New Scintillation Materials and Systems for Registration of Ionizing Radiations[1]

V.L. Petrov, B.V. Shulgin, A.V. Kruzhalov, V.Yu. Ivanov, O.V. Ignatiev, A.N. Tcherepanov, D.V. Raikov, K.V. Ivanovskikh, A.V. Ischenko, M.M. Kidibaev*, T.S. Koroleva*, Ch.Pedrini**, K. Lebbou**, B. Hautefeuille**, J.-M. Fourmigue***

Ural State Technical University–UPI, Mira Street, 19, Ekaterinburg, 620002, Russia, E-mail: bvs@dpt.ustu.ru
** Institute of Physics of NAS of Kyrgyzstan, Chui avenue, 265A, Bishkek, 720071, Kyrgyzstan*
*** Universitŭ Lyon 1, LPCML UMR 5620, Campus de la Doua, Villeurbanne, 69622, France*
**** Fibercryst S.A.S., rue Royale, 23, Lyon, 69001, France*

Abstract – Some new original results on advanced scintillation materials and detection systems for registration gamma-rays, neutrons, neutrinos, beta-particles, electron and ion radiation are presented.

1. Introduction

Scintillation method is still one of the main ones used for the detection of ionizing radiations. Universality of this method is considered to be its main advantage. It can be used for registration of almost all types of radiation in a wide range of energy (varying from several eV to 10 GeV).

In previous papers [1-3], we have reported results on the development of new scintillation materials and scintillation devices which have been made before 2005 (more than 100 inventions). In this short paper new original results are presented on advanced scintillation materials and scintillation detection systems developed and patented recently.

2. Scintillation materials

<u>(Li,Na)F based materials</u>. The new proposed scintillator [4] has the following composition (atomic %): $^6LiF:UO_2(NO_3)_2$ 99,94-99,98; ^3He 0,02-0,06. The registration of thermal neutrons occurs through the (n, б) reaction on the ^6Li-nuclei with an interaction cross section of 940Ч10^{-24} cm^2 and through the (n, p) reaction on the ^3He-nuclei with an interaction cross section of 4000Ч10^{-24} cm^2. Maximum of scintillation wavelength is $\lambda\sim$ 530 nm, Z_{eff} = 8.2. The efficiency of thermal neutron detection by the new compound is within 2-3 times the detection efficiency by the known compound $^6LiF:W$ [5] for current mode of scintillation detector.

For the registration of neutrinos, a new material was proposed [6] based on NaF with composition (mol%): NaF 99,97–99,60; YbF_3 0,01–0,3; $UO_2(NO_3)_2$ 0,01–0,05 and bound oxygen 0,01–0,05. The proposed NaF:Yb,U,O compound exhibits higher scintillation efficiency for neutrino detection due to the large neutrino capture cross-section by ^{176}Yb and ^{19}F isotopes and due to effective energy transfer to UO_5F luminescent centers [7].

<u>$(Ca,Sr)F_2$ based materials</u>. CaF_2:Eu is known as a good scintillation material for registration of thermal neutrons [8]. Two new scintillation materials based on CaF_2 have been developed in USTU-UPI. The first scintillator [9] has the following composition (atomic %): CaF_2 99,25-99,59; EuF_3 0,4-0,7; ^3He 0,01-0,05. The registration of thermal neutrons occurs through two ways. The first way is (n,p) reaction on the Eu-nuclei with an interaction cross section of 4600Ч10^{-24} cm^2 (for a natural composition of Eu isotopes). The second way is (n, p) reaction on the ^3He nuclei with a cross section of interaction of 4000Ч10^{-24} cm^2. Parameters of scintillations: τ = 800 ns, λ = 435 nm, Z_{eff} = 16.5, output is 52% of that of NaI:Tl (for ^{137}Cs), energy resolution is 12% (for ^{137}Cs).

The second new CaF_2 based scintillator was proposed for the registration of thermal and fast neutrons [10]. It has the composition (atomic %): CaF_2 99,25-99,59; EuF_3 0,39-0,66; ^3He 0,01-0,05; H 0,01-0,04. Due to the presence of H-nuclei, the proposed scintillator can detect fast neutrons. The scintillation parameters (decay time, maximum of scintillation wavelength, output, energy resolution) for $CaF_2:(Eu,^3He,H)$ are similar to scintillation parameters of $CaF_2:(Eu,^3He)$ described before.

$SrF_2:Er^{3+}$ as new (fast picoseconds range) VUV-scintillation material was proposed [11]. In $SrF_2:Er^{3+}$ crystals two emission bands in VUV-region were observed: the known band at 165.4 nm and a new fast emission band at 146.4 nm with a decay time around 500 ps. SrF_2:Tm (luminescence at 167 nm) and

[1] The work was supported by Detector Technology Center LTD (Ekaterinburg, Russia), FIBERCRYST firm (France), "University of Russia" grant (UR.02.01.433), NATO grant №PST.EAP.CLG 980674, ISTC grant №KR-994 and Russian-American program "Fundamental research and high education" (fond CRDF REC-005: grant EK-005-X1 Ural science-educated center "Advantage materials"

SrF_2:Nd (luminescence band at 187 nm) are promising VUV-scintillators as well [11].

AgCl-AgBr-AgI compound doped with Tl was proposed as a new scintillation material for the registration of gamma-rays and electron beams [12]. Parameters of the scintillator: $\lambda = 675$ nm, $\tau \sim 40$ ns, $Z_{eff} = 45.7$, transparent in the 0.4-40 мm range.

$AlN:Y_2O_3$ compound can be used as scintillation material [13]. X-ray luminescence spectra of $AlN:Y_2O_3$ exhibit two emission bands at 330-430 nm and 580-615 nm with a fluorescence decay time ≈ 50 ns. The intensity of the violet band is 10 times higher than the intensity of the red band. Another situation was discovered under pulse electron beam excitation. Two bands also are observed at 345-470 and 585-620 nm. But intensity of red band is much higher than intensity of violet band. This system allows discrimination of photons and electrons.

Glass based materials. The scintillation material $^6Li_2O\text{-}MgO\text{-}SiO_2\text{-}Ce^{3+}$ for registration of thermal neutrons was proposed [14] and is under development [15]. Parameters of scintillation: $\lambda = 400$ nm, decay time of fast component $\tau = 16.7\text{-}45.8$ ns, of slow components $\tau = 60\text{-}108$ ns. This glass has higher light output (1.25-1.8 times) than the well-known NE-905 glass [15].

3. Detection devices

In 2005 at USTU–UPI new scintillation detectors and systems for registration gamma-rays, beta-particles, electrons and neutrons have been developed with collaborators from France and Kyrgyzstan, and several inventions were proposed: "Fiber optic X-ray scintillation detector" on the base of AgCl-AgBr-AgI fibers [16], "Fast and thermal neutron scintillation detector" [17], "Scintillation detector of neutrons" [18], "Scintillation detector" with photodiode registration and spectrum shifter [19], "Scintillation sensor for electron and beta-particles registration" [20], "X-ray imaging scintillator" with 6 m space resolution [21], "Light fiber scintillation detector" on the base of BGO fiber [22], "Scintillation detector" [23] in collaboration with Fibercryst company, "Neutron scintillation detector" [24] in collaboration with State Optical Institute, spherical detector [25]. Some of these inventions are described below.

Scintillation wedge type detector for fast and thermal neutrons registration was proposed on the base of plastic and ^{6}Li glass scintillators [17], Fig. 1. Plastic H-containing scintillator in wedge form allows the registration of fast neutrons (decay time = 4-8 ns, λ= 420-440 nm). ^{6}Li-glass scintillator plates can be used for the registration of thermal neutrons (decay time of the main component: 60-80 ns, $\lambda = 390\text{-}400$ nm) and of gamma-rays. The detector works in account mode.

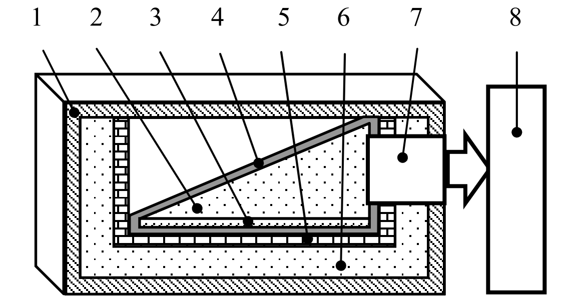

Fig. 1. Scintillation detector of fast and thermal neutrons: 1 – case; 2 – plastic H-containing scintillator; 3 – ^{6}Li-glass scintillator; 4 – light reflection film; 5 – Pb-collimator; 6 –-moderator and accumulator of thermal neutrons; 7 – photomultiplier; 8 – operation electronic block

Scintillation cone type detector for neutron registration was proposed using plastic and ^{6}Li-glass scintillators [18]. The scheme of the proposed device is presented in Fig.2. The fast neutrons are moderated by both external and internal H-containing moderators. Most of them are registered mainly by a ^{6}Li-glass scintillator disk ($\tau = 60\text{-}80$ ns, $\lambda = 390\text{-}400$ nm). The intermediate and slow neutrons are moderated mainly the external moderator and are registered by additional ^{6}Li-glass scintillator hollow cone. The detector works in account mode.

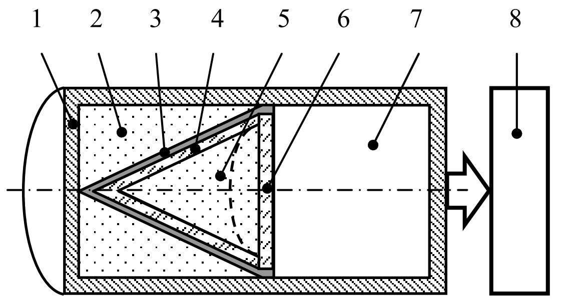

Fig. 2. Scintillation detector of neutrons: 1 – case; 2 – external moderator of neutrons; 3 – light reflection film; 4 – additional ^{6}Li-glass scintillator; 5 – internal moderator of neutrons; 6 – main ^{6}Li-glass scintillator; 7 – photomultiplier; 8 – operation block

Scintillation bulk-fiber type detector for registration of neutrons and gamma-rays was proposed using plastic and BGO fiber scintillators [23], Fig. 3. Plastic H-containing scintillating cylinder is used for the registration of fast neutrons ($\tau = 4\text{-}8$ ns, $\lambda = 420\text{-}480$ nm). BGO fibers are inserted inside a plastic scintillator situated between the mirror and the photodetector. BGO fibers are used for light collection of photons emitted by the plastic scintillator and as scintillation sensors for gamma-rays. Similar bulk-fiber construction for fast and thermal neutrons registration was proposed with ^{6}Li glass fibers [24].

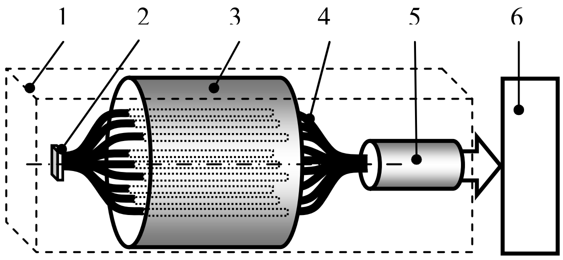

Fig. 3. Scintillation detector of neutrons: 1 – case; 2 – mirror; 3 – plastic scintillator; 4 – BGO fibers; 5 – photodetector; 6 – operation electronic block.

<u>Scintillation sensor for beta and electron radiation</u> was proposed [20]. The scheme of the proposed device is presented in Fig. 4. The sensor works as follows. Electron radiation passes through the wedge performer along the Z axis on the length of maximum extrapolated run of electrons. It means that only a part of the beta-radiation approach scintillation screen. So, along the X axis only a part of photodetector cells will be loaded. The last loaded cell will determine the thickness of the performer and it is possible to determine the energy maximum of incident radiation. Operation electronic block determine a coordinate of the last loaded cell and energy maximum of incident radiation.

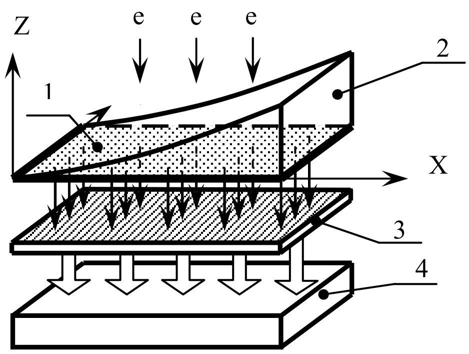

Fig. 4. Scintillation sensor for electron and β-radiation: 1 – one dimensional scintillation screen; 2 – performer of radiation; 3 – one dimensional photodetector; 4 – operation electronic block

<u>Scintillation spherical type detector for registration of gamma-rays and neutrons</u> was proposed [25], Fig. 5. This device contains a spherical scintillator (consisted of two hemispheres 1 and 2), reflecting layer 3 (disposed on the surface of the hemispheres), two PIN-photodiodes 4 and 5 (installed "back" to "back" into hole 6 situated into centers of the hemispheres), canal 7 for cable 8, which connects PIN-photodiodes with operation block 9. The device is situated into the case 10. Scintillating materials are CsI:Tl or $Bi_4Ge_3O_{12}$ or Lu_2SiO_5:Ce for gamma-rays detection and stilbene for neutrons detection. All photons appearing in hemispheres are focused to the center of the sphere (where PIN-photodiodes are situated) due to reflecting layer 3. So, the volume of the scintillation crystal is not limited by the dimensions of input windows of photodiodes. Furthermore, the proposed device provides 4p-geometry of light collection, improving its sensitivity to the radiation detection.

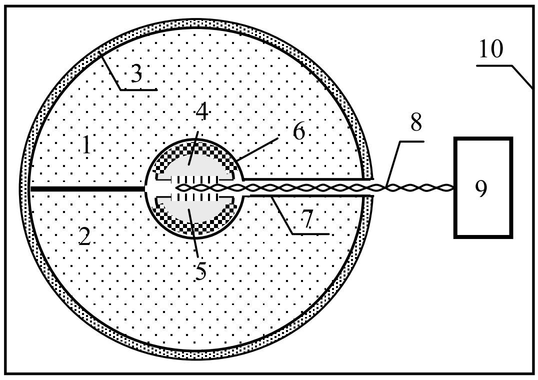

Fig. 5. Spherical radiation detector for registration of gamma-rays and neutrons

The examples of devices created on the base of new results obtained in USTU–UPI are shown below.

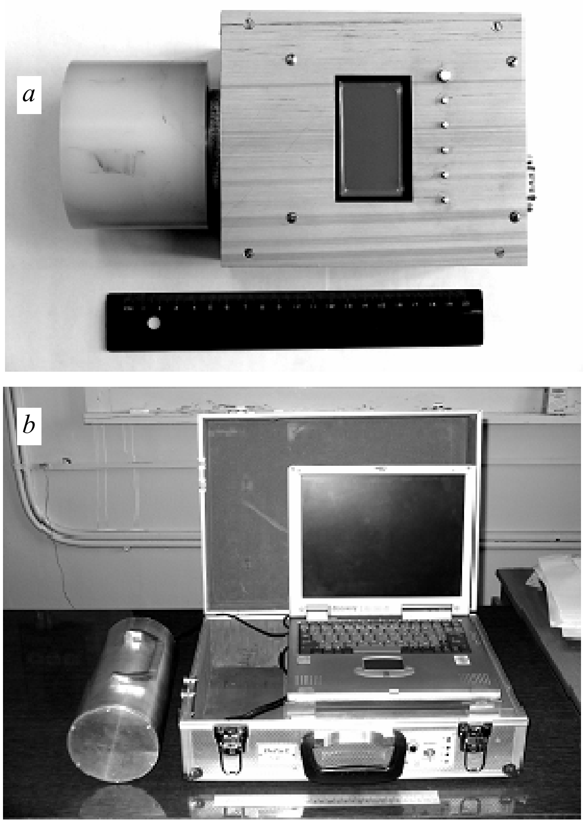

Fig. 6. Neutron detector (*a*) and gamma-spectrometer "PEGAS" (*b*)

The gamma-spectrometer "PEGAS" was created for ISTC project KR-994.

4. Conclusion

All proposed scintillation materials and devices can be used in nuclear physics, high energy physics, geophysics, biophysics, biochemistry, radiochemistry, for medical imaging, for industrial applications involving nondestructive radiation control, for radio ecological monitoring of areas, water and territories

References

[1] T.S.Koroleva, B.V.Shulgin, Ch.Pedrini, V.Yu.Ivanov, D.V.Raikov, A.N.Tcherepanov, NIM in Phys. Res., **A537**, 415 (2005).

[2] B.V.Shulgin, V.L.Petrov, V.Yu.Ivanov, A.N.Tcherepanov, T.S.Koroleva, Ch.Pedrini, K.Lebbou, O.Tillement, *Problem of spectroscopy and spectrometry*, Ekaterinburg, USTU–UPI, 2003, **Iss.15**, pp.158–175.

[3] B.V. Shulgin, V.L. Petrov, V.Yu. Ivanov, A.N. Tcherepanov, A.V. Anipko, T.S. Koroleva, Ch. Pedrini, Ch. Dujardin, K. Lebbou, O. Tillement, B. Hautefeuille, *in Proc. of the KEK-PCNP International School and Mini-workshop for Scintillating Crystals and their Applications in Particle and Nuclear Physics* (November 17–18, 2003. High Energy Accelerator Research Organization. KEK), 2004. pp. 71–86.

[4] B.V.Shulgin, A.N.Tcherepanov, V.Yu.Ivanov, T.S.Koroleva, S.V.Marks, V.L.Petrov, *Patent RU* 2270463, 2006.

[5] T.A.Charkina, L.G.Eidelman, V.I.Goriletsky, A.M.Kudin, *Book of Abstracts Int. Conf. on Inorganic Scintillators and Their Applications*, SCINT-95, 1995. P.161.

[6] B.V.Shulgin, G.S.Denisov, E.V.Varaksina, V.Yu.Ivanov, A.V.Ischenko, T.S.Koroleva, D.V.Raikov, A.N.Tcherepanov, *Application of patent RU* 2005140702, 2005.

[7] C.Pedrini, C.Dujardin, N.Garnier, *Problem of spectrometry and spectroscopy*, Ekaterinburg, USTU–UPI, 2002, **Iss.11**, pp.3-29.

[8] Yu.Ya.Stavisskii, A.V.Shopar, Rus. Pribori i Technika experimenta, **5,6**, 177 (1962).

[9] B.V.Shulgin, V.L.Petrov, V.Yu.Ivanov, D.V.Raikov, A.N.Tcherepanov, T.S.Koroleva, *Patent RU* 2244320, 2005.

[10] K.V.Ivanovskikh, V.Yu.Ivanov, V.L.Petrov, A.N.Tcherepanov, B.V.Shulgin, *Application of patent RU* 2004138913, 2004.

[11] K.V.Ivanovskikh, V.A.Pustovarov, M.Kirm, B.V.Shulgin, E.I.Zinin, *Int. conf. "Vacuum ultraviolet spectroscopy and radiation interaction with condesed matter VUVS 2005"*. Book of abstracts. Irkutsk, 2005.

[12] L.V.Zhukova, B.V.Shulgin, V.V.Zhukov, S.I.Gorkunova, D.V.Raikov, A.I.Chazov, A.V.Sergeev, *Application of patent RU* 2005114646, 2005.

[13] A.N.Tcherepanov, B.V.Shulgin,. Yu.D.Afonin, A.V.Sergeev, O.A.Snigireva, V.I.Solomonov, N.L.Tcherny, N.E.Poryvai, *Book of Abstracts SCINT 2005. International conference on inorganic scintillators and their industrial application*. Alushta, Ukraine, 2005, P.61.

[14] B.V.Shulgin, V.L.Petrov, V.A.Pustovarov, V.I.Arbuzov, D.V.Raikov, K.V.Ivanovskikh, and A.V.Ishchenko, Physics of the Solid State, **47**, *8*, 1464 (2005).

[15] V.I.Arbusov, N.Z.Andreeva, V.A.Vitenko, M.A.Milovidov, Radiation Measurements, **25**, *1-4*, 475 (1995).

[16] B.V.Shulgin, L.V.Zhukova, V.L.Petrov, D.V.Raikov, A.N.Tcherepanov, *Patent RU* 2248011, 2005.

[17] B.V.Shulgin, D.V.Raikov, V.I.Arbusov, K.V.Ivanoskikh, L.V.Viktorov, A.N.Tcherepanov, V.S.Andreev, V.L.Petrov, A.V.Kruzhalov, V.V.Sokolkin, *Patent RU* 2259573, 2005.

[18] D.V.Raikov, B.V.Shulgin, V.I.Arbusov, A.V.Kruzhalov, A.N.Tcherepanov, V.L.Petrov, P.V.Raikov, A.V.Ishenko, *Application of patent RU* 2004133470, 2004.

[19] B.V.Shulgin, D.V.Raikov, V.Yu.Ivanov, A.N.Tcherepanov, A.I.Kosse, V.I.Solomonov, T.S.Koroleva, M.M.Kidibaev, *Patent RU* 2248588, 2005.

[20] A.N.Tcherepanov, B.V.Shulgin, V.L.Petrov, T.S.Koroleva, *Patent RU* 2251124, 2005.

[21] A.N.Tcherepanov, B.V.Shulgin, T.S.Koroleva, Ch.Pedrini, Ch.Dujardin, *Patent RU* 2261459, 2005.

[22] B.V.Shulgin, A.N.Tcherepanov, V.Yu.Ivanov, T.S.Koroleva, Ch.Pedrini, B.Hautefeuille, O.Tillement, K.Lebbou, J.-M.Fourmigue, *Patent RU* 2262722, 2005.

[23] B.V.Shulgin, V.L.Petrov, A.V.Anipko, A.N.Tcherepanov, V.Yu.Ivanov, J.-M.Fourmigue, Ch.Pedrini, K.Lebbou, Ch.Dujardin, *Application of patent RU* 2005131345, 2005.

[24] V.I.Arbusov, K.V.Dukelskii, A.V.Kruzhalov, V.L.Petrov, D.V.Raikov, A.N.Tcherepanov, B.V.Shulgin, *Application of patent RU* 2005125151, 2005.

[25] B.V.Shulgin, V.Yu.Ivanov, T.S.Koroleva, A.I.Kosse, V.L.Petrov, D.V.Raikov, A.N.Tcherepanov, A.A.Chudinovskikh, *Application of patent RU* 2006103686, 2006.