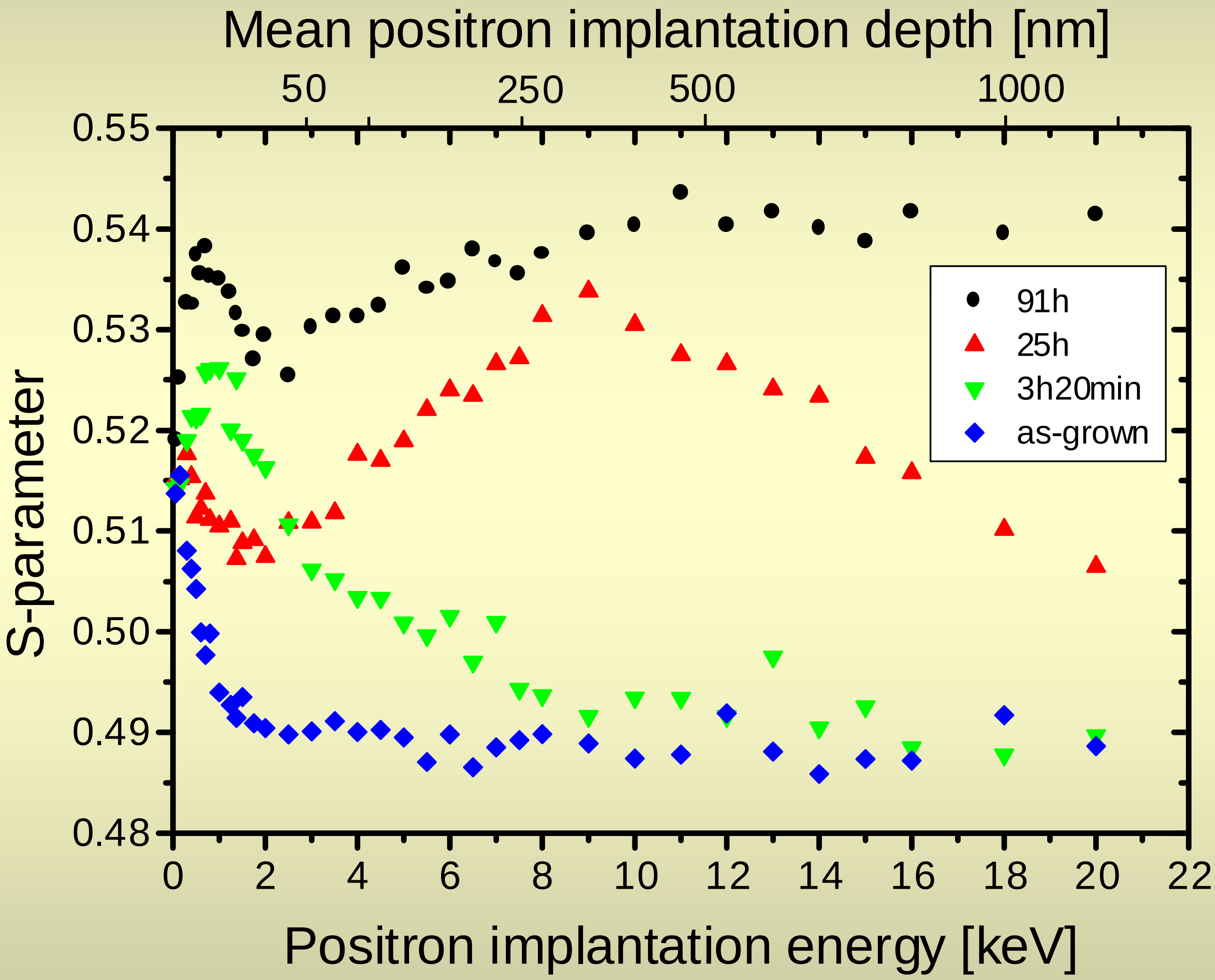
Metal-doped glasses ($SiO_2+Bi_2O_3$)



Conducting glasses (SiO_2+PbO_2)

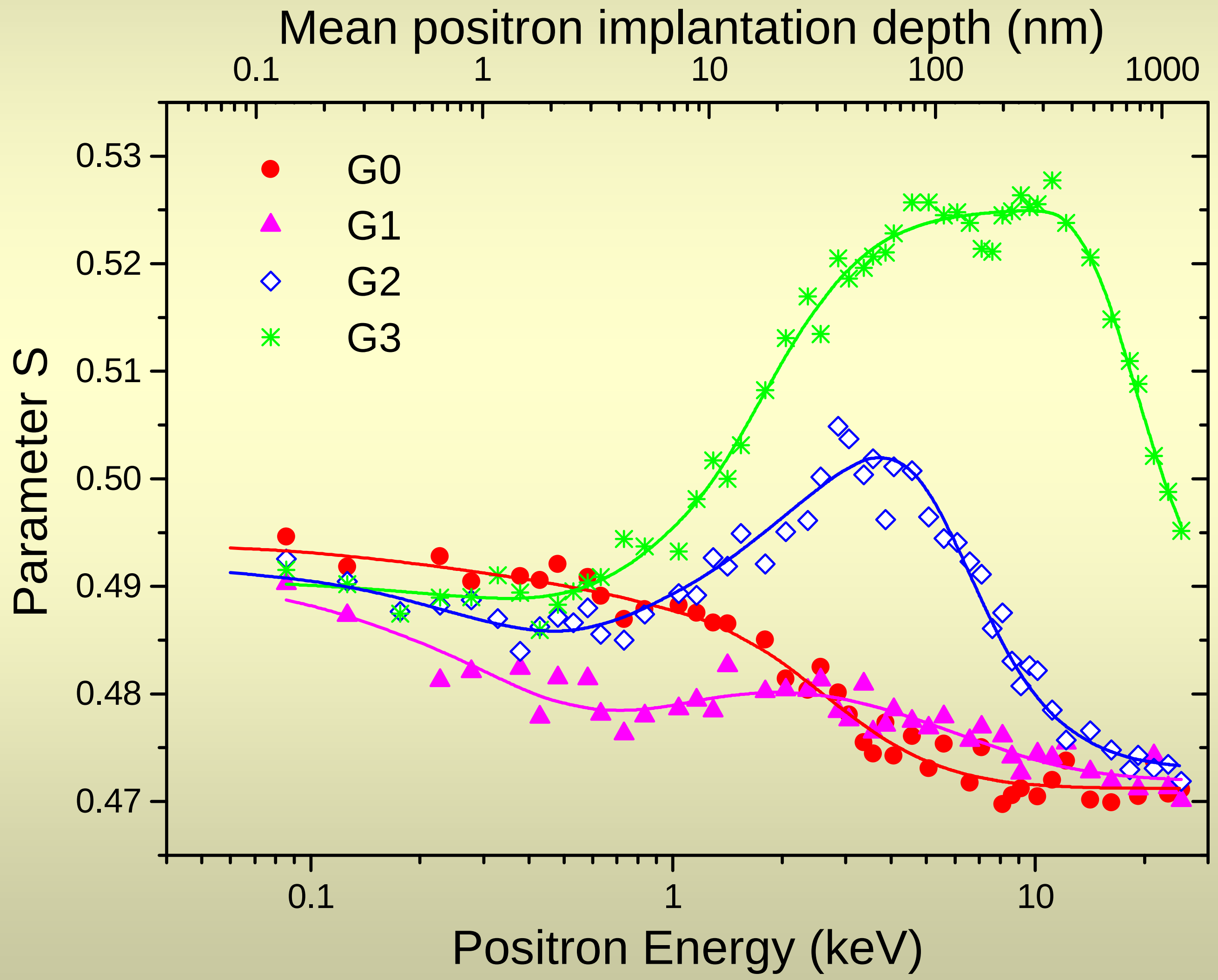


Doped glasses (SiO_2+Bi_2O_3)



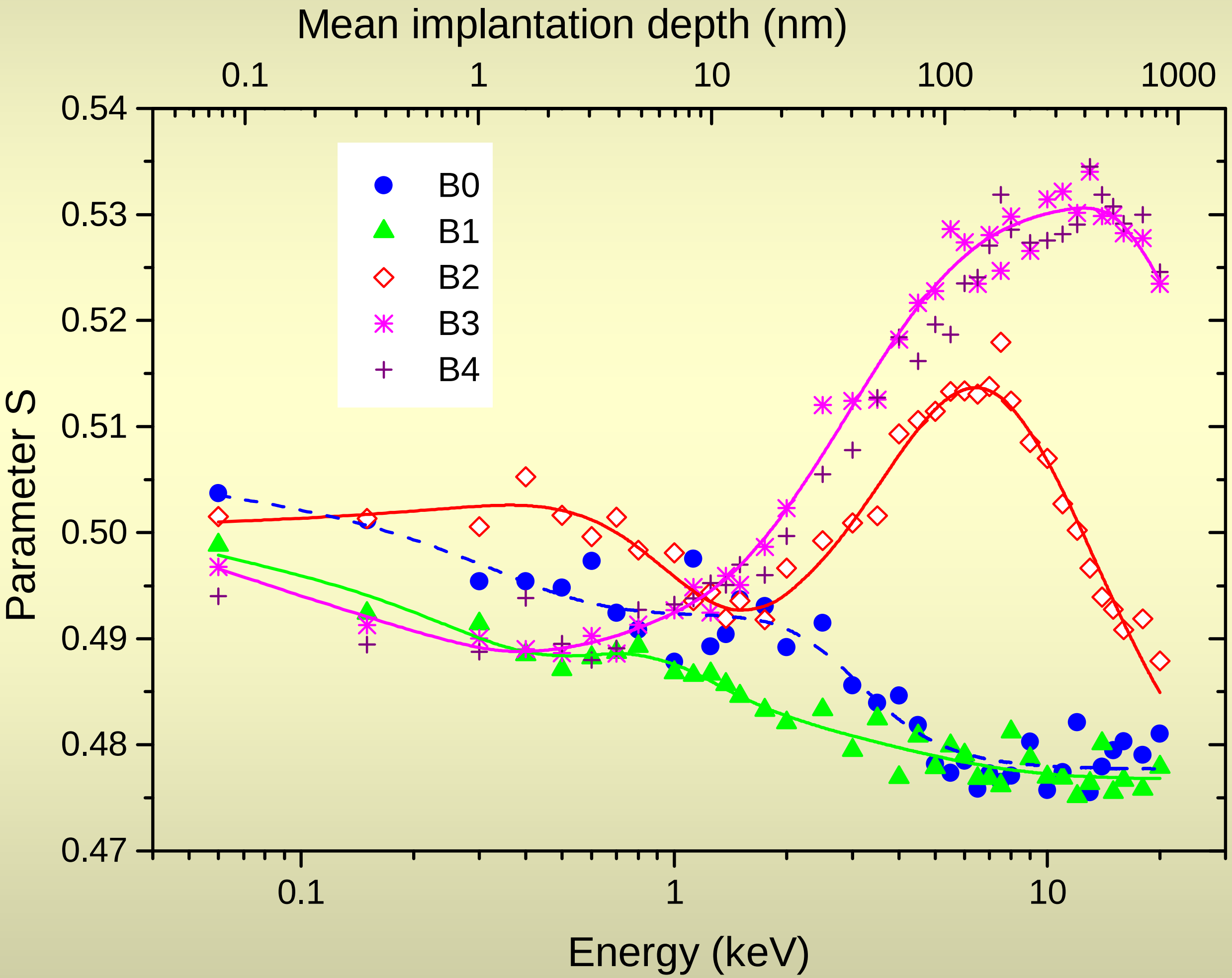
Conducting glasses (GeO_2+Bi_2O_3)

Metal precipitates – depth profiling

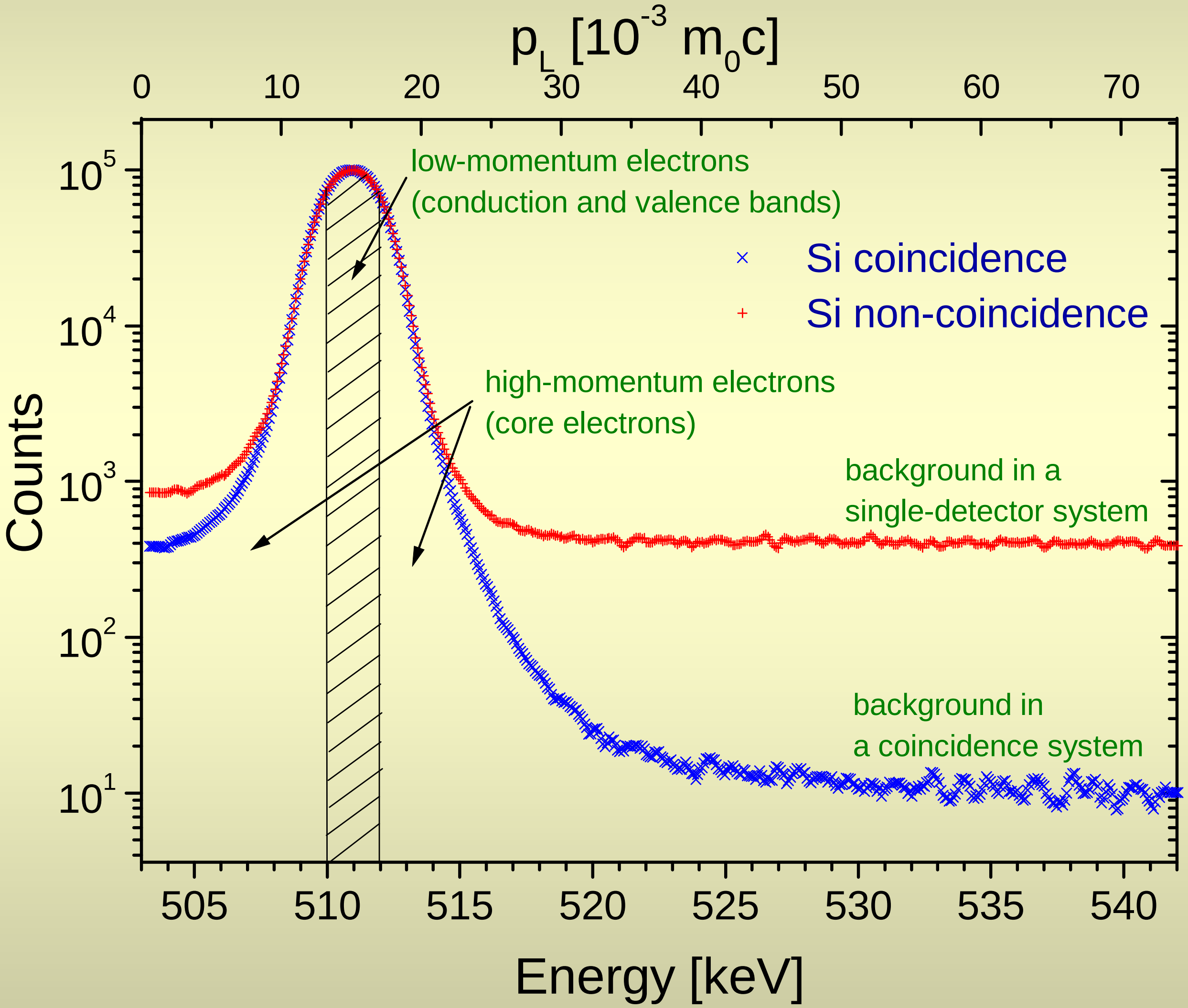


Conducting glasses ($SiO_2+Bi_2O_3$)

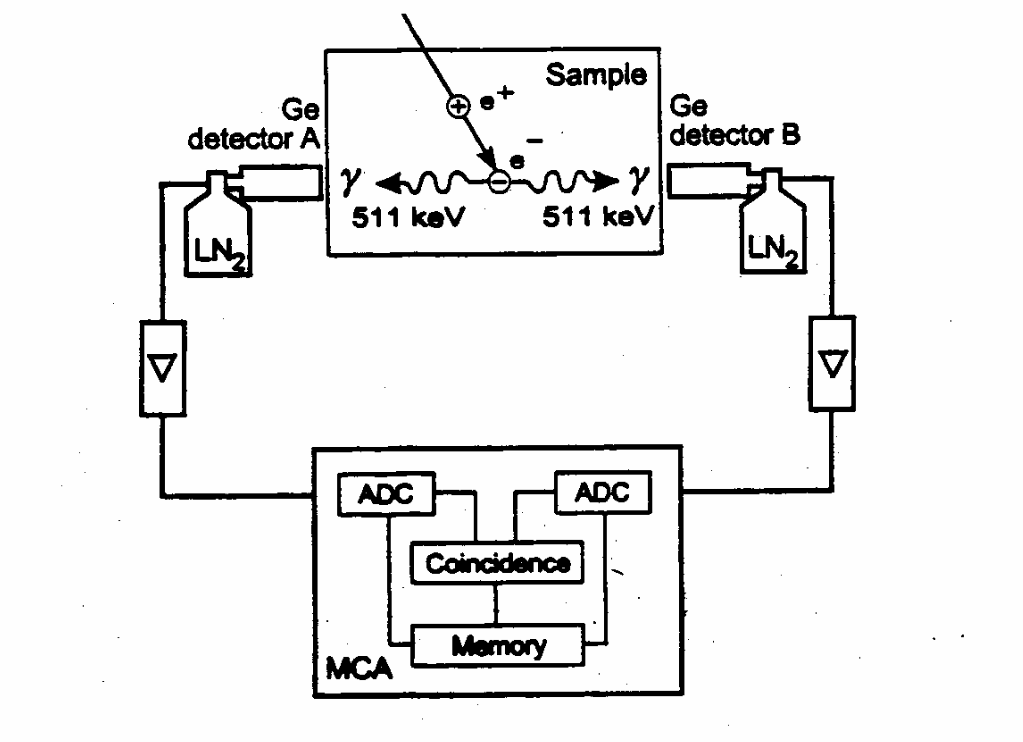
Metal precipitates – depth profiling

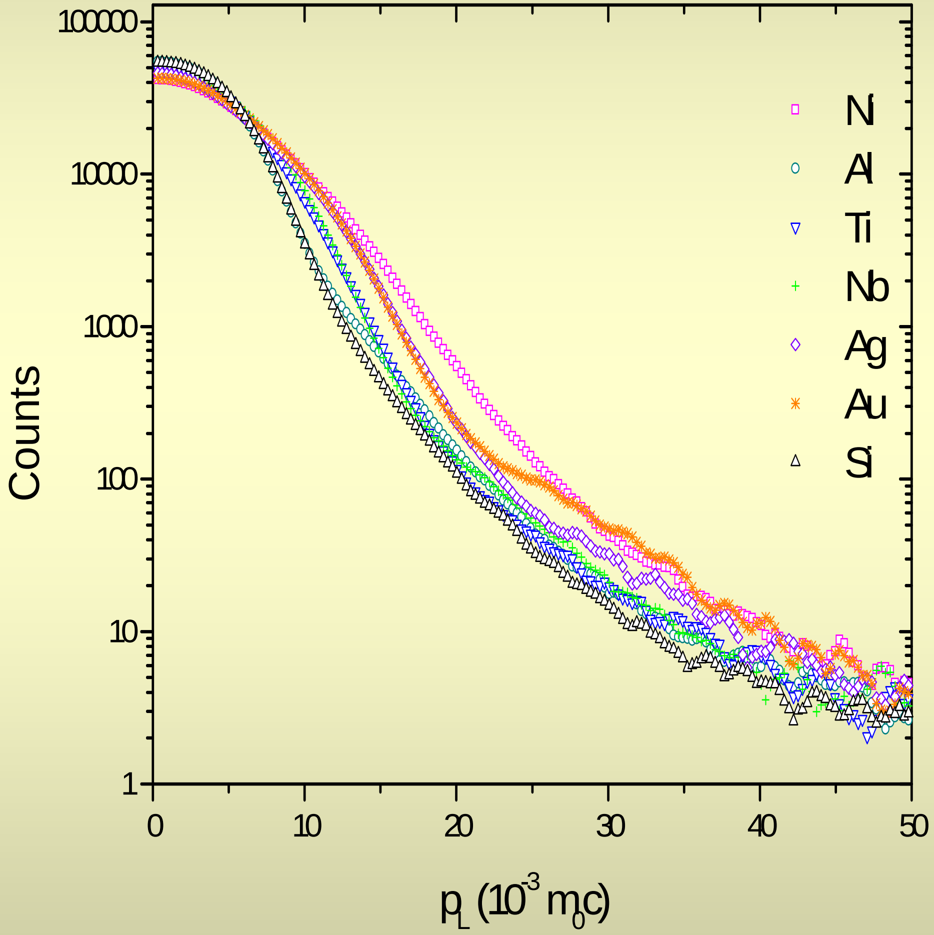


3. Doppler-coincidence technique



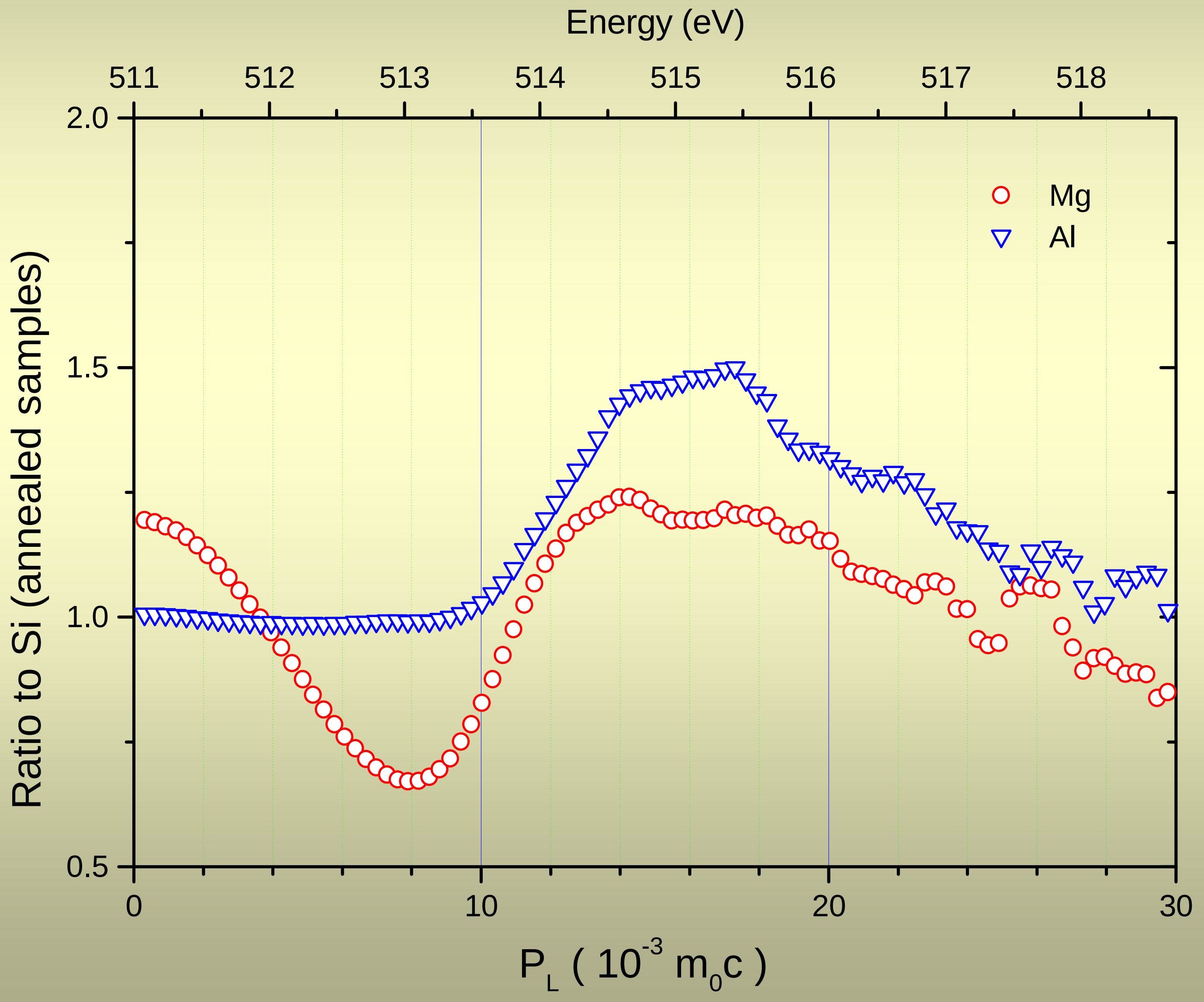
Doppler-coincidence spectra





rys

Doppler coincidence – element fingerprints



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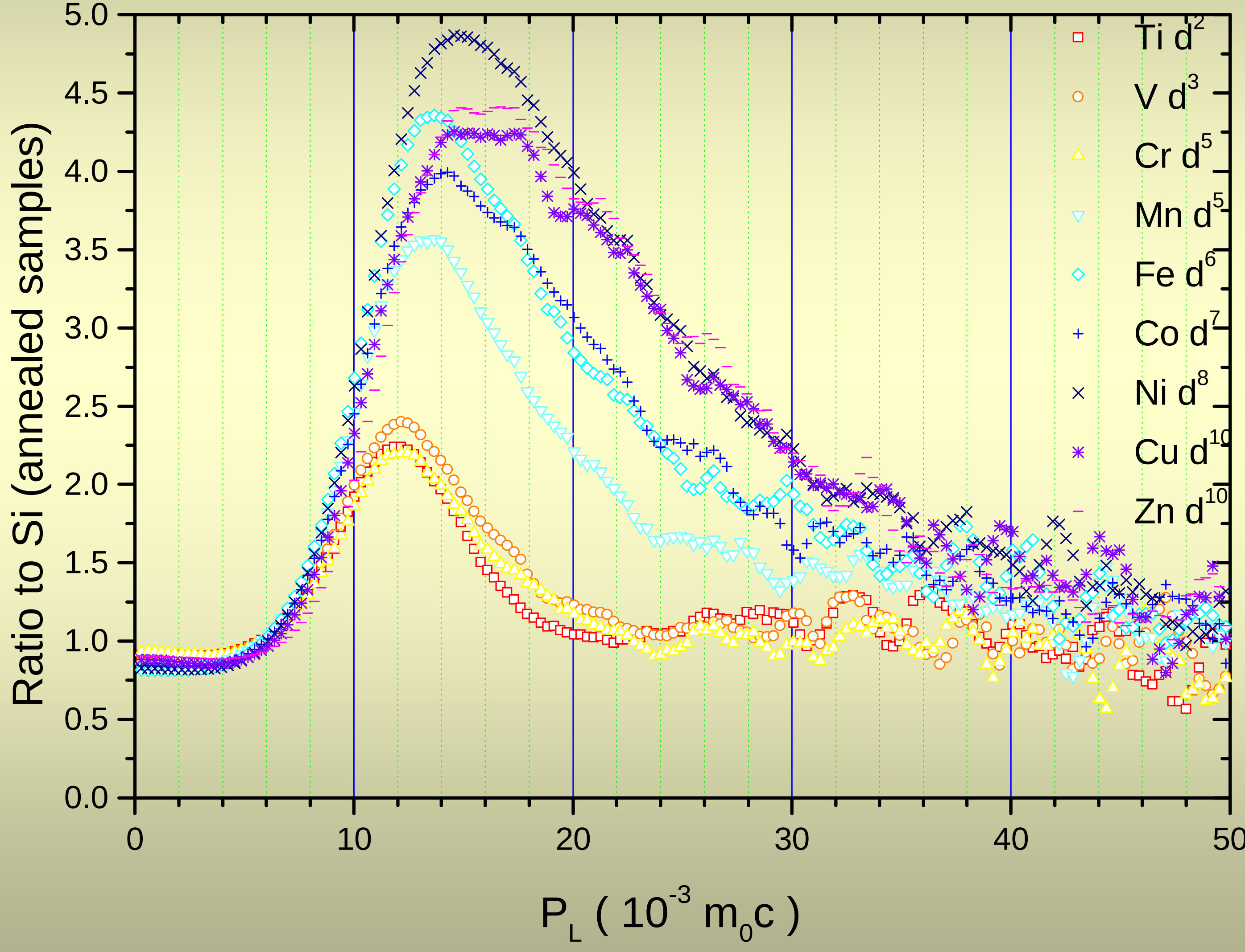
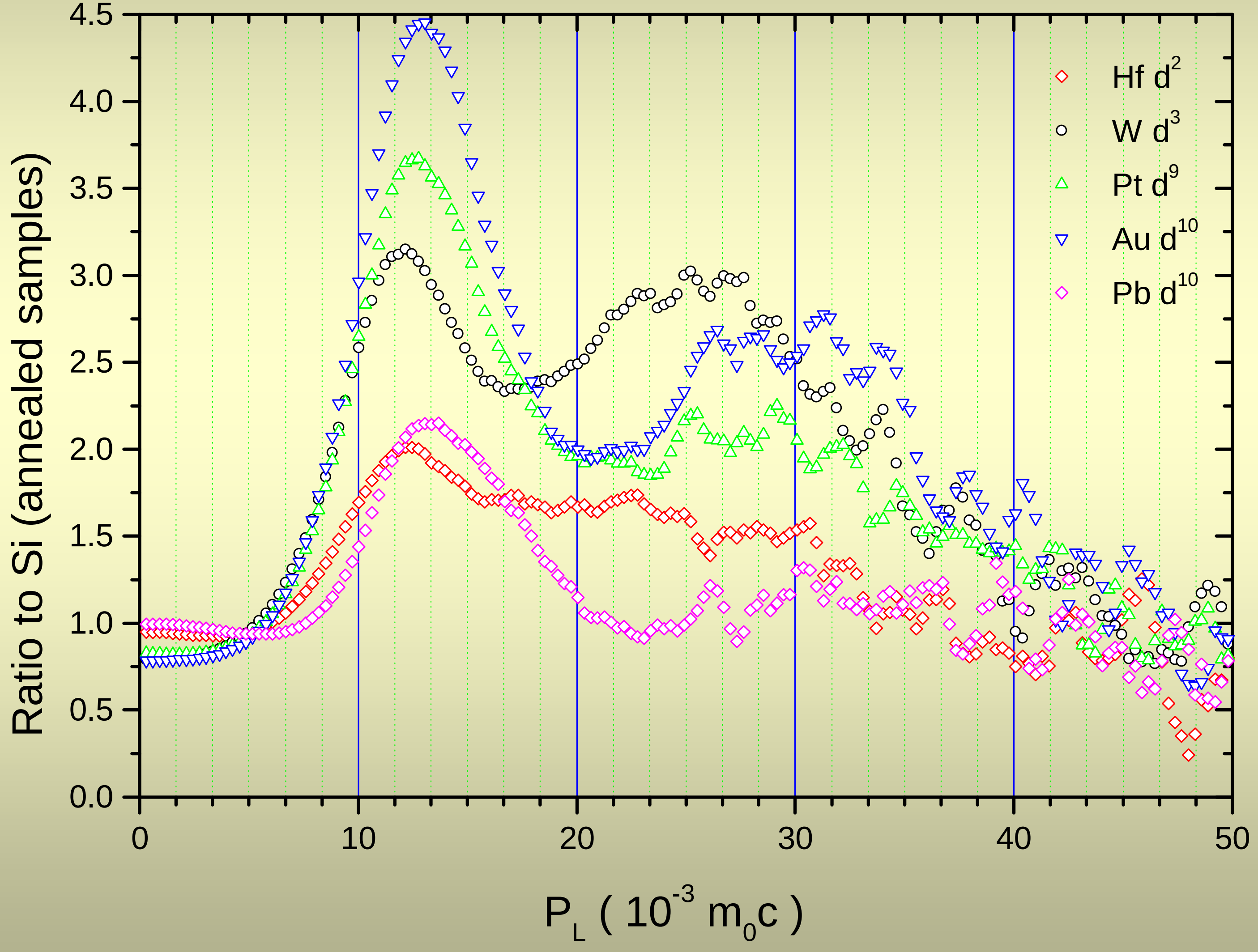


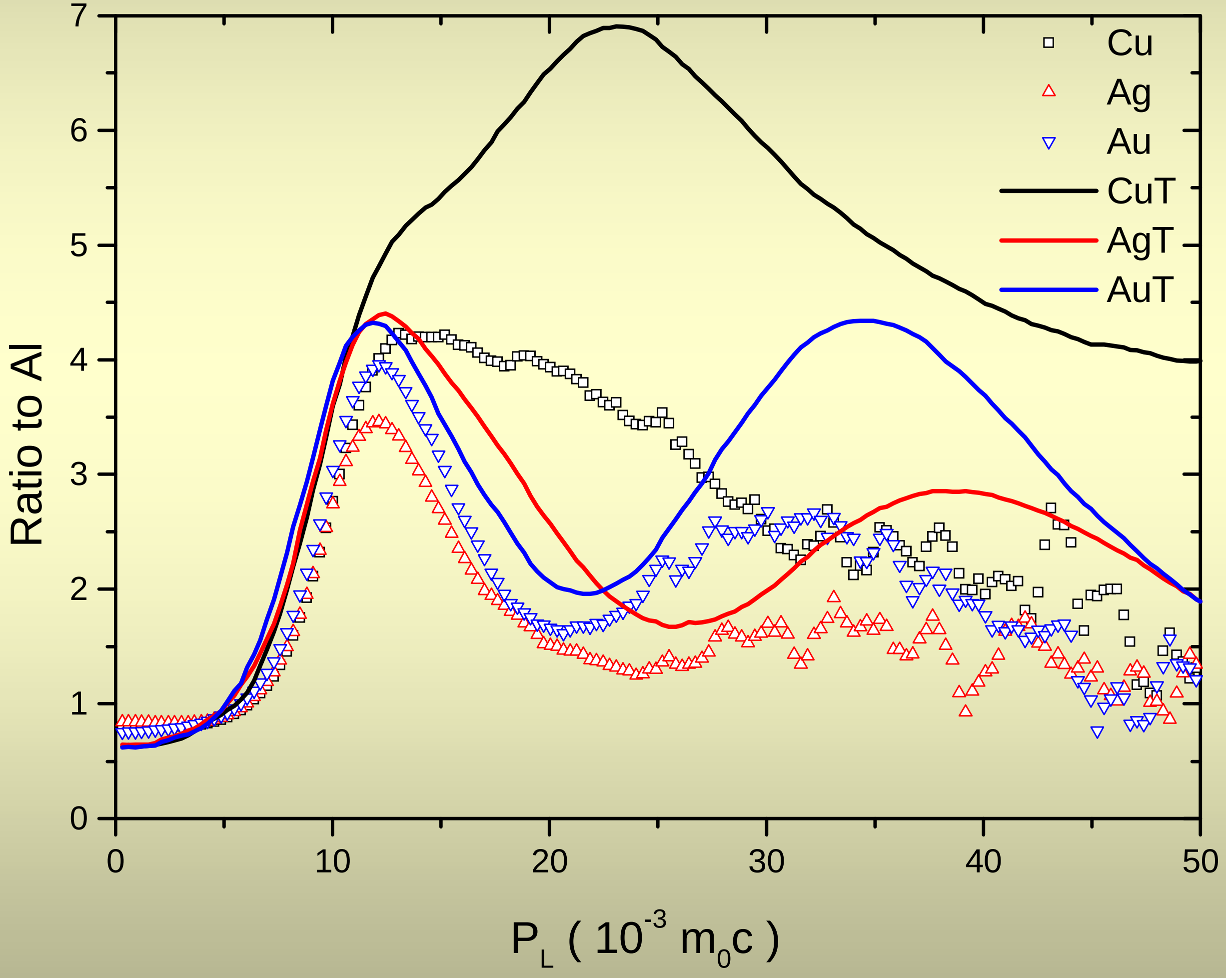
rys5wr2

Doppler coincidence – element fingerprints

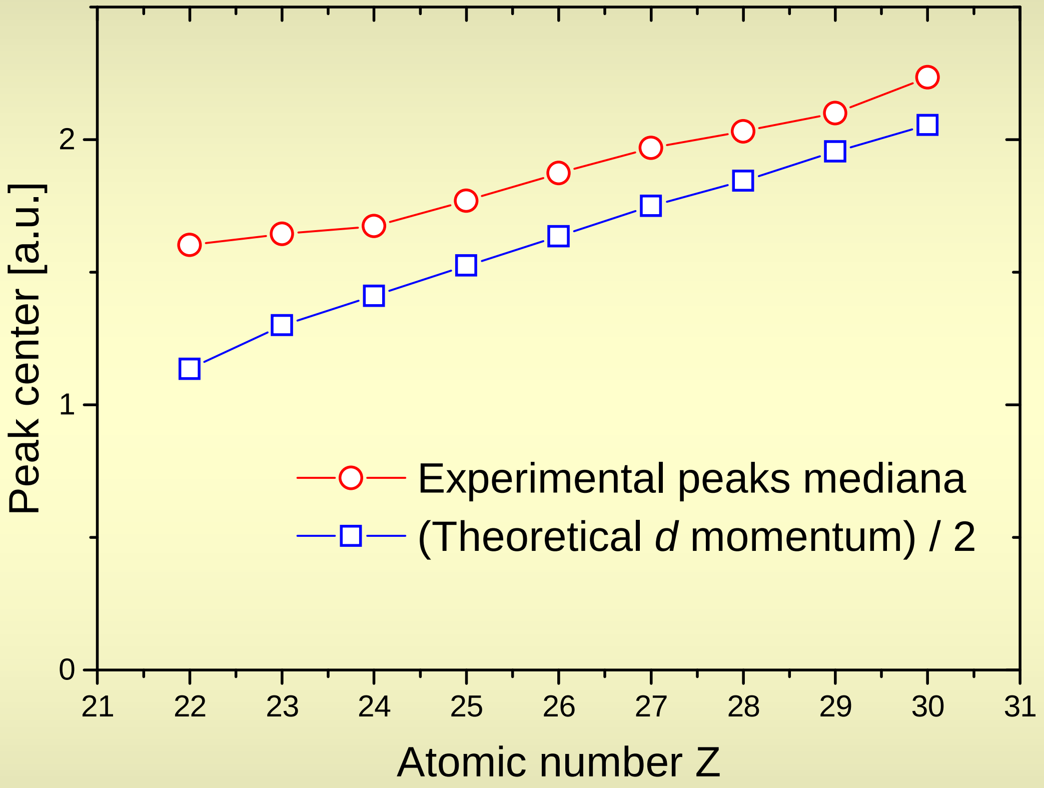


Fingerprints - theory

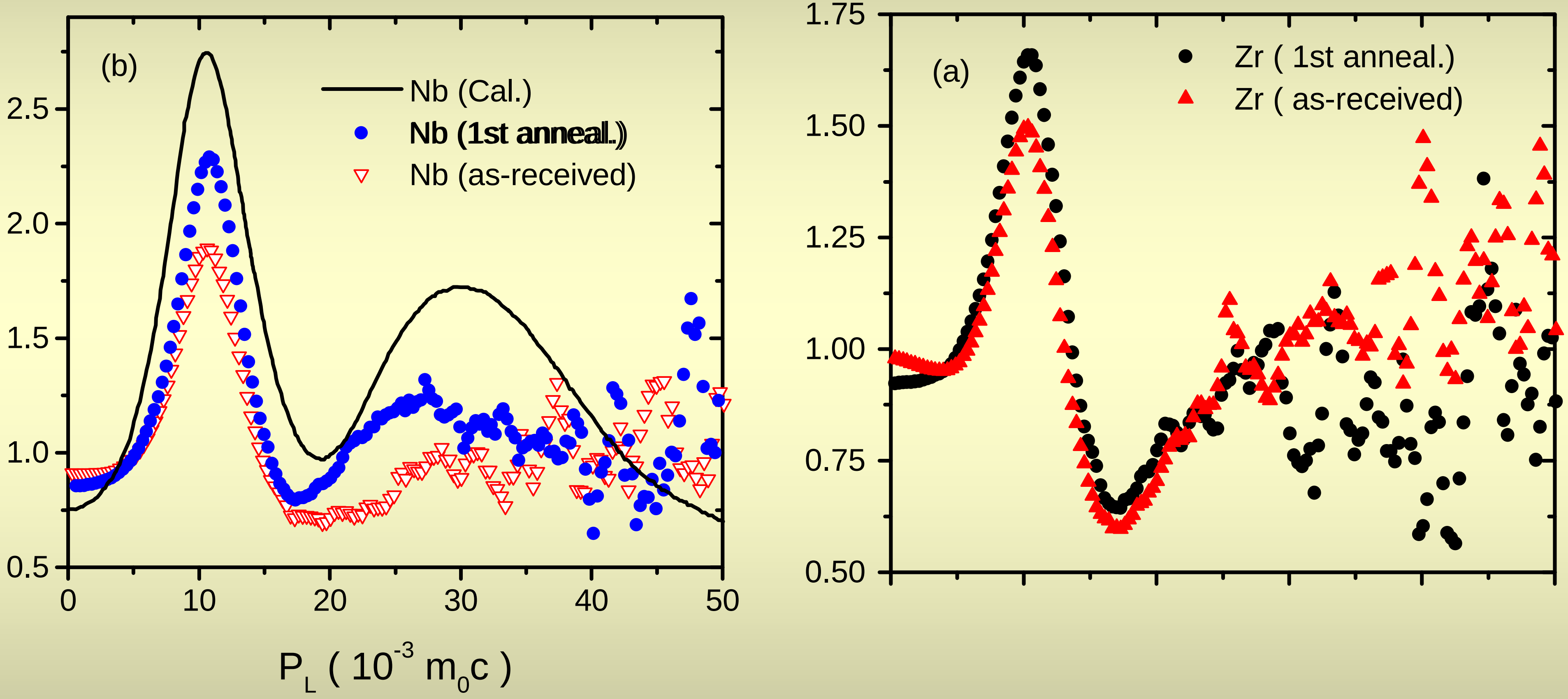
Noble metals



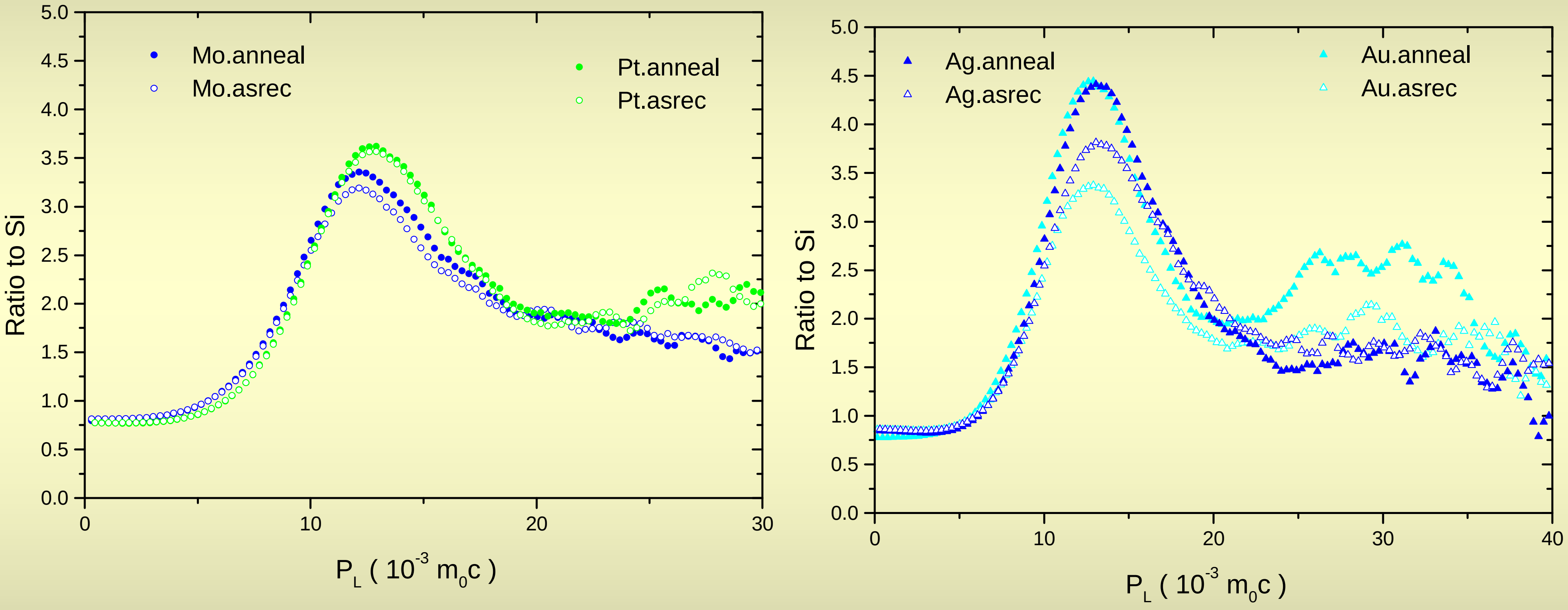
Core-electron momenta



Doppler coincidence – defects

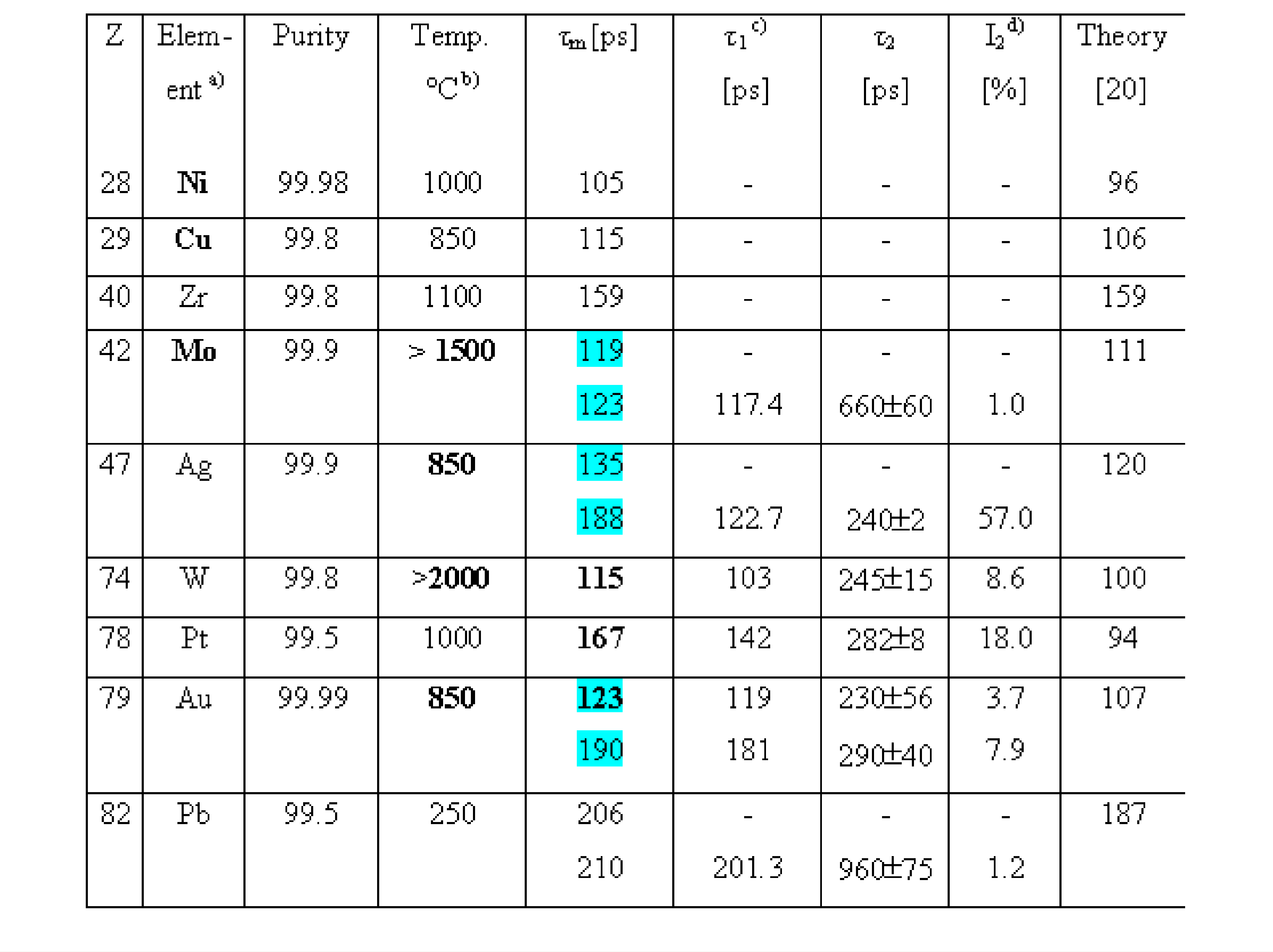


Doppler coincidence – defects



Life-time technique

High-purity metals (annealing)



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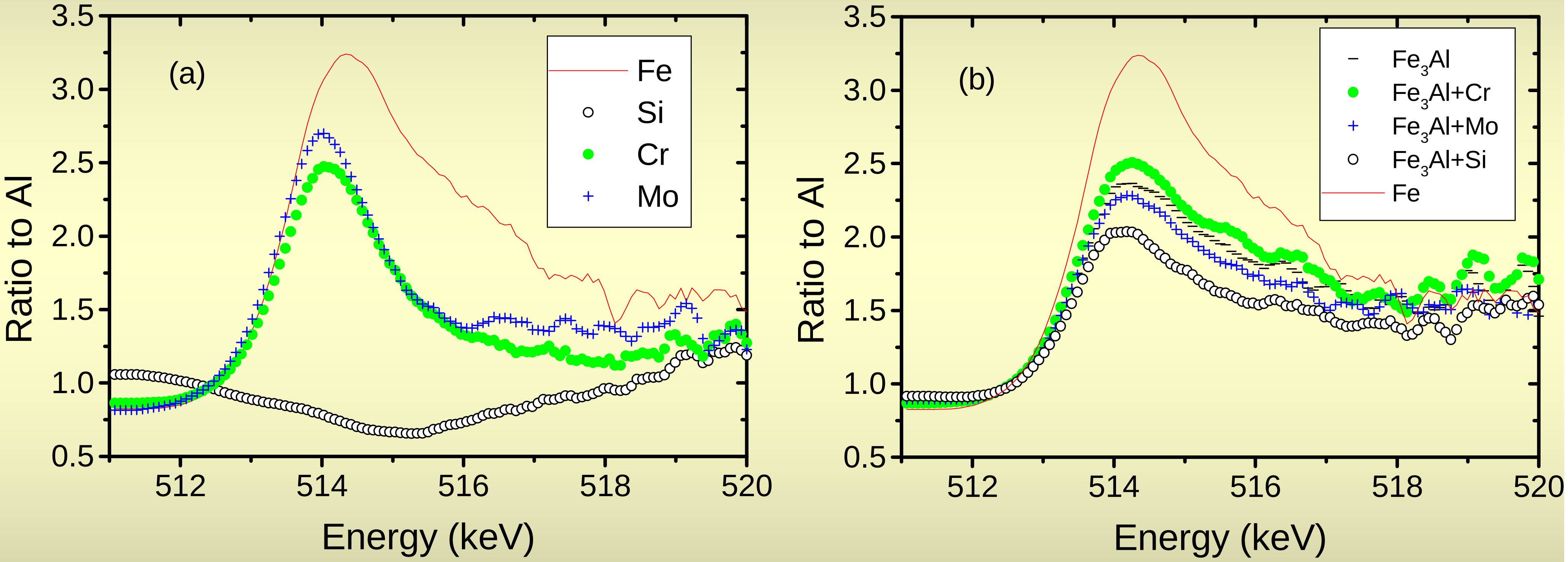
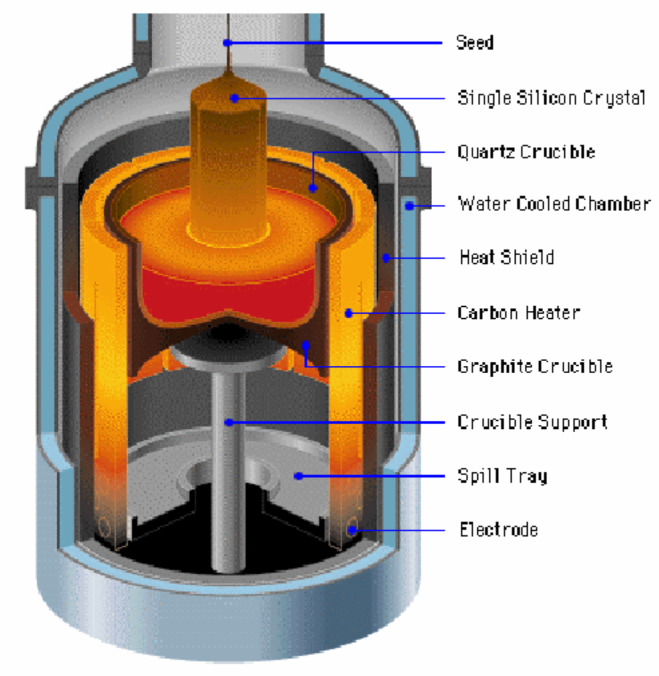
Doppler coincidence – alloys

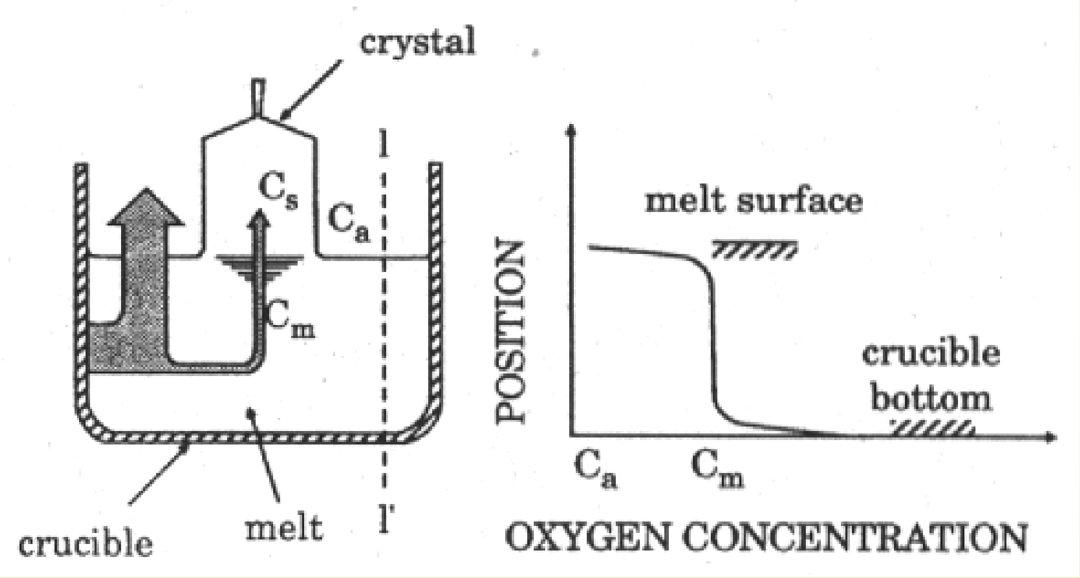


Not a simple sum!

1+2+3=Combine methods – case study

Czochralski-grown Silicon

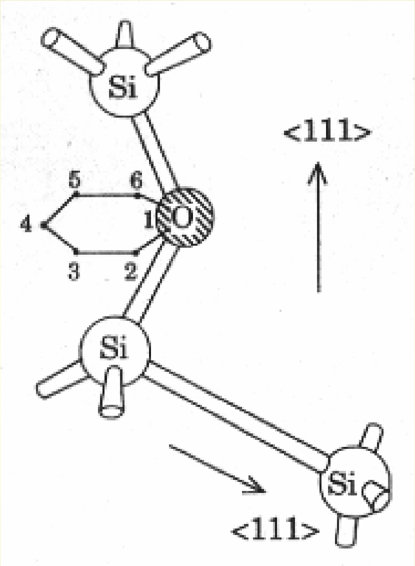




$c_O \approx 10^{18}\ \mathrm{cm}^{-3}$

$c_B \approx 10^{16}\ \mathrm{cm}^{-3}$

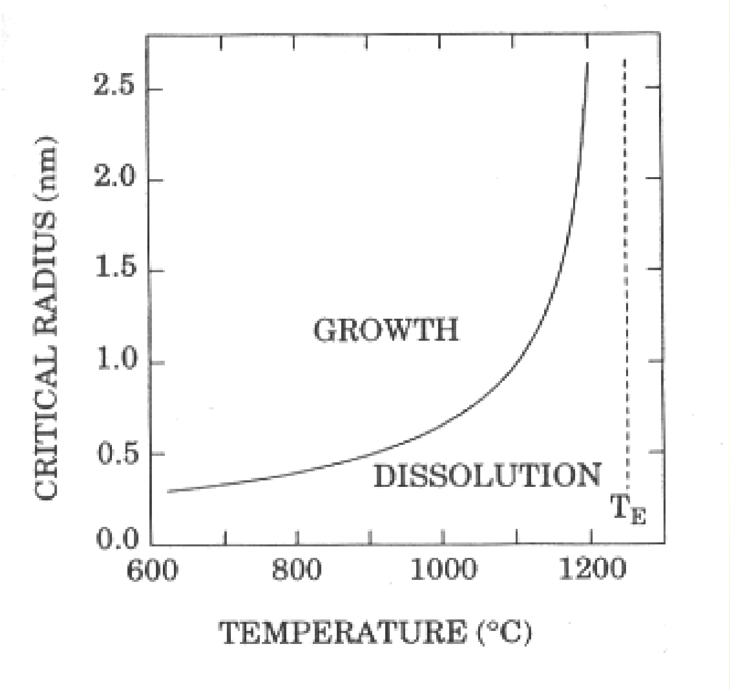
Oxygen in Cz-grown silicon



thermal donors

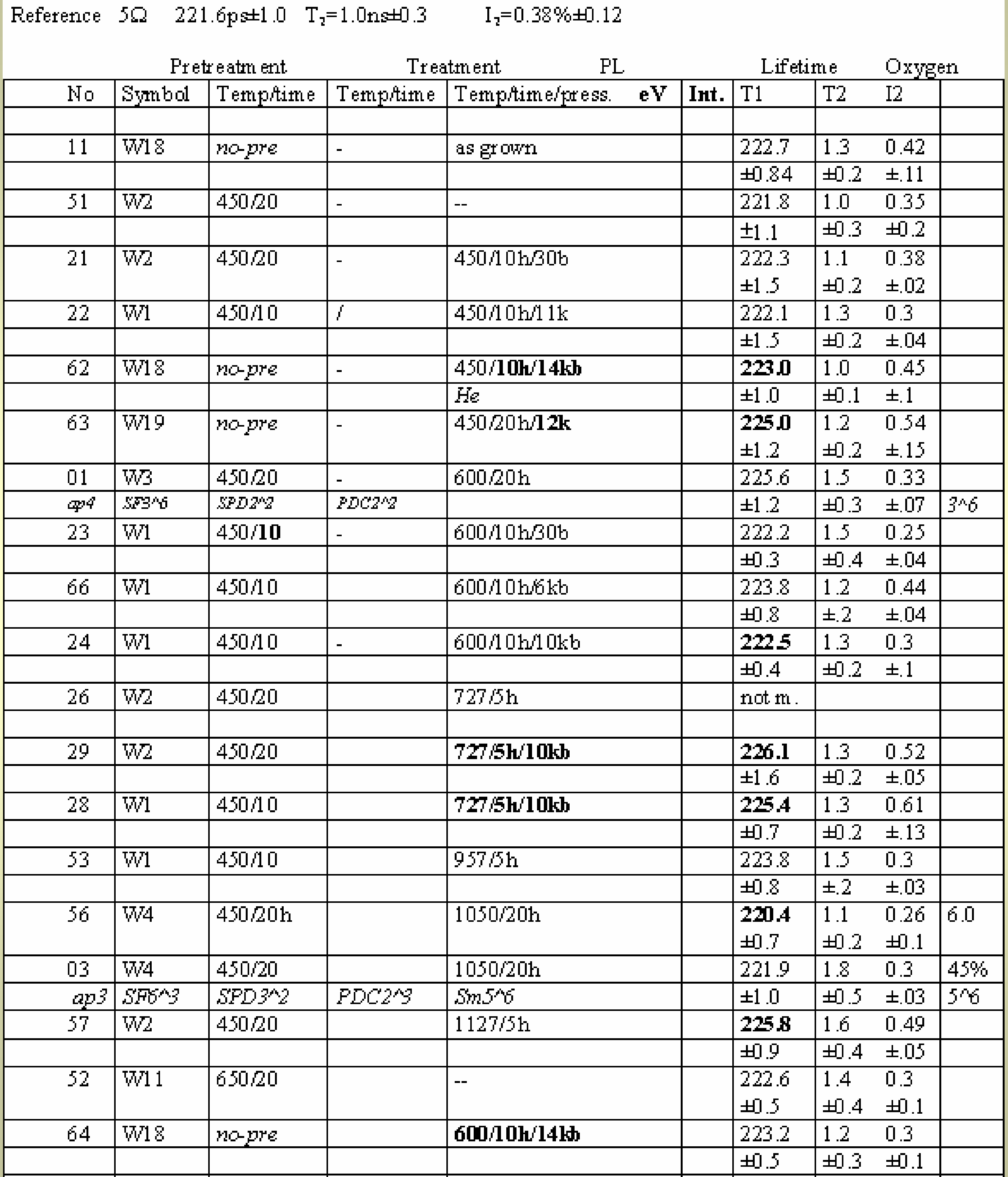
precipitates

new donors



“as grown”: annealed at 450°C

1.Positron lifetime

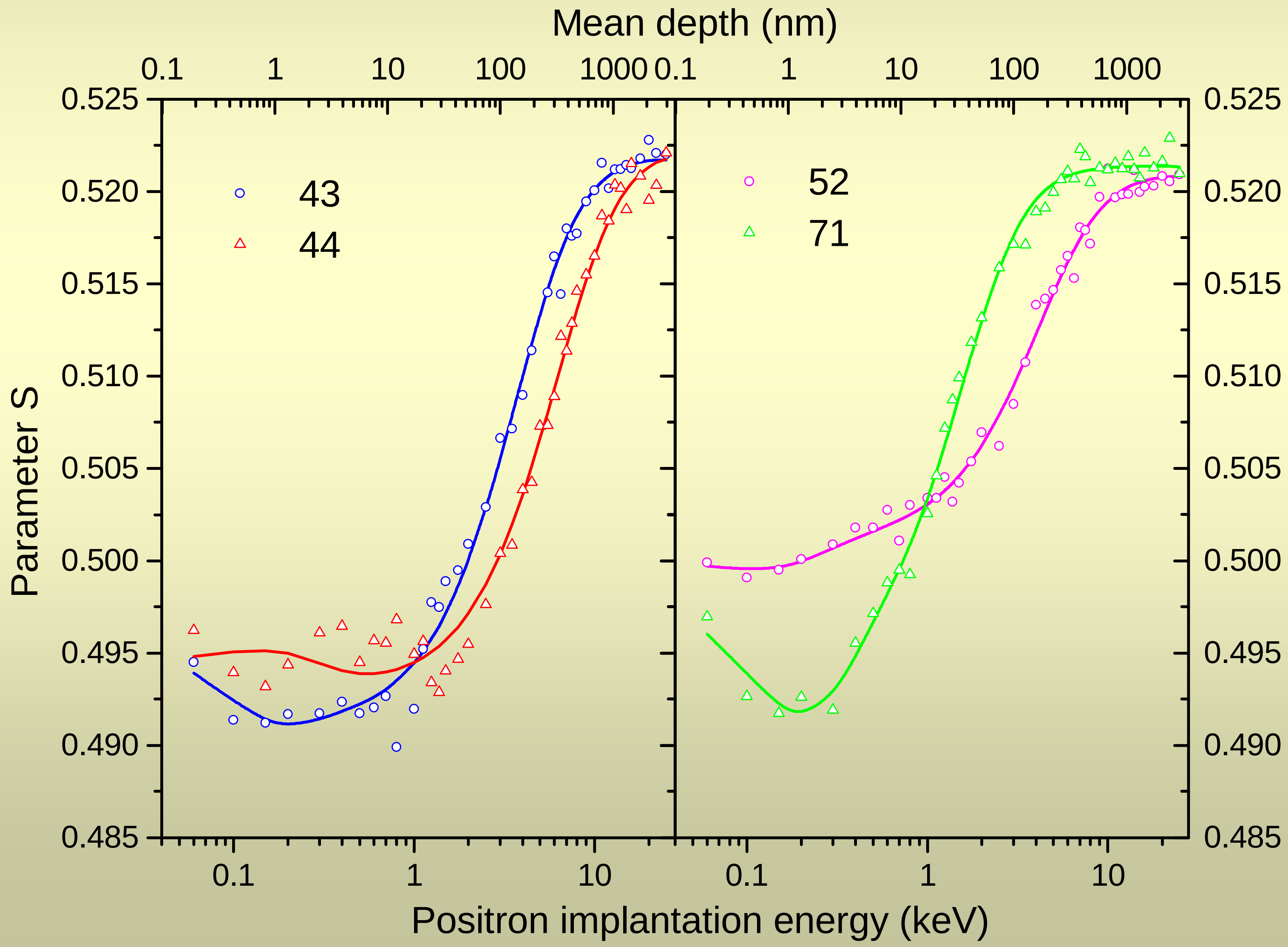


Reference 5Ω 221.6ps±1.0 T_2=1.0ns±0.3 I_2=0.38%±0.12

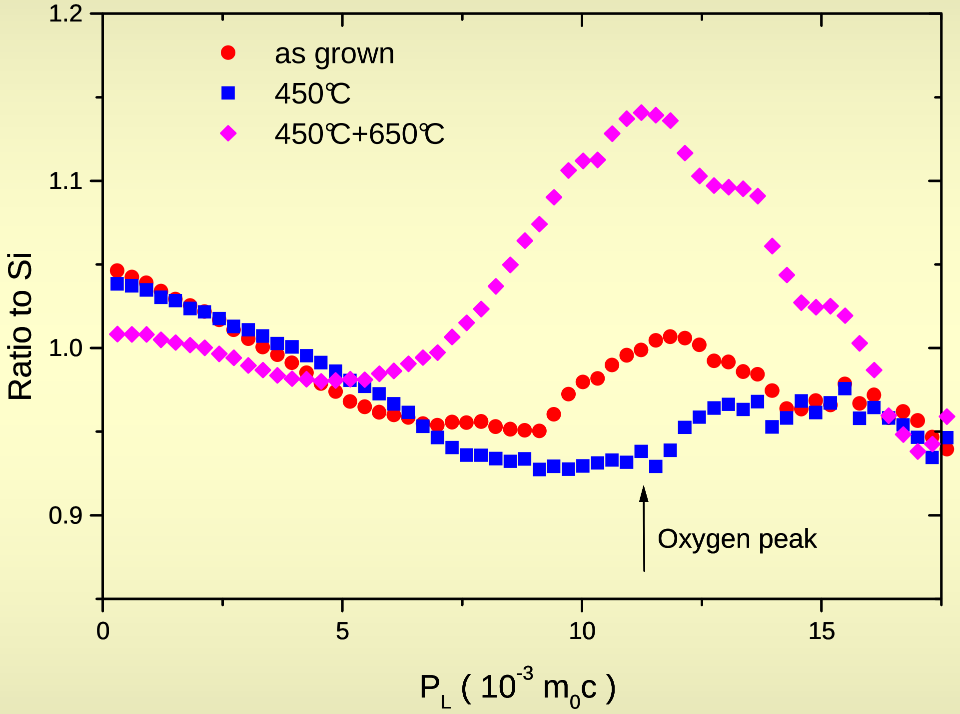
	Pretreatment		Treatment	PL		Lifetime		Oxygen	
No	Symbol	Temp/time	Temp/time	Temp/time/press. **eV**	**Int.**	T1	T2	I2	
11	W18	*no-pre*	-	as grown		222.7	1.3	0.42	
						±0.84	±0.2	±.11	
51	W2	450/20	-	--		221.8	1.0	0.35	
						±1.1	±0.3	±0.2	
21	W2	450/20	-	450/10h/30b		222.3 ±1.5	1.1 ±0.2	0.38 ±.02	
22	W1	450/10	/	450/10h/11k		222.1	1.3	0.3	
						±1.5	±0.2	±.04	
62	W18	*no-pre*	-	450/**10h/14kb**		**223.0**	1.0	0.45	
				He		±1.0	±0.1	±.1	
63	W19	*no-pre*	-	450/20h/**12k**		**225.0** ±1.2	1.2 ±0.2	0.54 ±.15	
01	W3	450/20	-	600/20h		225.6	1.5	0.33	
ap4	*SF3^6*	*SPD2^2*	*PDC2^2*			±1.2	±0.3	±.07	*3^6*
23	W1	450/**10**	-	600/10h/30b		222.2	1.5	0.25	
						±0.3	±0.4	±.04	
66	W1	450/10		600/10h/6kb		223.8	1.2	0.44	
						±0.8	±.2	±.04	
24	W1	450/10	-	600/10h/10kb		**222.5**	1.3	0.3	
						±0.4	±0.2	±.1	
26	W2	450/20		727/5h		not m.			
29	W2	450/20		**727/5h/10kb**		**226.1**	1.3	0.52	
						±1.6	±0.2	±.05	
28	W1	450/10		**727/5h/10kb**		**225.4**	1.3	0.61	
						±0.7	±0.2	±.13	
53	W1	450/10		957/5h		223.8	1.5	0.3	
						±0.8	±.2	±.03	
56	W4	450/20h		1050/20h		**220.4** ±0.7	1.1 ±0.2	0.26 ±0.1	6.0
03	W4	450/20		1050/20h		221.9	1.8	0.3	45%
ap3	*SF6^3*	*SPD3^2*	*PDC2^3*	*Sm5^6*		±1.0	±0.5	±.03	*5^6*
57	W2	450/20		1127/5h		**225.8**	1.6	0.49	
						±0.9	±0.4	±.05	
52	W11	650/20		--		222.6 ±0.5	1.4 ±0.4	0.3 ±0.1	
64	W18	*no-pre*		**600/10h/14kb**		223.2	1.2	0.3	
						±0.5	±0.3	±0.1	

2. Doppler broadening – positron beam

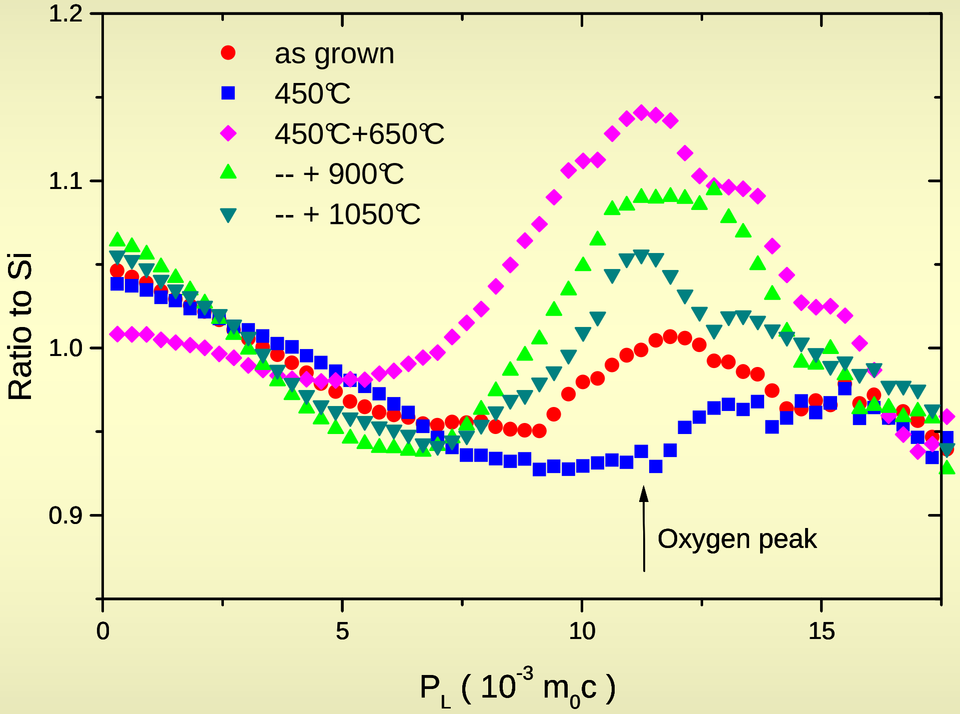
Oxygen in Cz-grown silicon



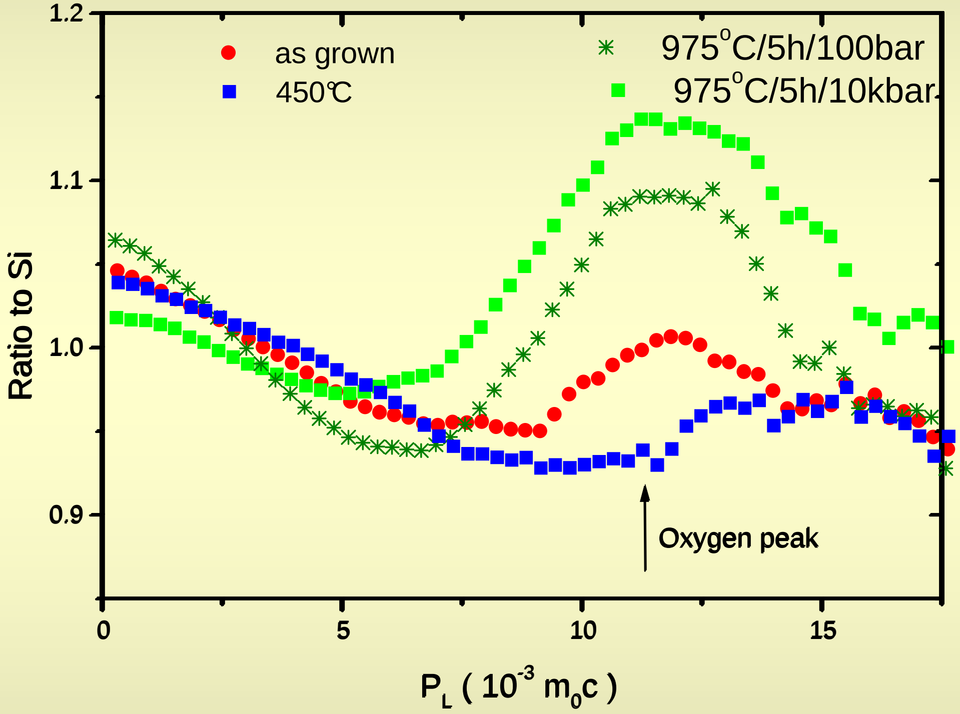
Oxygen in Cz-grown silicon



Oxygen in Cz-grown silicon



Oxygen in Cz-grown silicon



Silica based, low ε materials - structure

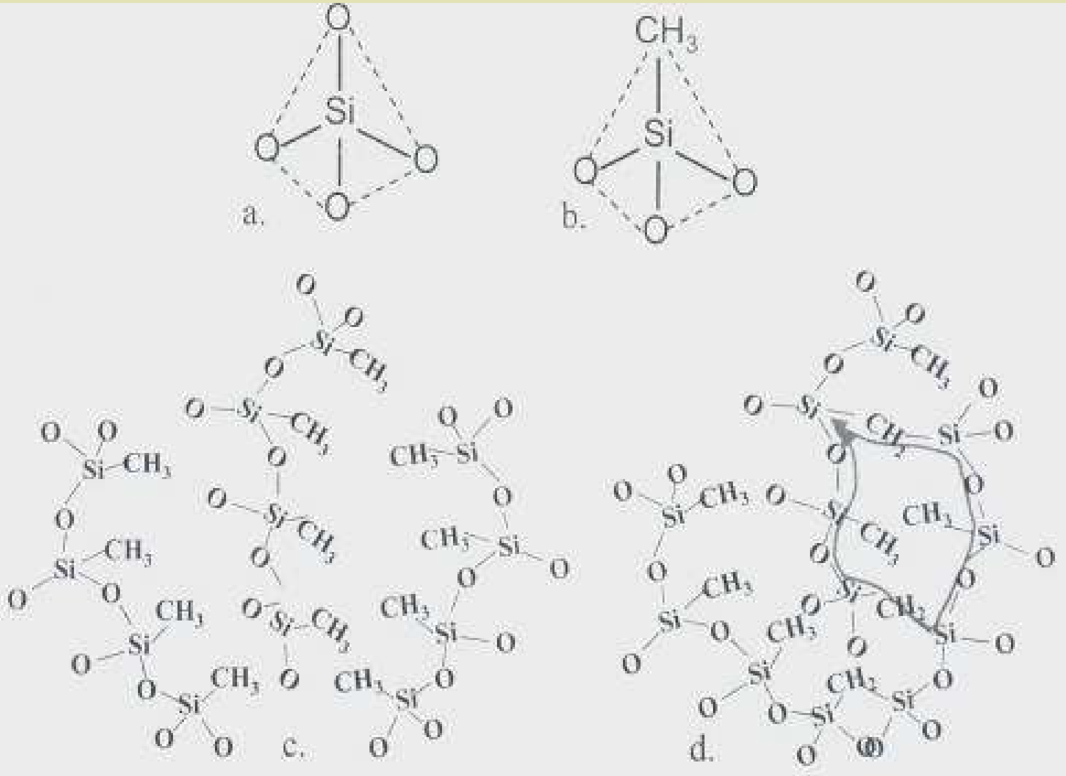
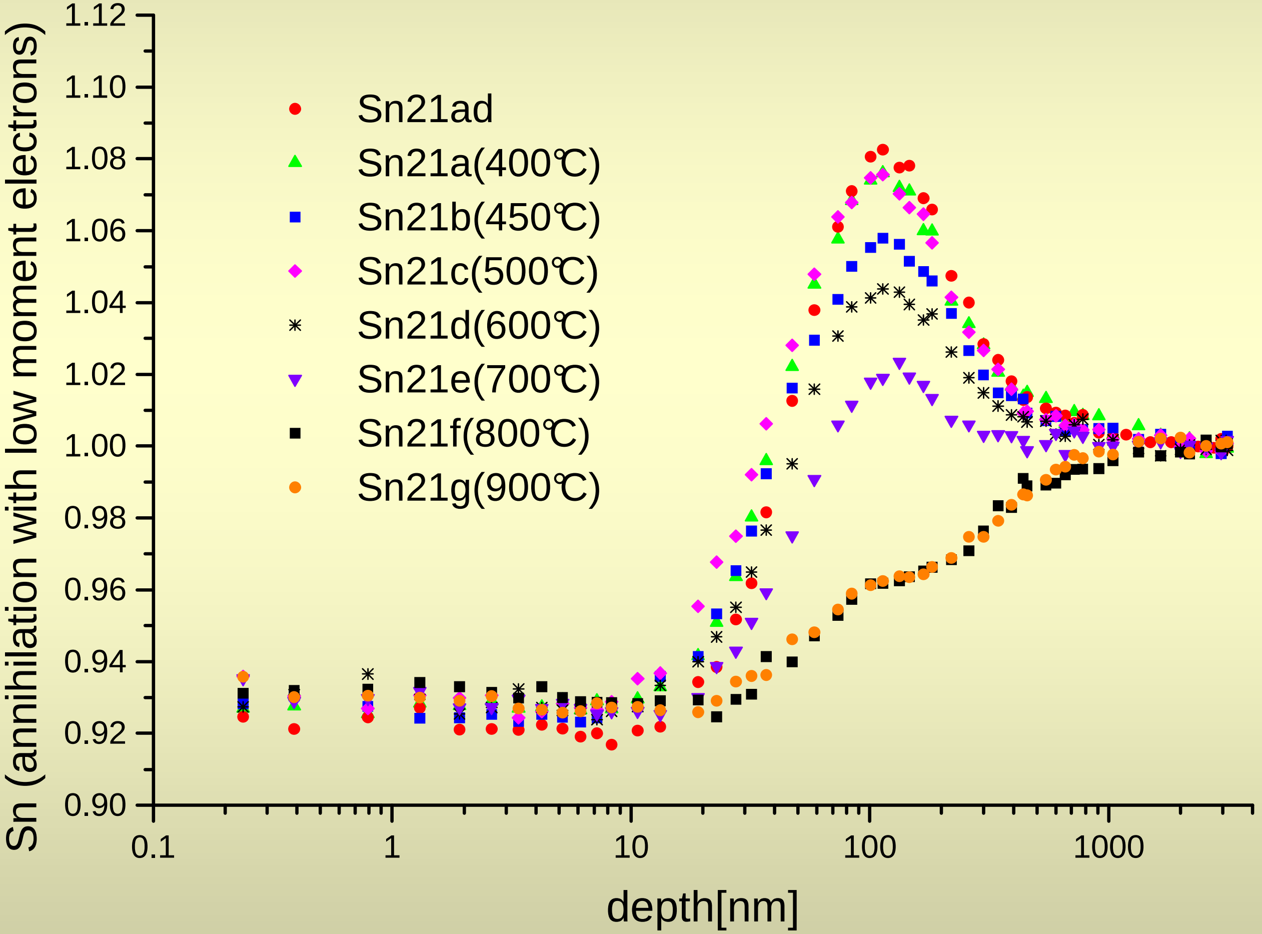


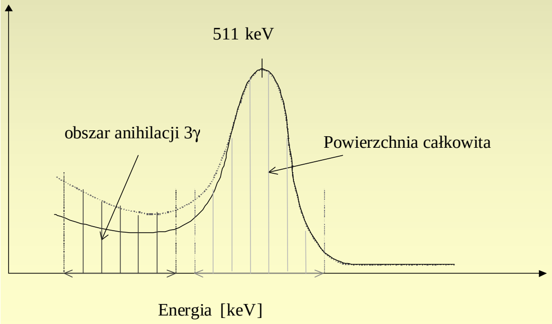
FIG. 5. Elementary unit of: (a) SiO_2, of (b) C doped silica glass and schematic bonding structure (c) without and (d) with cross linking.

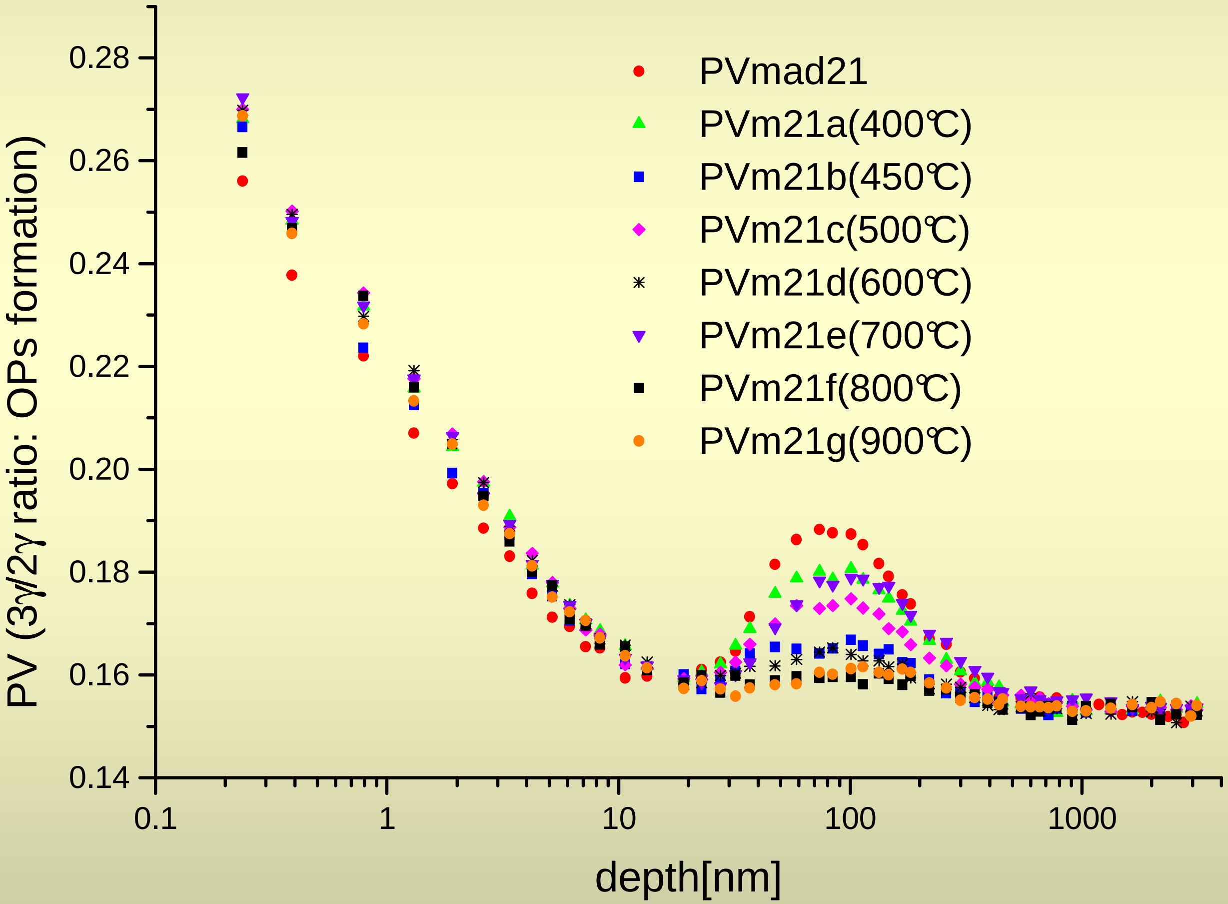
From K.Maex et al. J. Appl. Phys. 11, 93, 8793

low ε materials - annealing

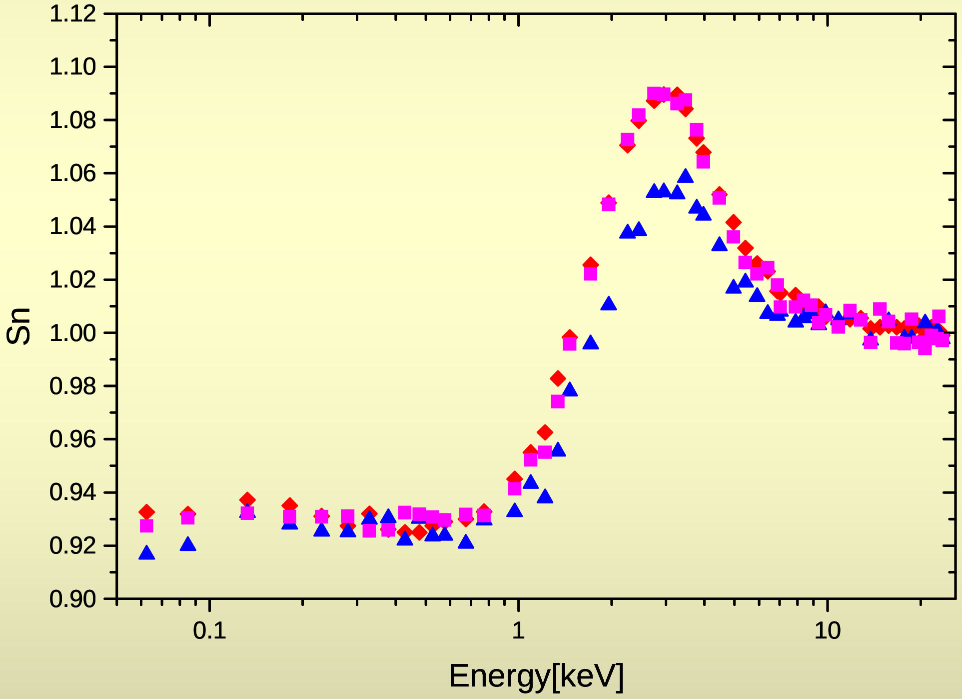


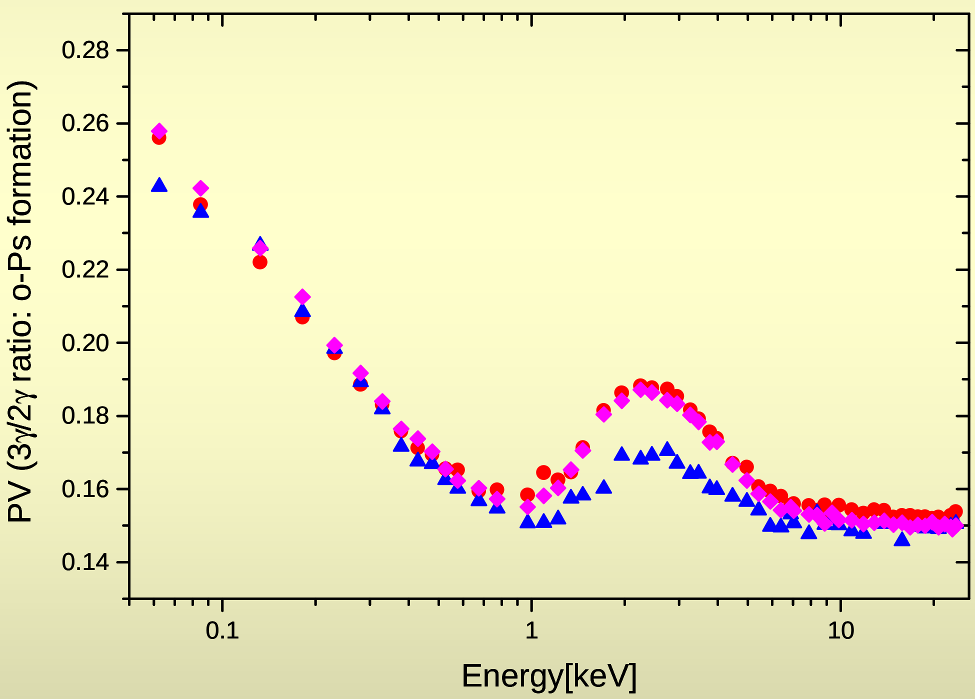
low ε materials - annealing





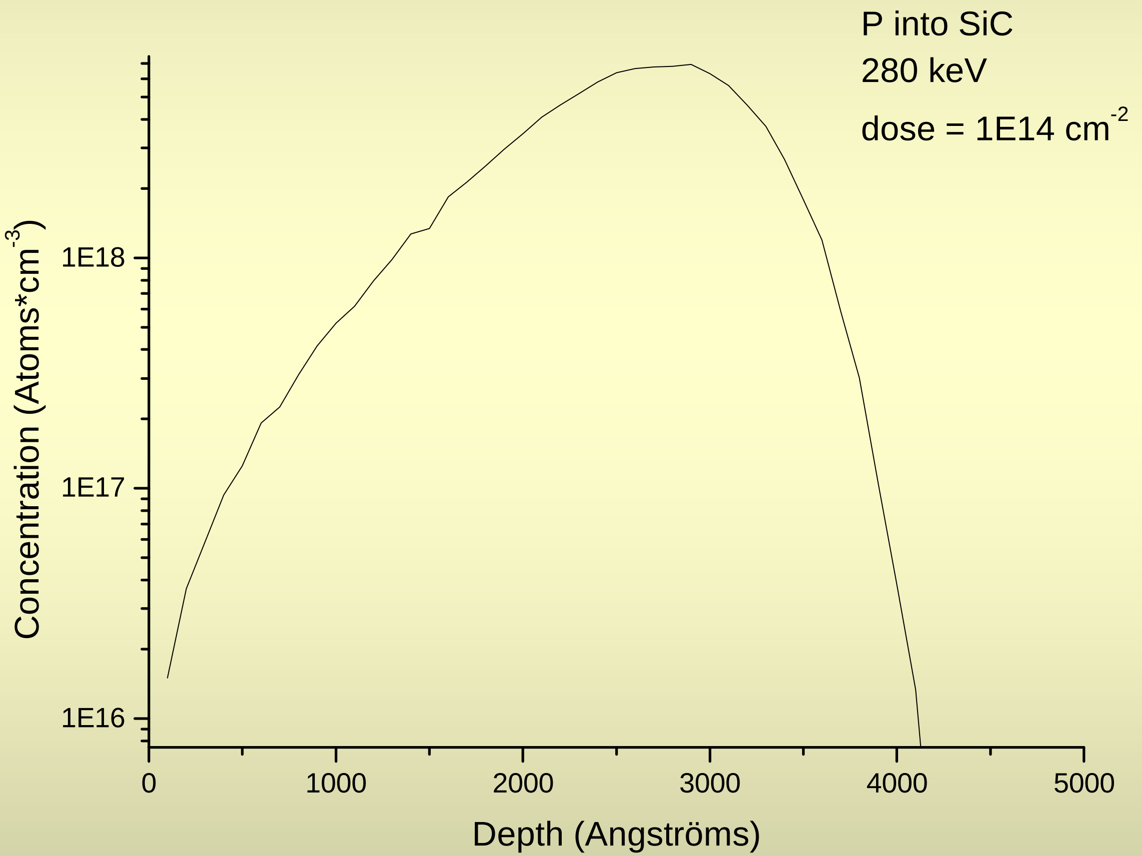
low ε materials - ageing





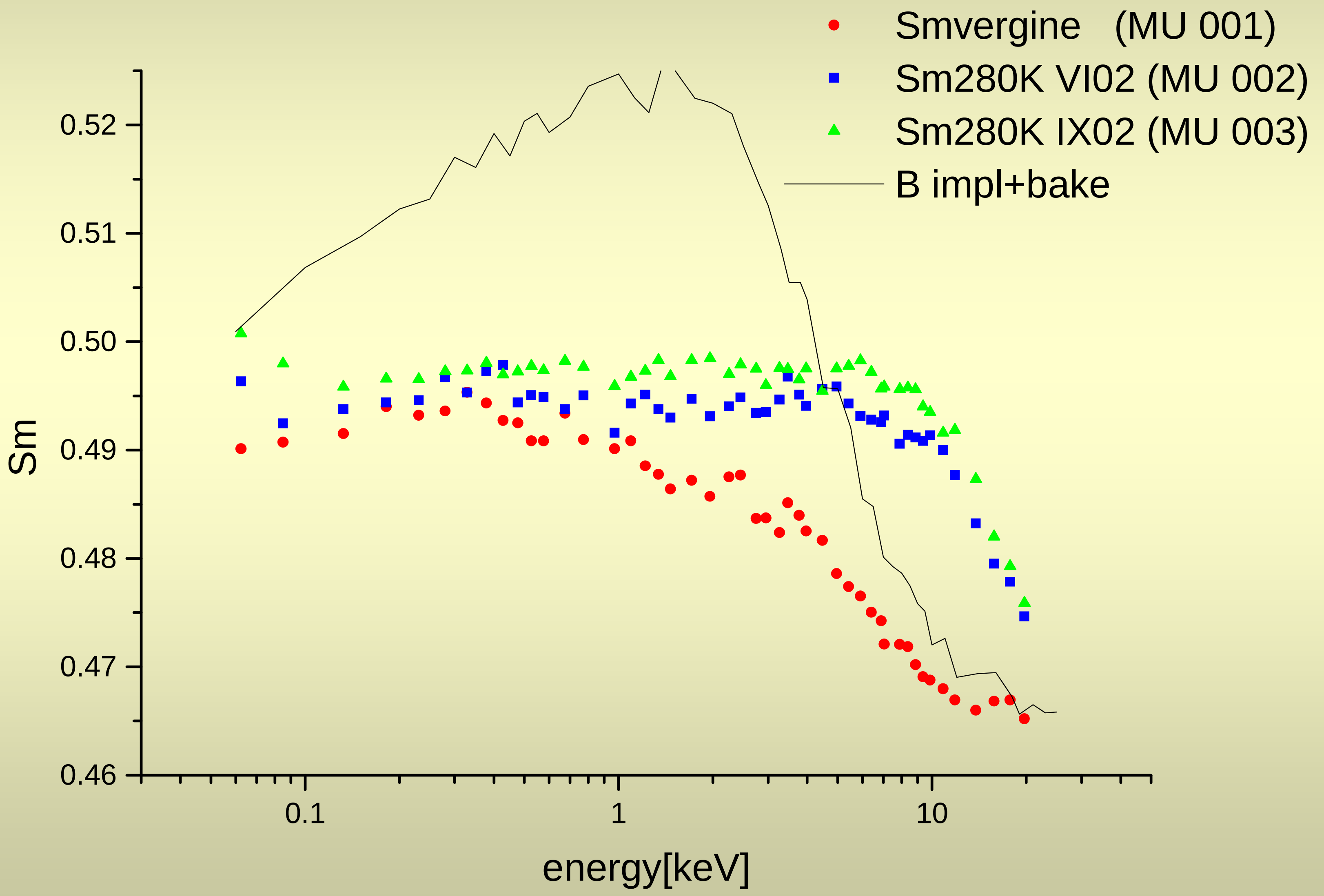
6*H*- SiC

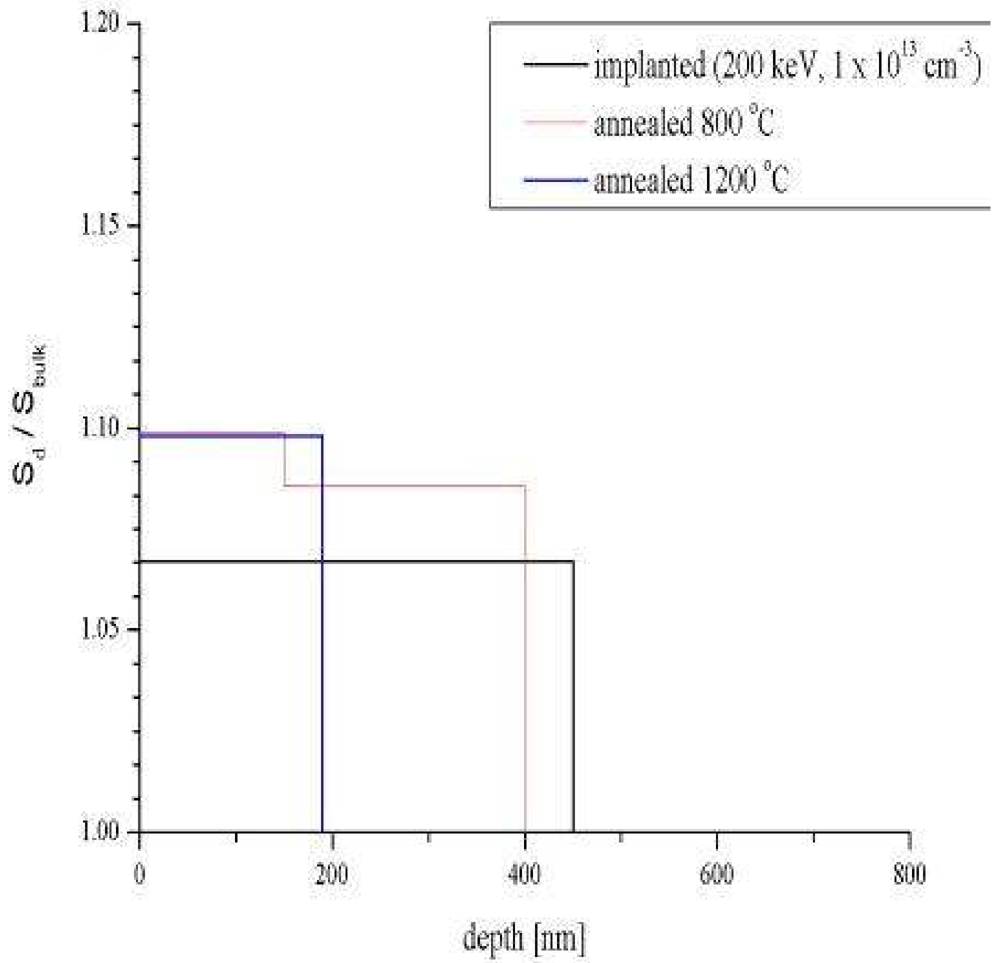
P^+ implanted 10^{14} cm^{-2} dose @280 keV



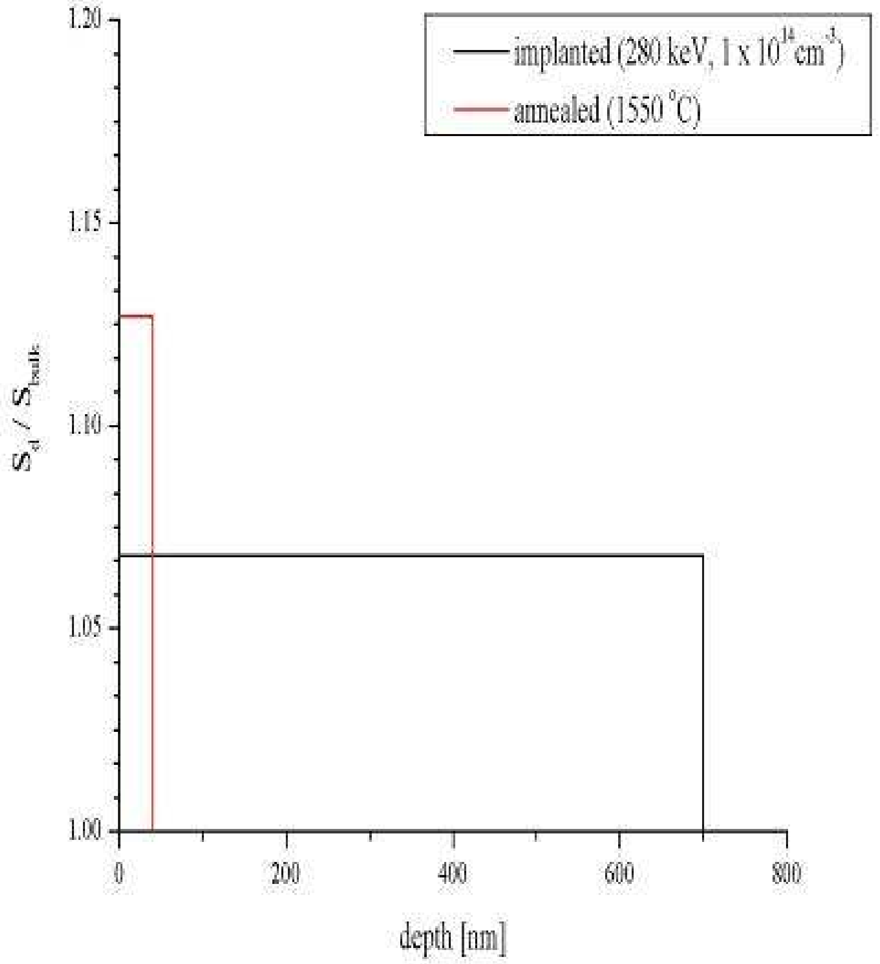
Annealed in 1550°C for 30 min

“S”- parameter (= No. of defects)



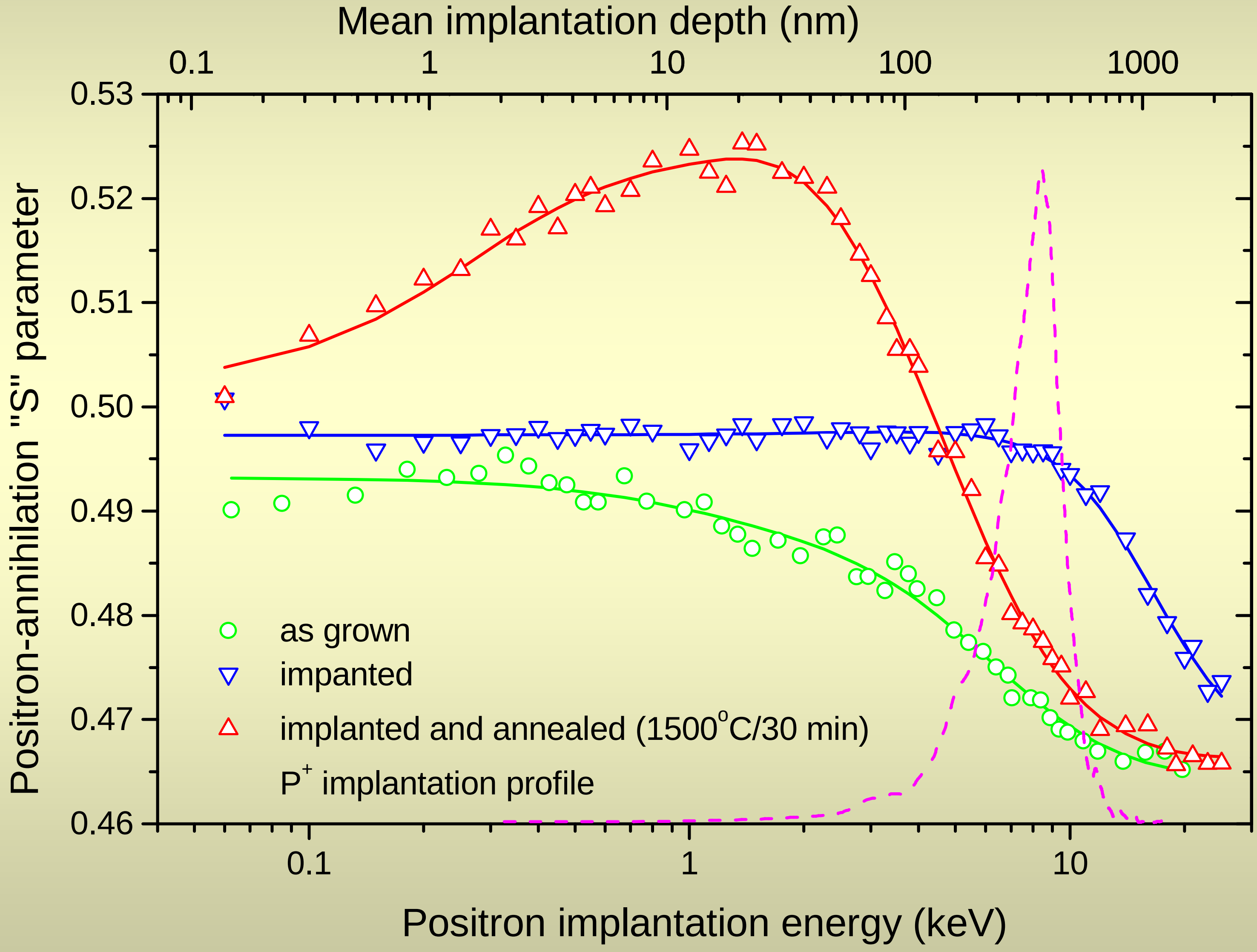


Ohshima *et al.*
[Appl Phys. A, **67**, 407-412 (1998)]

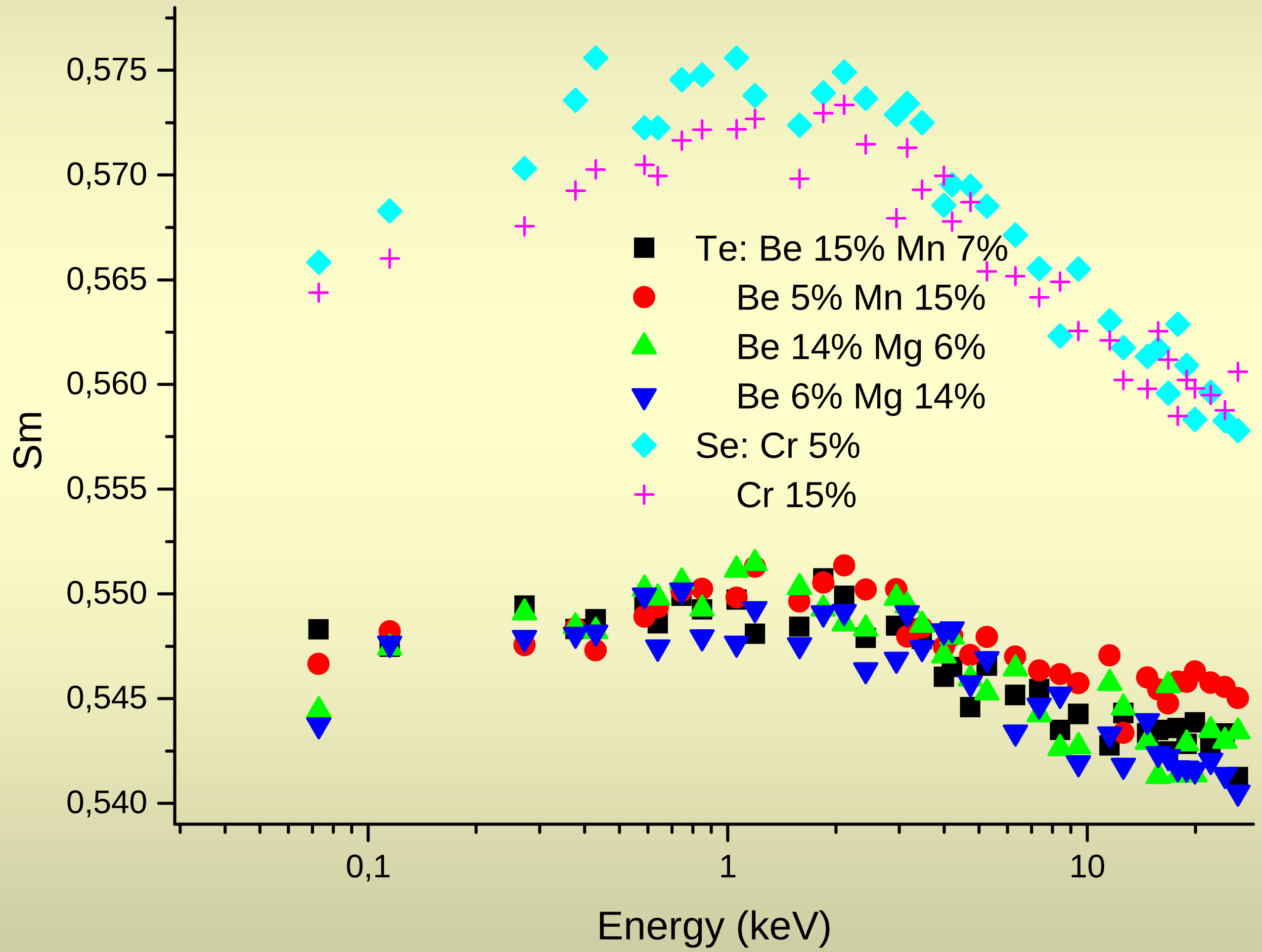


present

Modelling (`VEPFIT`)



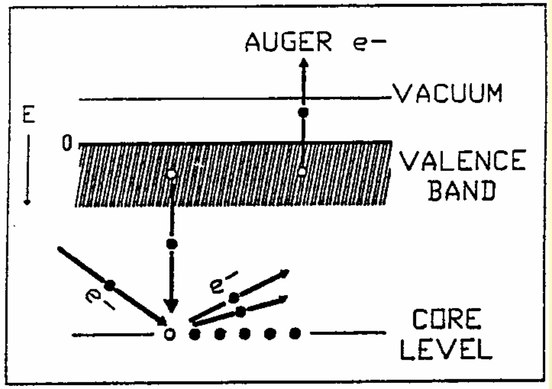
ZnSe and ZnTe



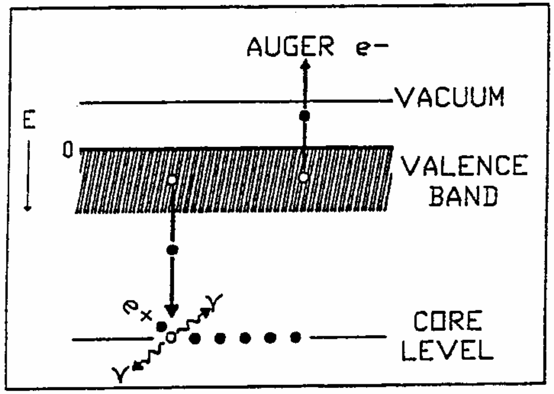
Positron Spectroscopy in Solid State Physics

Future ? **Combined techniques!**

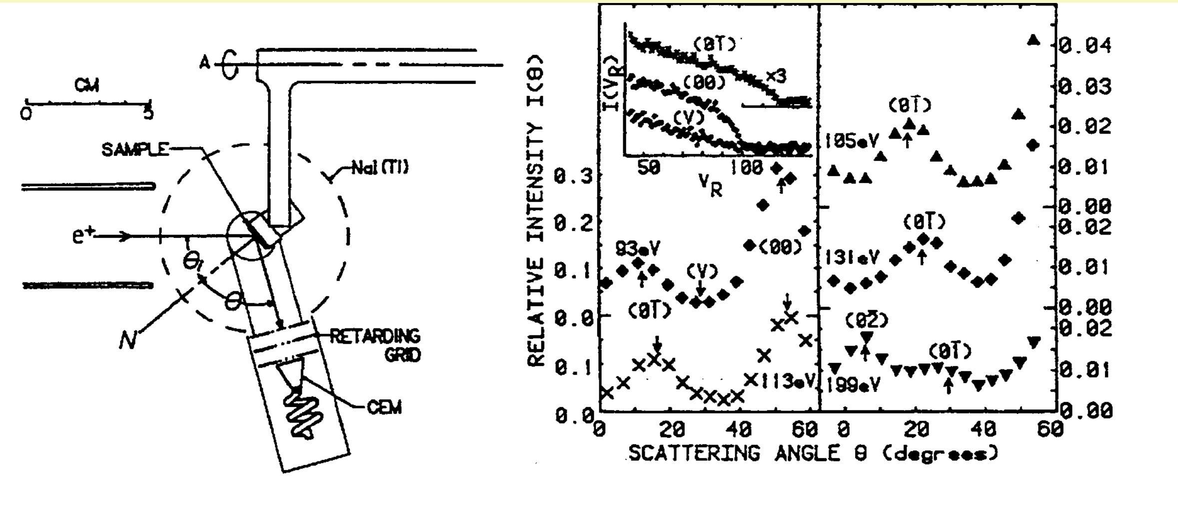
Auger Spectroscopy



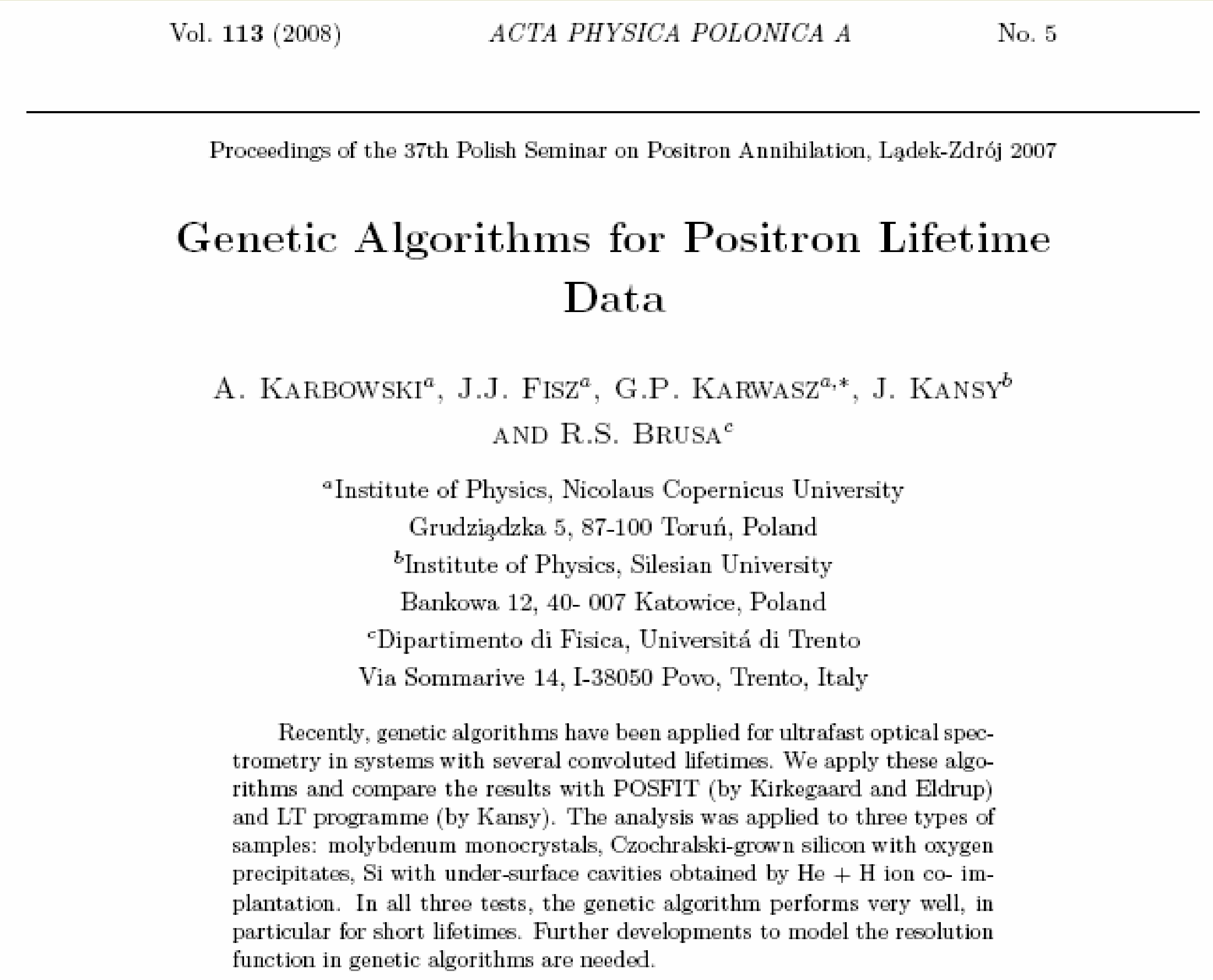
POSITRON A.E.S.



Low-energy Positron Diffraction



Genetic algorithm



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Proceedings of the 37th Polish Seminar on Positron Annihilation, Lądek-Zdrój 2007

Genetic Algorithms for Positron Lifetime Data

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Via Sommarive 14, I-38050 Povo, Trento, Italy

Recently, genetic algorithms have been applied for ultrafast optical spectrometry in systems with several convoluted lifetimes. We apply these algorithms and compare the results with POSFIT (by Kirkegaard and Eldrup) and LT programme (by Kansy). The analysis was applied to three types of samples: molybdenum monocrystals, Czochralski-grown silicon with oxygen precipitates, Si with under-surface cavities obtained by He + H ion co- implantation. In all three tests, the genetic algorithm performs very well, in particular for short lifetimes. Further developments to model the resolution function in genetic algorithms are needed.

Pozytony - narzędzie badań strukturalnych

Podziękowania:

Dr Antonio Zecca
Dr Roberto Brusa

Mgr Andrzej Karbowski
Prof. J. Fisz
Prof.. F. Firszt

Dziękuję!

More precipitates (in Trento)