Polished surface modification for fission fragments detection using NaI:Tl crystal

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It is well known that NaI:Tl crystal is widely used in experiments devoted to the search of Dark Matter. Present experiment DAMA and new perspective projects SABRE and AMORE involve the use of NaI:Tl crystals up to 250 mm in length. A goal of these experiments consists in registration of rare interactions between hypothetical WIMP particle and Na^+ or I^- ions. It has been assumed that possible events correspond to 3-10 keV energy in equivalent scale of γ-ray energy. To determinate real energy of noted ions we need a quenching factor. This factor show a difference in conversional efficiency η for concrete ion compared to electron efficiency. Unfortunately η value is well known for electron not for sodium or iodine ions. Value of the η for ^{23}Na can be estimated taking into account the quenching factor of similar ^{20}Ne ion with a mass close to the mass of sodium. For neon conversional efficiency can be determined compared to α-particles or γ-rays. Scintillation efficiency for α-particles can be determined directly.

As for $^{127}J^-$ ions, their η can be estimated by measuring the light yield for fission fragments from ^{252}Cf source. It is known that ^{252}Cf source emits fission fragments with an average energy of about 90 MeV. Light fragments have mass numbers about 105, and average mass of heavy fragments located near 140. So, the ^{127}J mass approximately coincides with average mass of fission fragments. The estimations noted above can be performed in one measurement, due to the presence of required peaks in pulse height spectrum of ^{252}Cf source. This spectrum contains a full absorption peak of α-particle (E_α = 6.08 MeV) and a double peak of the fission fragments is presented also.

It is well known that dead layer exists near polished surface of NaI:Tl crystal. Dead layer manifests itself like a decrease of scintillation efficiency for low energy X- and gamma-rays [1], as well as charged particles like alphas, which is absorbed near entrance surface of scintillator. It is clearly that dead layer has a great importance for fission fragments detection due to big ionization density and as results its low penetration depth. Nature of dead layer closely connected with the presence of water molecules on the surface of scintillator.

The goal of present work consists in review of modern techniques of surface preparation to prevent the negative influence of dead layer on light yield. It has been shown that there are three methods how to prepare a surface for certain detection of slightly penetrating radiation, first of all charged particles and heavy ions.

The first technique rejects polishing. Entrance surface is prepared like a cleavage plane. Such surface has a low quantity of defects and widely used for X-ray detector production. Disadvantages of this technique consists in the fact that cleavage plane cannot be realized for sample with polycrystalline structure. Using of this method for perfect single crystal of large area is a problem also.

The second technique involves the use of a conventional polishing and existence of dead layer at initial stage. Recovery of dead layer has been achieved by using of photochemical modification of crystal surface. On a base of experimental results [2] we supposed that polished surface is contaminated by NaOH not a crystal hydrate $NaI{\cdot}2H_2O$. To delete hydroxyl ions we used an idea proposed in patent [3]. It is known that hydroxyl ions can be transformed to bicarbonate ions according to reaction:

$$NaOH + CO_2 = NaHCO_3 \qquad (1)$$

To shortening recovery process we used a photochemical treatment of sample which means an irradiation of entrance surface by UV light in CO_2 atmosphere [3].

The third way consist in prevention of dead layer formation on a stage of polishing. It has been shown that hydrolysis process is stimulated strongly by blue light illumination. To prevent dead layer we propose a conventional polishing by alcohol carried out in a red light. Subsequent rinsing of the sample is carried out in heptanes.

To confirm the efficiency of latest proposed technique we measure a pulse height spectra of NaI:Tl crystal with thallium concentration of 0.18 mole % at excitation by ^{252}Cf source. As it known this radionuclide emits α-particles of 6.08 MeV energy and fission fragments with average energy about 90 MeV.

Obtained results confirms the Kubota's conclusion presented in the paper [4] that scintillation efficiency of NaI:Tl crystals increase with growing of Tl concentration up to 0.22 mole %. Unfortunately Kubota used a surface polishing which causes a dead layer formation. So, the results of paper [4] can be improved.

It has been shown that developed technique of surface treatment permits to increase the light yield and enhance the energy resolution of NaI:Tl crystal compared to standard polishing of entrance surface. Improvement of spectrometric parameters is observed at excitation by α-particles as well as fission fragments or soft X-ray. For soft X-ray of 5.9 keV energy the presented results coincide with the data obtained for cleavage plane. It has been shown that measured quenching factor for fission fragments depends on the quality of surface polishing.

References:

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