Germanium Detectors in Positron Annihilation Spectroscopy Experiments

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Outline:

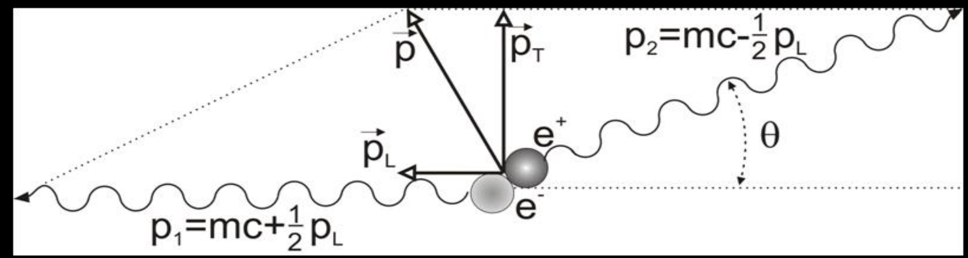
- Basics of PAS
- DBGL technique
  - spectrometer
  - analysis of annihilation line
- Example of application
- Summary

Basics of PAS

ANNIHILATION e^+e^-

$e^+ + e^- \rightarrow 2\gamma$

($99.8\ \%$, $E_\gamma \approx 511$ keV)



Two gamma quanta emission (511 keV) from the pair e^+e^- with momentum **p** annihilation.

POSITRON SOURCES

β^+ decay isotopes

$$p^+ = n + e^+ + \nu_e$$

Isotope	$T_{1/2}$	Positron energy [MeV]
^{11}C	20 min.	0.96
^{13}N	9.96 min.	1.20
^{15}O	2.05 min.	1.74
^{18}F	1.83 hours	0.64
^{22}Na	2.62 years	0.55
^{44}Ti	47 years	1.47
^{58}Co	71.3 days	0.48
^{64}Cu	12.8 hours	0.66
^{68}Ge	275 days	1.88

Examples of β^+ decay isotopes

INTERACTION

- elastic scattering
- nonelastic scattering
- bremsstrahlung

INSIDE THE MATTER

- implantation into medium
- thermalization
- diffusion
- annihilation with electron

THE DEVIATION FROM COLINEARITY

$$\theta = \frac{p_\perp}{mc}$$

CHANGING OF GAMMA QUANTA ENERGY
as a result of the Doppler shift

$$E_\gamma \cong m \cdot c^2 + E_B \pm \frac{p_\parallel \cdot c}{2}$$

Basics of PAS

EXPERIMENTAL TECHNIQUES

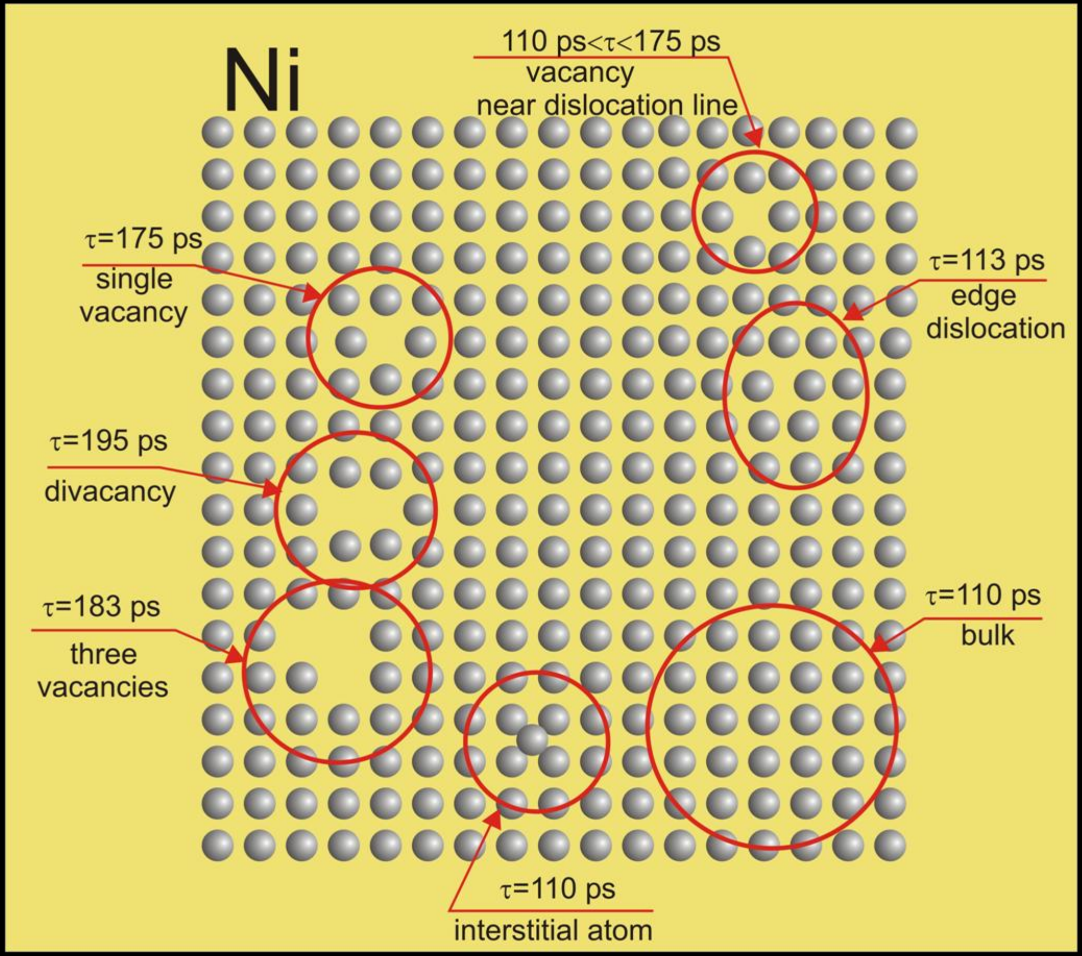
- Doppler broadening of annihilation gamma line (DBGL)
- positron life times (LT)

POSSIBILITIES

- defect concentration
- defect concentration profile
- detection of the kind and size of defects

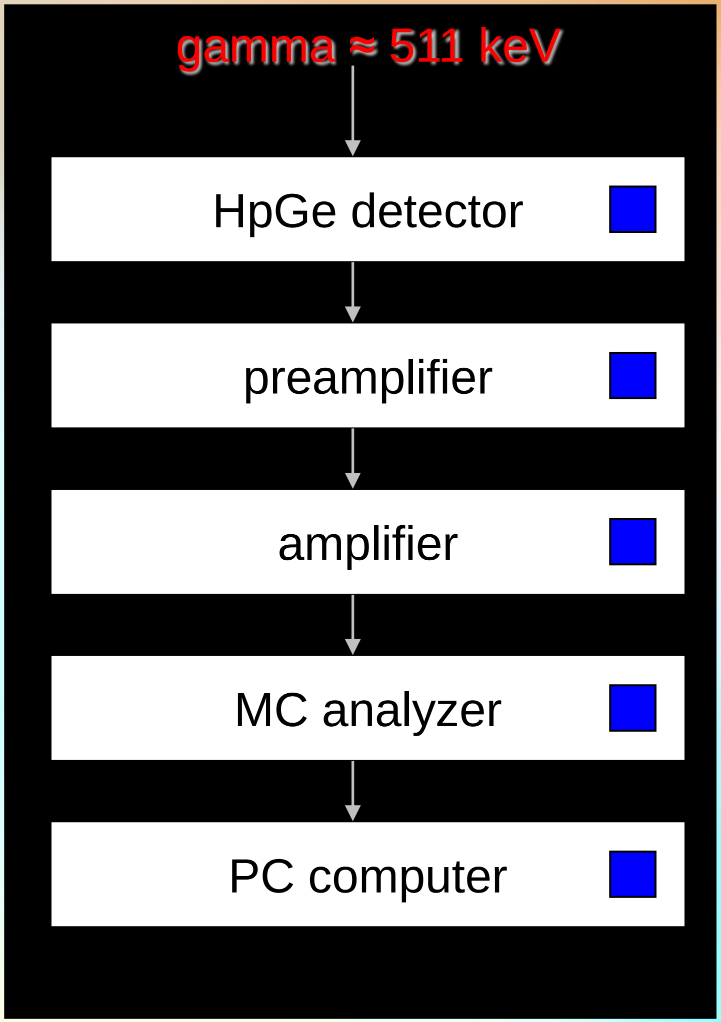
APPLICATIONS

- solid body physics
- material and surface engineering
- metals, semiconductors, thin layers



The examples of structural defects.

DBGL technique



The energy resolution of DBGL spectrometer at LEPTA project is 1.2 keV interpolated at 511 keV.

DBGL technique

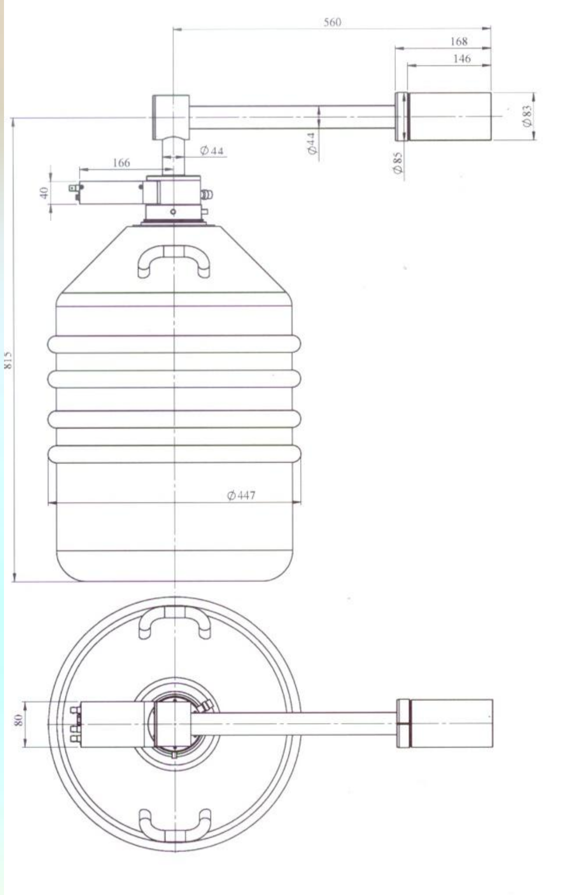
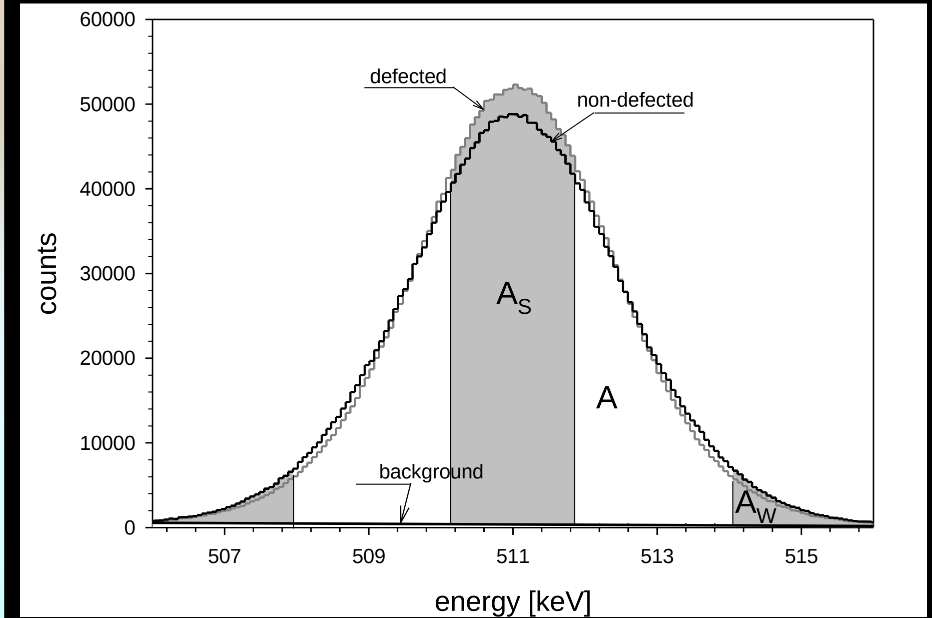


Fig 1. Detection unit GCD-30 185 overview

	Parameter Name	Value
1.	Gamma – ray energy range, keV	40 - 10000
2.	Energy resolution for energies, eV: 122 keV 511 keV 1332 keV *** total system resolution for a source at 1000 counts/s measured in accordance with ANSI/IEEE Std. 325-1996, using spectrum analyzer Multispectrum Hibrid, BSI Ltd.**	 834 1210 1787
3.	Relative efficency for energies 1,33 MeV to (NaI)Ti, % Peak/Compton ratio:	30.0 58:1
4.	Optimal shaping time, μs	6
5.	Optimal operating voltage, V, plus	4600
6.	Sensitive area: diameter, mm depth, mm	 57.4 57.45
7.	Al end cap thickness, mm	0.7
8.	Spacing between detector face and end cap window, mm	8
9.	Cooling	LN_2

DBGL technique



Comparison of annihilation lines for defected and nondefected samples. The rule of calculation of S- and W-parameters.

S - parameter

- relation of area under the central part of annihilation line to whole area below this line

$$S = \frac{A_S}{A}$$

- defines the participation of pairs positron-electron with low momentum
- the bigger value the bigger concentration of such defects as vacancies

W - parameter

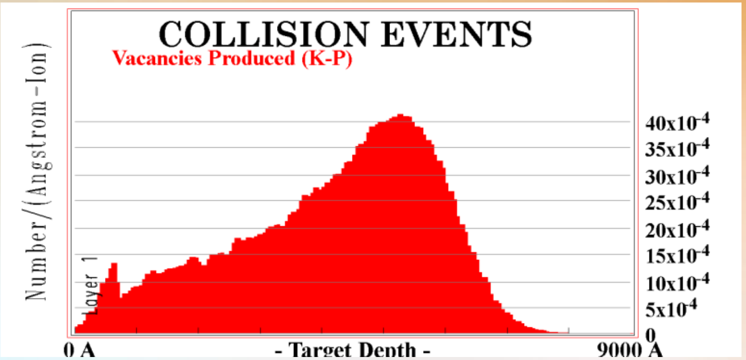
- defines the participation of pairs positron-electron with high momentum

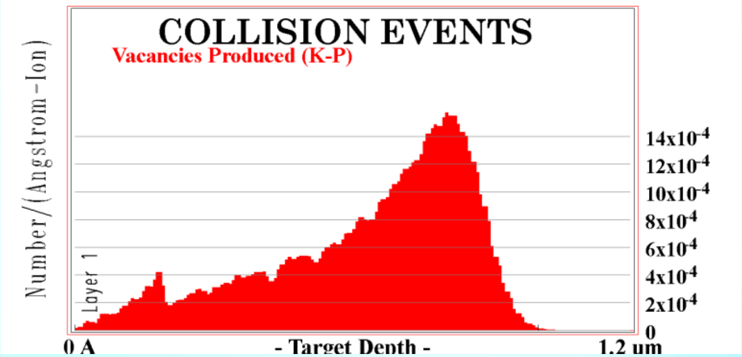
$$W = \frac{A_W}{A}$$

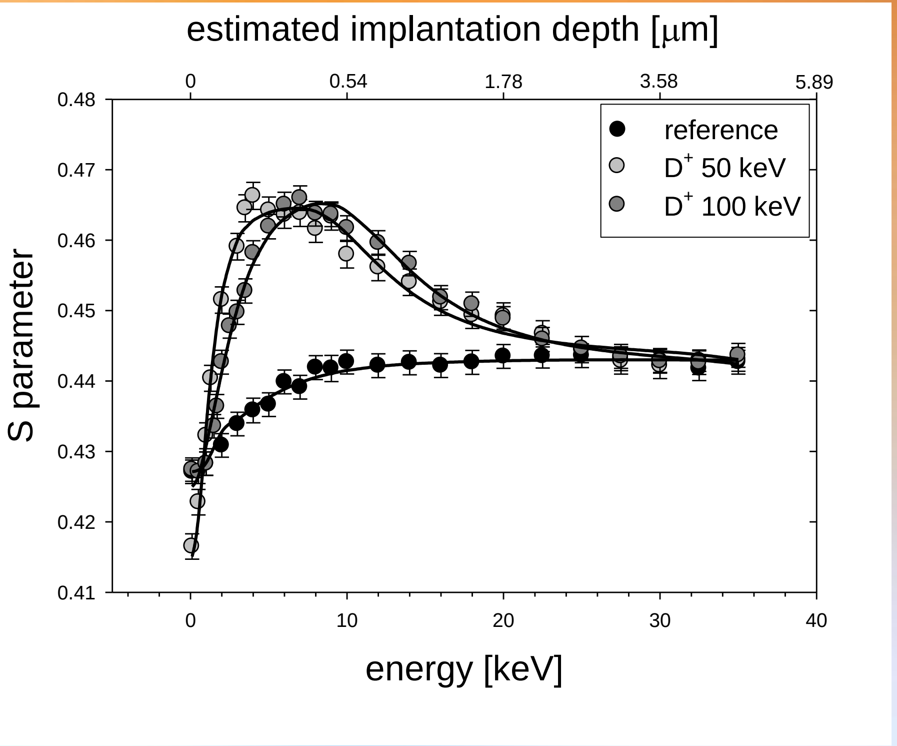
- together with S- parameter gives information about kinds of defects

At the beginning of the measurement session ΔE intervals are chosen to have about **0.5 for S- parameter** and lower than **0.01 for W- parameter**

Example of application







OBJECTS:

- ✓ Si (1,0,0) samples after deuterium implantation
- ✓ the fluence of D^+ beam: 6×10^{16} at/cm^2
- ✓ energy of D^+ beam: 50, 100 keV

THE DIFFUSION EQUATION

$$S(E) = S_{zone} + (S_{surface} - S_{zone}) \times \int_0^\infty P(x,E)\exp\left(-\frac{x}{L_+}\right)dx$$

✓ VEPFIT program solves it to fit the model function to experimental data

Example of application

THE DEFECT CONCENTRATION

$$C = \left[\left(\frac{L_{bulk}}{L_+} \right)^2 - 1 \right] \Big/ (\tau_{bulk} \mu)$$

where τ_{bulk} is 109.6 ps, μ is the trapping coefficient for divacancies in pure Si equal 8×10^{14} s^{-1}, L_{bulk} is 218 nm (the positron diffusion length) in the bulk)

Sample	L_+ [nm]	Thickness [nm]	C_{2V}
reference	220 (13)	-	-
50 keV	43 (1)	571 (18)	7.2×10^{18} cm^{-3}
100 keV	50 (1)	877 (27)	5.3×10^{18} cm^{-3}

It is usual to calculate the defect concentration of open volume defects (up to small vacancy cluster) with the positron trapping coefficient for divacancies $\mu_{2V}=8\times10^{14}$ s^{-1}. For comparison in the samples of Si multiimplanted with B ions with energies 50, 100 and 150 keV the concentration of divacancies observed by infrared absorption spectroscopy (IRAS) was ca. 1.8×10^{19} cm^{-3}.[Borner et.al, Phys. Rev. B 56 1997, 1393]

❑ Summary

- PAS is the sensitive method for detection the structural defects
- It does not need advanced detectors for measuring the annihilation characteristics
- HpGe detectors offered by many companies are fully available and they are not connected with high costs in comparison to huge experiments

Thank you for your attention !!!