ZECOTEK

White Paper
Zecotek Lutetium Fine Silicate (LFS) Scintillation crystals
"Enabling the future of imaging and detection"

Zecotek Photonics Inc. (TSX-V: ZMS; Frankfurt: W1I) **www.zecotek.com** is a Canadian photonics technology company developing high-performance crystals, photo detectors, lasers, optical imaging and 3D display technologies for commercial applications in the medical diagnostics and high-tech industries. Founded in 2004, the company has three distinct operating divisions: imaging, lasers, and 3D display systems with labs and production facilities located in Canada, Singapore, Korea, and Russia. Zecotek commercializes its novel, patented and patent-pending technologies both directly and through strategic alliances and joint ventures with multinational OEMs, distributors and other industry leaders.
In 2009, Zecotek was honored with the prestigious Frost and Sullivan award for 'Best Enabling Technology' for its MAPD (Multi-pixel Avalanche Photo Diode) and LFS (Lutetium Fine Silicate) scintillation materials. The Company has featured on Discovery Channel's Daily Planet, and in 2010 was cited as one of the top ten Canadian technology companies to be the next 'big thing' for its 3D display system.

Zecotek Scintillation Crystals

Many of the contemporary photonics technologies dealing with detection of radiation owe their existence to diverse scintillation materials. Among those, solid-state crystalline substances play a decisive role in the registration of X-rays and γ-quanta necessary in many fields of application in industry, medicine, fundamental research, and security where they are used to convert high-energy photons into visible light. Zecotek's scientists have pioneered research in high-performance scintillation detectors and maintain a comprehensive research program, which has resulted in our proprietary LFS crystal — a new bright and fast scintillation material for use in medical imaging systems, in experiments of high-energy physics, and other industrial applications providing for cost effectiveness, higher resolution and better timing as compared to other materials.

Competitive Advantages of Zecotek LFS

Cerium-doped oxide materials, such as GSO (gadolinium silicate) or BGO (bismuth germanate) have long established themselves in the detection of high-energy photons because of their high density and atomic numbers, chemical and physical stability, and good performance in the detection of ionising radiation. Among these oxides, particular promise is held by lutetium-containing silicates, such as LSO (lutetium orthosilicate).

Zecotek has developed its patented LFS family of materials, which retain the best detection properties of LSO and similar scintillators, such as attenuation length and density, while at the same time improving the parameters critical to many modern applications (*e.g.* nuclear medicine) taking them to the highest levels yet attained. Zecotek's line of scintillators feature very high light output (80–85% on the Tl:NaI scale) and record-fast decay constant, the highest performance yet demonstrated among this class of scintillators. While certain other scintillation materials, such as alkali-halide compounds, may outperform LFS in some parameters, their much lower density, chemical instability, or other major drawbacks effectively exclude them from any high-end applications.

Zecotek's technology makes it possible to tailor the spectral response properties of LFS materials to specific sensitivity curves of existing photo-detectors, such as PMT (Photo-Multiplier Tube) APD, or Zecotek's flagship range of MAPD avalanche photo-detector arrays.

LFS scintillation crystals: Industry product comparison

Crystal* Parameter	**Tl:NaI**	**BGO**	**LSO**	**GSO**	**LYSO**	**LFS**
Density, g/cm^3	3.67	7.13	7.4	6.71	7.1	**7.35**
Effective at. number	51	74	66	57	66	**64**
Attenuation length, cm	2.6	1.11	1.14	1.38	1.12	**1.15**
Decay constant, ns	230	300	40	30–60	41	**< 33**
Max emission, nm	415	480	420	430	420	**425**
Light yield (NaI:Tl=100%)	100	7–12	40–75	20	70–80	**80–85**
Refractive index	1.85	2.15	1.82	1.85	1.81	**1.81**
Energy resolution ^{137}Cs, %	8	12–14	10–14	9.5	8.0	**8**
Absorbed γ-ray irradiation dose, rad †	10 (?)	10^{2-3} (?)	10^8 (7)	10^{8-9} (6)	10^8 (7)	**10^8 (2) (rad. hardness, %/cm)**
Hygroscopicity	strong	No	No	No	No	**No**
Hardness, Moh	2	4.5	5.8	5.7	5.8	**5.8**
Cleavage	(100)	none	none	(100)	none	**none**
Boule size, mm	∅400x600	∅100x250	∅75x200	∅75x150	∅75x150	**∅90x250**

* The chemical composition of the competing crystals: BGO — $Bi_4Ge_3O_{12}$, LSO — $Ce:Lu_2SiO_5$, GSO — $Ce:Gd_2SiO_5$; LYSO — $Ce:Lu_{1.8}Y_{0.2}SiO_5$.

† Induced optical transmission loss after exposure to radiation is a more realistic and quantifiable measure of the radiation hardness than the absorbed radiation dose.

As part of the development process, Zecotek has created a proprietary technology of chemical treatment of LFS pixel surfaces that maximises the light yield and delivers excellent energy resolution. While some manufacturers use chemical processes to create micro-structured surfaces of their materials (for instance, GSO), LFS crystal pixels treated with the Zecotek's proprietary process demonstrate significantly improved levels of light output. This technological know-how for fabrication of micro-structured pixel surfaces is important for commercial production of high-quality and cost-effective crystal elements for PET scanners as it avoids expensive mechanical all-face polishing of pixels for PET scanners currently used in the industry. In contrast, LFS arrays and elements using Zecotek's proprietary process technology require only one polished face.

These performance advantages enable faster, higher-resolution operation of imaging devices that rely on detection of X- and γ-rays, giving rise to multifarious improvements in cost-efficiency and performance in different branches of medical, research, and industrial applications. Medical imaging devices can achieve particularly high performance and compact size by combining spectrally matched LFS and MAPD detectors. The comparative table given above lists the most important parameters of the conventional scintillation materials and some of the LFS types.

In particular, it should be noted that the LFS technology provides the fastest decay constant, the highest light output and radiation hardness, which are taking many existing applications to a new level and enabling others. It has also proven to be superior to other scintillation materials in its resistance to high-energy hadron irradiation used in high-energy physics experiments. Moreover, Zecotek's proprietary LFS manufacturing technologies permit the growth of very large-diameter boules with uniform properties and without cracking (a problem with many other competing materials), thereby securing a consistent and high element yield, which also provides for lower unit costs.

These factors (radiation hardness and cost competitiveness) will play a decisive role in controlling the costs of maintenance and the downtime of major experimental installations, such as CERN's Large Hadron Collider, where high volume consumption of these materials is anticipated (see below).

Applications of LFS Scintillation Crystals

Zecotek's scintillation crystal is essential for PET devices, and especially for high-resolution scanners. Scintillator elements in PET detectors are a major component that may constitute up to one third (1/3) of the total system cost, and improved manufacturing economy together with higher performance place LFS as a lead contender for the next generation PET and combined PET/CT or PET/MRI systems. Micro-PET devices used particularly in pharmaceutical research require the highest spatial and energy resolution, and LFS fulfils all the requirements, providing extremely high performance close to the physical limit.
Scintillation materials are also heavily used in high-energy particle physics, and due to their superior light yield and unique radiation hardness, LFS crystals are very attractive in many large-scale experiments of the high-energy physics, such as CMS/ECAL and ALICE/PHOS calorimetric detectors at LHC (Large Hadron Collider, CERN) or the PANDA detector (under construction) of the FAIR (Facility for Antiproton and Ion Research, Darmstadt). These applications often use inferior materials, such as PWO (lead tungstate), which fulfil many of the requirements, but exhibit very low light yield and limited radiation hardness, which necessitates very costly periodic replacement of the scintillation elements. Choosing LFS will allow these international projects to achieve better performance and considerably reduce the cost of maintenance.
Highly efficient scintillation materials exemplified by LFS are able to bring innovation and modern technologies to many fields whose paramount importance is internationally recognised today. Applications in homeland security stand to benefit greatly from the introduction of higher-performance and more cost- efficient scintillators, which will allow construction of more sensitive and larger gamma cameras for baggage and cargo monitoring. The compact and rugged design of small portable dosimeters and radiation monitors possible through integration of Zecotek's two complementary technologies, LFS and MAPD, will be a key factor in ensuring a thorough penetration of safety and security measures with respect to ionising radiation

both in security application and in environmental monitoring: in transport and storage of fissile materials, in tracking radioactive emissions from nuclear power plants, in controlling traffic of radioactive isotopes, in ensuring medical safety of personnel working with ionising radiation, in monitoring environmental pollution in disaster zones.
The performance and cost competitiveness of Zecotek's scintillation crystals, which hold a considerable room for tailoring their properties to specific applications or detection techniques, opens the door for many other applications.

LFS Intellectual Property

The Lutetium Fine Silicate (LFS) scintillation crystals developed and patented by Zecotek (US patent No. 7,132,060) are distinguished by their exceptional combination of high light yields, uniquely high radiation hardness, and ultra-fast fast decay times. The LFS patent protection has been obtained in the USA, Europe, China, Japan, and Russia regarding the chemical composition of its crystal and ceramic forms for achievement of maximal light output (in the range of 412–430 nm) and short decay time. Highly efficient transformation of the energy of gamma quanta into that of blue light photons resulting in light output of about 35,000 ph/MeV is a hallmark of LFS attained due to very low concentrations of nano-structured cerium-doped and Gd-, Sc-, Y-, La-, Tb-, or Ca- co-doped emission centres distributed at the molecular scale through the lutetium silicate crystal host. Our crystal growth process based both on our patented innovations and Zecotek's powerful know-how portfolio is indispensable for fabrication of very uniform large-size boules without cracking, a unique feature only available through Zecotek's patented technology.

Future Development

The fundamental technology of scintillation material fabrication and processing has been fully developed and tested both at Zecotek's own laboratories and around the world. Our standard LFS material is now being internationally sold and has proven to be a superior material in its area of application. Different modifications of our base formula are being developed and introduced, which are adapted to specific areas of application that pose special requirements on parameters such as emission wavelength, radiation hardness, decay time, &c.
Zecotek's R&D programme remains a key priority to ensure Zecotek's future technology lead in scintillation crystals. Zecotek continuously works on introduction of its scintillation products to new applications and on their wider adoption in those where they have already demonstrated their superior performance.

Integrated Detector Module (IDM)

Integration of detector elements and their assembly into complex installations, of which PET scanners represent a good example, requires much more than state-of-the-art materials. Highly scalable methods of mass manufacturing are necessary to provide the tens of thousands of individual elements that make up detector blocks in PET systems or nuclear detectors. The currently made (and even many under development) PET and PET/CT machines using mechanically polished and manually assembled scintillation pixels must eventually give way to their next generation, which will rely on mass production technologies, such as chemical treatment of the element surface instead of mechanical polishing and single-process fabrication of entire detector blocks already introduced or under development at Zecotek.

To meet these challenges, in addition to the introduction of our LFS scintillation materials in a variety of modifications, Zecotek is developing an Integrated Detector Module (IDM) configuration which marries the LFS with our another pioneer product, an array of MAPD's (Micro-pixel Avalanche Photo-Diode) in a patented 'plug and play' replacement for the PMT and crystal sets used in the current generation of PET and other detectors. This module features a scintillator block manufactured in a single technological process, which eliminates the processing of each individual element. It further removes the necessity of manual assembly of the scintillator block. Both these fabrication steps currently constitute a significant portion of the overall costs of detection modules. The IDM also uses a Zecotek patented configuration, important for the high-resolution medical imaging known as DOI or (Depth Of Interaction). Together with a rich portfolio of PET software and hardware solutions based on Zecotek's MAPD, LFS, and IDM technologies jointly developed with the University of Washington, Seattle, this unique combination of technologies will provide a complete foundation for a new low-cost, high-performance generation of PET scanners.

Appendix Experimental Performance Data

Zecotek's LFS materials demonstrate the highest radiation hardness of all crystal scintillators currently used in high-energy physics. This is demonstrated by the results of our experiments with exposing LFS samples to high-fluence proton beams, in which the LFS crystal is showing negligible degradation of transmittance.

Fig 1. Transmission spectra of LFS crystals before and after proton irradiation.

The data shown below are the decay constant measurements performed with a ^{137}Cs source and two of our LFS crystal samples. Logarithmic scale makes it easy to see fast light pulse slopes, indicative of LFS short decay time.

Fig. 2. Decay time of sample LFS crystals (vertical axis: intensity in arb. units, horizontal: time in ns).