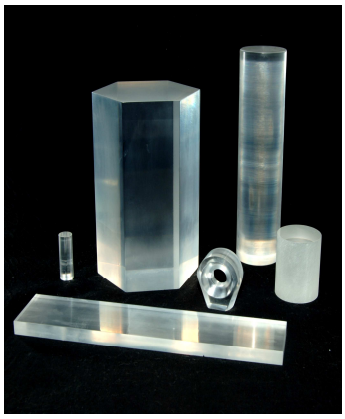
Scintillation Materials, Detectors and Electronics

Scintillation Material Data Sheet

ALKALII HALIDE SCINTILLATION CRYSTALS



A substantial part of scintillation materials for detectors of ionizing radiation is based on alkali halide single crystals. At present, they represent not less than 80% of the total quantity of scintillators used in the world. In traditional application fields of alkali-halide scintillators application, the scintillators used are based on two crystal matrices — NaI and CsI.

Single-crystal NaI (Tl) *is a classic scintillation crystal for detecting of gamma-radiation of intermediate and low energies. NaI (Tl) has very high luminescence efficiency and is available in single crystal or polycrystalline forms in a wide variety of sizes and geometries.*

Wide application of NaI (Tl) crystals is largely due to relative simplicity of using and low cost of crystals. Because of favourable combination of physical properties, NaI (Tl) scintillators are widely used in different detecting systems in radiation medicine, in apparatus for monitoring of radionuclides, in nuclear physics, high energy physics, geology, etc.

NaI (Tl) single crystals remain second to none among scintillator materials as for their light output, energy resolution, good matching of the radioluminescence spectrum to the maximum sensitivity region of commonly used PMT (415+5 nm) and fast response (among activated alkali metal iodides).

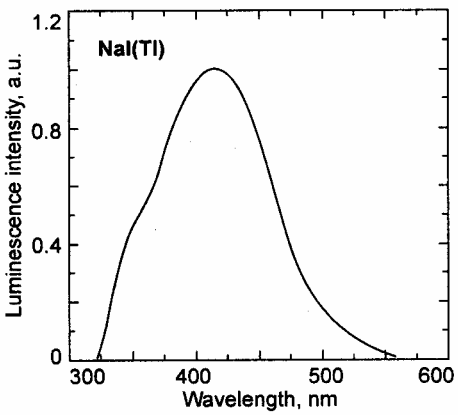


Fig.1. Fluorescence spectra of NaI (Tl) scintillator

Maximum of the thallium luminescence band (415 nm) lies near to the sensitivity maximum of standard photomultipliers (X-ray luminescence spectra of NaI (Tl) scintillator is shown in Fig.1 together with the sensitivity curves of standard photomultipliers).

NaI (Tl) single crystals have relatively high density and atomic number, which ensures high peak and full detection efficiency of gamma- and X-ray radiation. High transparence to the intrinsic radiation ensures good light absorption in large-sized single crystals.

The kinetics of scintillation decay involves several components. At room temperature, the main (and the fastest) scintillation component with time constant of about 230 ns is responsible for more than from 90 to 95% of the integral

intensity; the rest of intensity belongs to slower scintillation components. Due to fast decay, NaI (Tl) scintillator can be used for detecting of strong flux of γ-particles. The luminescence decay time and light output of NaI (Tl) single crystals are shown as functions of temperature in Figs. 1.2 and 1.3, respectively.
At higher temperatures the decay time of NaI (Tl) is decreased, making it possible to use this material in radiometric equipment operating at high temperatures, e.g., in geophysical instruments. The light output of NaI (Tl) is the highest at room temperatures, the temperature coefficient is 0.22 — 0.5%/K, substantially depending upon the sample and radiation.

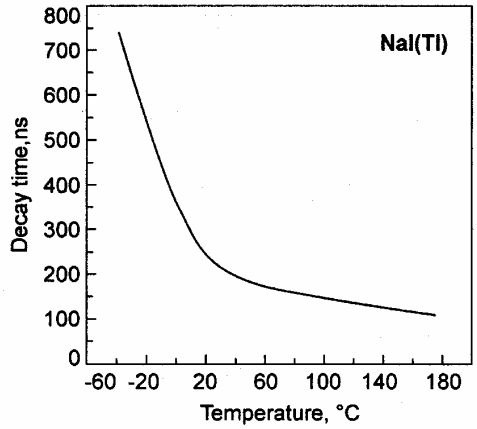


Fig.2. Scintillation decay time of NaI (Tl) scintillator as a function of temperature

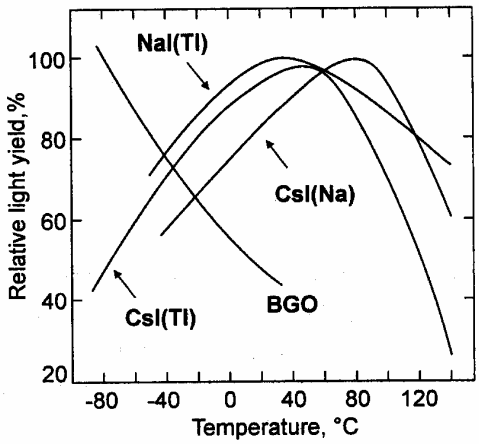


Fig.3. Light yield of some alkali halide scintillators

The important demerit of NaI (Tl) scintillators is their high hygroscopicity, which requires a special protection of crystals using moisture-proof housing (containers). Another drawback is their phosphorescence, which causes rather high afterglow in the millisecond and minute range. The relatively high afterglow limits the application fields of NaI (Tl).

NaI (Tl) single crystals have radiation stability that is quite satisfactory for many applications. They can be used under γ-radiation with flux density of up to 10^5 photons/(s*cm^2) without any noticeable variation of their characteristics. With loads above 10^7 photons/(s*cm^2), characteristics can change irreversibly. Studies of gamma-radiation effects upon optical and spectrometric characteristics of NaI (Tl)-based scintillation detectors at temperatures from — 100°C to +200° C have shown that the observed worsening of scintillation parameters is mainly due to lower transparence to the intrinsic radiation.

Good energy resolution of NaI (Tl) scintillators in combination with avalanche photodiodes makes their promising for application in nuclear medicine. In this field, broad possibilities are opened for NaI (Tl) scintillators in creation of multi-functional scanning-systems.

NaI (Tl) Polycrystalline Scintillators

For severe operation conditions (vibration, sharp mechanical stresses, thermal shocks) NaI (Tl) as scintillation material is generally used in the polycrystalline form, which are obtained by pressure compaction and extrusion. The single crystalline ingot is re-crystallized at high temperature and high pressure, resulting in a quasi-amorphous polycrystalline material, in which the mosaic blocks are strongly disoriented. Such

structure increases the polycrystal hardness, not worsening their optical and scintillation properties. High mechanical hardness characteristics of NaI (Tl) polycrystal allow their broad use in geology and geophysics, in outer space studies and environmental monitoring. Simpler production technology is another advantage of polycrystal as compared with single crystals.

Polycrystals can be easily shaped into any desired form and prepared as pieces of any size. A long NaI (Tl) polycrystal can be used as a positron-sensitive detector with good spectrometric characteristics.

NaI (Tl) polycrystal plates are used for production of housed scintillators for tomographic medical imagine systems.

Cesium iodide *is a scintillation material with a high gamma-ray stopping power due to its relative high density and effective atomic number. It is used either in its undoped form or doped with sodium or thallium for scintillation counting. CsI has not high resistance to thermal and mechanical shock due to the absence of a cleavage plane. Compared to NaI (Tl) it is relatively soft and plastic material.*

CsI (Tl) and CsI (Na) scintillation crystals are rather similar, as for their electronic structure and scintillation properties, to NaI (Tl) scintillators, having certain specific advantages and disadvantages. As compared with sodium iodide, cesium iodide has a high effective atomic number and, consequently, larger cross-section of the γ-radiation photoabsorption. For practical applications, it is very important that CsI (Tl) and undoped CsI are slightly hygroscopic, and hydroscopicity of CsI (Na) is much less than that of NaI (Tl). Due to a high plasticity of CsI scintillators, their mechanical processing is easier as compared with NaI (Tl) scintillators where cleavages and fissures appear under mechanical stresses. Therefore CsI (Tl) and CsI (Na) scintillators are convenient for fabrication of samples of various dimensions and shapes.

On the basis of CsI matrix, the first scintillation material proposed was CsI (Tl). The light output of CsI (Tl) single crystals is one of the highest among the known inorganic scintillation materials. However, the luminescence maximum is observed at 550 nm, which does not give good matching with bialkali photocathodes of PMT. Consequently, the photoelectron yield for gamma-radiation is only 45% with respect to NaI (Tl). With higher photocathode sensitivity in the green region and the signal formation time constant of the order of 5 μs, the signal amplitude rises to 85%. Because a scintillator-photodiode pair can be used, it is possible to reduce the size of the detection system significantly, to operate without high-voltage power supply, and to use the detection system in magnetic fields.

The luminescence spectra of CsI-based single crystals are shown in Fig 4. Scintillation intensity of CsI, CsI (Tl) and CsI (Na) as function of temperature is shown in Fig 3.

CsI (Tl) is a relatively slow scintillator with average decay time of 1 μs (for γ-radiation). Therefore, electronic circuitry with matching signal formation times is to be used, which limits the counting rate ensured by the detector.

The decay time of CsI (Tl) is determined by more than one component. The fastest component is of the order of 0.6 μs, and the slowest — 3.5 μs.

Radiation damage in CsI (Tl) crystals can be rather significant when the absorbed dose is higher than 10^3 rad; however, it is at least partially reversible. As most of the radiation damages give rise to optical absorption bands that are observed mainly at lower wavelengths, the use of photodiodes for recording the

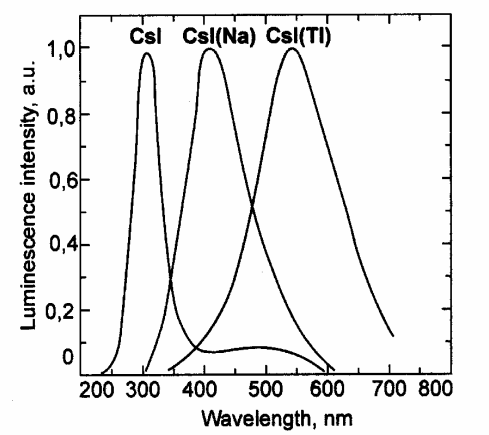


Fig.4. Luminescence spectra of CsI(Tl), CsI(Na) and undoped CsI scintillators

scintillation light decreases the effects of radiation-induced damage upon light output and pulse height resolution.

CsI (Na) scintillator is a good alternative for NaI (Tl) in many standard applications. Luminescence spectrum of CsI (Na) single crystals has maximum at 420 nm, which is well matched to the bialkali PMT photodiode sensitivity (see Fig.). The light output is up to 85% with respect to NaI (Tl) for γ-radiation. The decay time is reduced to 630 ns. A drawback of CsI (Na) scintillators, as well as of CsI (Tl) ones, is their rather high afterglow, which substantially limits the counting rate. The decay time of CsI (Na) is shorter than of CsI (Tl).

The light output temperature dependence for CsI (Na) single crystal suggests that maximum scintillation efficiency is obtained at -80° C, which makes this material suitable for application at high temperatures.

CsI (Tl) and CsI (Na) scintillators, due to their high mechanical strength and thermal stability, are used in the geophysical and cosmic space equipment. CsI (Tl) and CsI (Na) scintillators have been used in the experimental high-energy physics as scintillation elements of electromagnetic calorimeters.

Undoped CsI has its luminescence maximum at 315 nm (see Fig. 4) with intensity much lower than for both activated crystals on its base. Decay time of CsI is rather short — 16 ns. Therefore, this material can be used in these cases when high recording speed is required. Alongside with the fast component at 315 nm, there is also a much slower component with decay time of about 1 μs, which constitutes 15 — 20% of the total light output of CsI.

This material finds its applications in high-energy photon spectroscopy. Undoped CsI can be used in combination with standard glass PMT, though better results are obtained with quartz windows.

Undoped CsI has higher radiation stability than when doped with thallium or sodium, and its properties can be largely restored after a certain time. No substantial radiation damage was observed in CsI up to doses of 10^5 rad.

Europium activated LiI is a scintillator mostly used for thermal neutron detection. Neutrons are detected in ^{6}LiI (Eu) through their interaction with the ^{6}Li atoms of the material through the reaction:

$$^6_3Li + ^1_0n \rightarrow ^4_2He + ^3_1H + Q$$

This reaction is particularly suitable since no γ-ray is released.

The peak for thermal neutrons appears at equivalent γ-ray energy of about 3 MeV, permitting effective discrimination against all natural γ-rays.

LiI (Eu) has a light yield of about 30-35% of NaI (TI). The emission consists of a broad band with a maximum at 470 nm. Due to some self absorption in the crystal, large crystal dimensions will degrade the energy resolution.

The decay time for γ-rays was measured to be 1.4 µs at room temperature (300K). For the ratio between the response to γ-rays and α-particles/ tritons (light yield per MeV), values around 0.6 are reported.

LiI (Eu) is very hygroscopic and is therefore supplied in hermetically sealed detector assemblies.

Selection Guide for Alkali Halide Scintillators

NaI (Tl)	Very high light output, good energy resolution	General scintillation counting, health physics, environmental monitoring, high temperature use
CsI (Tl)	Non-hygroscopic, rugged, long wavelength emission	High energy physics, general detection, photodiode readout
CsI (Na)	High light output, rugged	Geophysical
Undoped CsI	Fast, non-hygroscopic, radiation hard	High energy physics (calorimetry)
LiI (Eu)	High neutron cross-section, high light output	Thermal neutron detection and spectroscopy

Physical Properties of Alkali Halide Scintillators

	NaI (Tl)	**CsI (Na)**	**CsI (Tl)**	**CsI pure**	**LiI (Eu)**
Density [g/cm^3]	3.67	4.51	4.51	4.51	4.08
Melting point [K]	924	894	894	894	719
Thermal expansion coefficient [K^{-1}]	47.4x10^6	49x10^6	49x10^6	49x10^6	40x10^6
Cleavage plane	<100>	none	none	none	<100>
Hardness (Mho)	2	2	2	2	2
Hygroscopicity	yes	yes	slightly	slightly	very
Wavelength of emission maximum [nm]	415	420	550	310	470
Refractive index at emission maximum	1.85	1.84	1.79	1.95	1.96
Light output [% of NaI(Tl)] (for gamma rays)	100	85	45	5-6	30-35
Primary decay time [ms]	0.23	0.63	1	0.01	1.4
Afterglow (after 6 ms) [%]	0.3-5	0.5-5	0.1		
Lower wavelength cutoff [nm]	300	300	320	260	425