GaAs Detectors with LiF Layer for Detection of Thermal Neutrons

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MOTIVATION

NEUTRON TRANSMISSION IMAGING

- **Complementary method to radiography**:
  (different attenuation coefficients of neutrons and X-rays)
- **Overcoming drawbacks of radiography**:
  (ability of neutrons to penetrate layers of thick material (Z > 90) and to effectively image the light elements)

SEMI-INSULATING GaAs DETECTORS

- **Successfully managed X-ray imaging with SI GaAs detectors**
  (Digital X-Ray Portable Scanner [1], Gamma-Ray Computer Tomograph for Industrial Purposes [2])
- **Radiation resistance of SI GaAs material**
  (proved radiation resistance of SI GaAs detectors to photons [3] and resistance of SI GaAs material to neutrons [4])

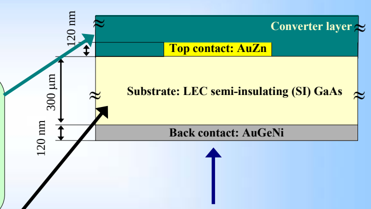
APPLICATIONS: petrology, geology, archeology, automotive and aviation industry, nuclear technology or as a complementary diagnostic method to X-ray radiography

NEUTRON DETECTORS

THE PHOTOGRAPH OF DETECTOR

SI GaAs detector ("C") with ^{6}LiF converter layer.

CROSS-SECTION VIEW OF DETECTOR



CONVERTER LAYER:

^{6}LiF (90 % enriched ^{6}Li):

$$^{6}Li + n \rightarrow \alpha(2.05 MeV) + ^{3}H(2.72 MeV)$$

Detector A: 8.8 mgLiF/cm², C: 2.9 mgLiF/cm²

Prepared at: Institute of Experimental and Applied Physics CTU in Prague, The Czech Republic

SUBSTRATE:

Resistivity 9.5 × 10⁷- 1.24 × 10⁸ Ωcm,
Hall mobility 4990 – 5120 cm²/Vs

Prepared by: CMK Ltd. Žarnovica, Slovakia

DETECTOR:

Top Schottky contact (circle ø 0.8 mm) Au
Back ohmic contact (full-back-side) AuGeNi

Prepared by: Institute of Electrical Engineering SAS in Bratislava, Slovakia

CURRENT-VOLTAGE CHARACTERISTICS

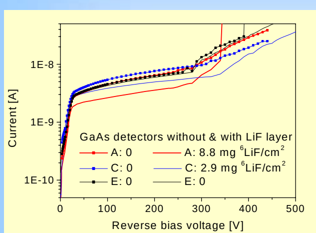


Figure 1: The reverse current-voltage characteristics of tested detectors.

- The Figure 1 shows the reverse current-voltage characteristics measured before and after the converter layer deposition onto the tested detectors
- Application of converter layer decreased the saturation reverse current at 303 K, depending on the surface density of the layer
- Thicker converter layer reduced the reverse current more markedly
- This phenomenon can be explained by the isolating character of the layer

CONCLUSIONS

- The SI GaAs detectors were successfully modified by ^{6}LiF converter layers to detectors of thermal neutrons
- The first measured spectra, when irradiating the detectors with thermal neutrons obtained from ^{239}Pu-Be source, showed the evidence of ^{6}Li (n, α) ^{3}H reaction
- The influence of the neutron converter layer thickness on the detection efficiency of SI GaAs neutron detectors was observed
- The application of the ^{6}LiF converter layer decreased the saturation reverse current, depending on the layer surface density

DETECTION OF NEUTRONS

NEUTRON SOURCE

Radionuclide ^{239}Pu-Be:

- ^{239}Pu – source of α (250 GBq, $T_{1/2}$ = 24,110 y)
- **$^{4}_{2}He + ^{9}_{4}Be \rightarrow ^{1}_{0}n + ^{12}_{6}C + 5.71$ MeV**
- Total yield of fast neutrons: 67 / 10⁶ α
- Flux of fast neutrons 1.7 × 10⁷ n / s
- Thermal neutrons obtained by deceleration in polyethylene

Table 1: α particles released from ^{239}Pu with subsequent γ-ray emission.

Energy α (MeV)	Probability (%)	Energy γ (keV)	Intensity γ / s
5.105	11.9	38.66	810 × 10⁷
		51.62	2,160 × 10⁷
5.144	17.1	12.98	680 × 10⁷
5.156	70.8	0.08	-

www.nndc.bnl.gov (National Nuclear Data Center, Brookhaven National Lab.)

OPTIMIZATION OF SETTING

- Former setting of GaAs detectors used for γ-ray detection (applied voltage 100 – 500 V, signal gain 1000) unsuitable
- Experimental dependence of depletion region depth in SI GaAs on the applied voltage (> 20 V):
  w [µm] = 24 + 0.7 × U [V] published in [5]
- The projected range of 2.05 MeV α particles from neutron conversion in GaAs is 6 µm
- Too deep depletion region ⇒ possible detection of gamma rays from the neutron source (Tab. 1), which intensity is about ~ 100 – 1,000 higher than the intensity of fast neutrons released from the used source
- Figure 2 shows the α spectra from ^{241}Am measured by the detector "E" (without converter layer) at different settings of voltage and gain.

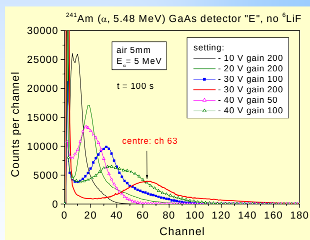
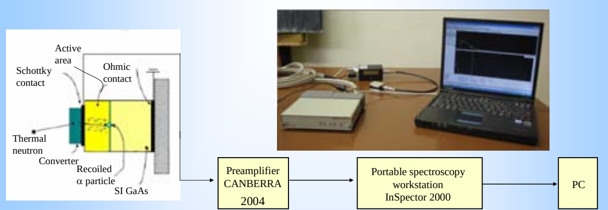


Figure 2: ^{241}Am alpha spectra measured by detector "E" (without converter layer).

- The energy of impinging α particles is 5 MeV (projected range in GaAs 17.7 µm) and position of the peak at chosen setting (- 30 V and 200 gain) is the channel 63. Expected position of 2.05 MeV α particles from neutron conversion is the channel 25.

MODEL OF CONVERSION REACTION & EXPERIMENTAL SET-UP



OBTAINED RESULTS

Table 2: The comparison of number of counts in peak detected by tested detectors with various surface densities of converter layers, when irradiated by thermal neutrons.

Detector label	^{6}LiF layer (mg/cm²)	Integrated counts per 24 h
A	8.8	10,482
C	2.9	2,768
E	0	275

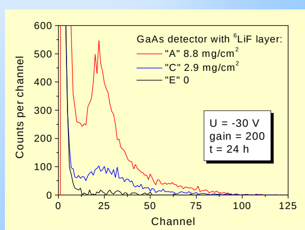


Figure 3: The spectra measured by tested detectors, when irradiated by thermal neutrons.

- The peak in spectra measured by irradiation of detectors with thermal neutrons was observed in channel 24 (detector "C") and channel 23 (detector "A"), which refers to the alpha particles with energy of about 2 MeV according to the results displayed in Figure 2 and proves the registration of ^{6}Li (n, α) ^{3}H reaction products.

References:

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[2] DUBECKÝ, F., et al.: Development and Performance of Imaging Radiation Detector based on Semi-insulating GaAs: Application in γ-ray Computer Tomograph for Industrial Purposes. In *Proceedings of the XIIth International Conference on Semiconducting and Insulating Materials SIMC-XII-2002*. Smolenice Castle, Slovakia (2002) pp. 258-264. 0-7803-7418-5/02/$17.00©2002 IEEE.

[3] LY ANH, T. et al.: Radiation resistance study of semi-insulating GaAs-based radiation detectors to extremely high gamma doses. In *Nuclear Physics B (Proc. Suppl.)* 150 (2006), pp. 402-406.

[4] MOROVIC, M. et al.: Electrical properties of semi-insulating GaAs irradiated with neutrons. In *Nuclear Instruments and Methods in Physics Research* **B197** (2002) pp. 240-246.

[5] CASTALDINI, A. et al.: Analysis of the active layer in SI GaAs Schottky diodes. In *Nuclear Instruments and Methods in Physics Research* **A410** (1998) pp. 79-84.

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