Developing NIR Scintillators and the Associated Pulse Processing Chain to Detect NIR Wavelengths

Nuclear Science & Security Consortium

Ketaki Joshi[1,2], Chuck Melcher[1,2], Jason Hayward[1]

[1]Department of Nuclear Engineering, University of Tennessee – Knoxville

[2]Scintillation Materials Research Center, University of Tennessee - Knoxville

Introduction

Comparison of Strontium Iodide scintillators with commercial gamma spectroscopy scintillators:

- LaBr3
  Light Yield: > 60,000 Ph/MeV
  Resolution: <3.5%
  High Cost
- NaI
  Light Yield: >35,000 Ph/MeV
  Resolution: <7%
  Low Cost
- SrI_2:Eu2+
  Light Yield: >35,000 Ph/MeV
  KSI:Eu2+ Resolution: ~2.4% [1]

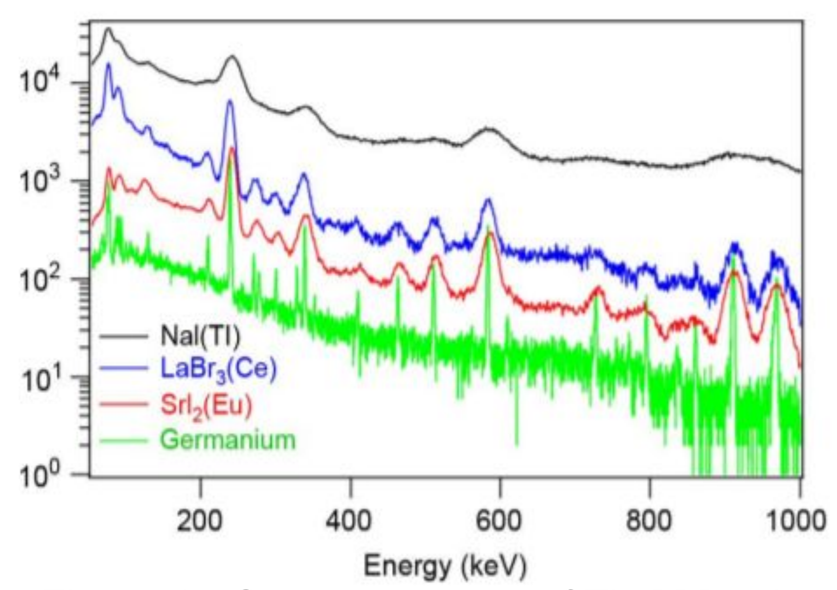


Figure 1. Gamma spectra of Th-232 using a SrI2(3%Eu) crystal, compared with a Germanium detector, a LaBr3(Ce) crystal and a NaI(Tl) crystal [2]

Motivation

Why NIR Scintillators?

- In Europium doped scintillators, Eu2+ self-absorption process affects scintillator performance, especially at larger sizes. Sm2+ co-doping shown to shift the emission to near-infrared wavelengths to reduce Eu2+ reabsorption [3]
- Improved performance of Europium doped scintillators could be achieved with Sm2+ co-doping through better crystal growth techniques
- NIR scintillators have an ideal emission wavelength for transmission through optical fibers used for high dose radiation testing [4]

NSSC Mission Relevance

- NIR scintillators can be developed for use in hand-held detectors for gamma spectroscopy or radiation sensing in high dose radiation environments
- Relevant to the NSSC mission of reducing global nuclear security threats by development of technologies to detect special nuclear materials

NIR Scintillator Crystal Growth

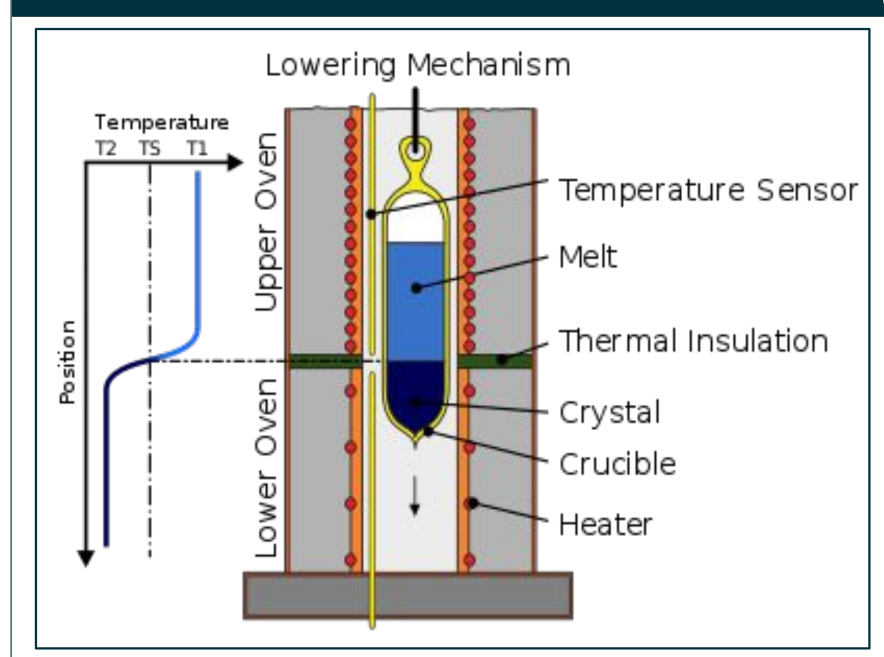


Figure 2. A diagram illustrating the vertical Bridgman crystal growth method [5]

- Start materials were filled in ampoule, vacuum dried and melt synthesized before growth
- Two SrI_2:Eu2+ crystals were grown using the vertical Bridgman growth method shown on the left
- Size – 12mm⌀, 10g sample
- Growth parameters:
  - 0.7mm/hr translation rate
  - Cooldown ~5500 mins

Post-Growth Characterization

SrI₂ doped with 2% Europium and 0.02% Samarium:

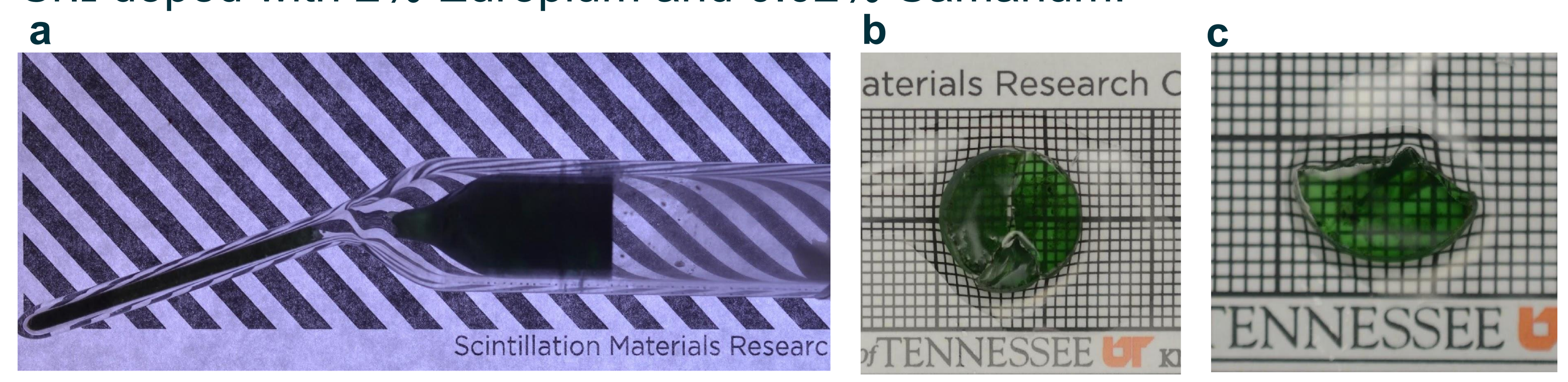


Figure 3. Pictures of SrI_2(Eu2+ 2%, Sm2+ 0.02%):
a: Full grown crystal before removing from quartz ampoule
b: 3mm disk cut from boule after cutting off last-to-freeze and cone sections
c: Same disk from picture b, broken along internal crack while polishing

SrI₂ doped with 2% Europium and 0.02% Samarium Characterization

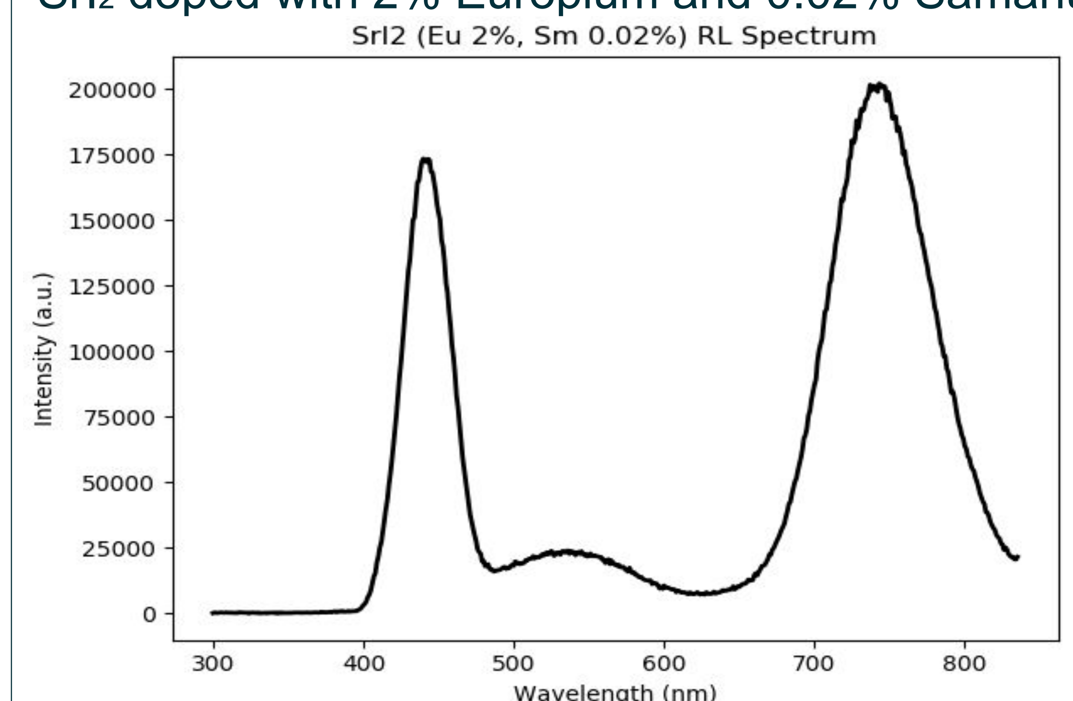
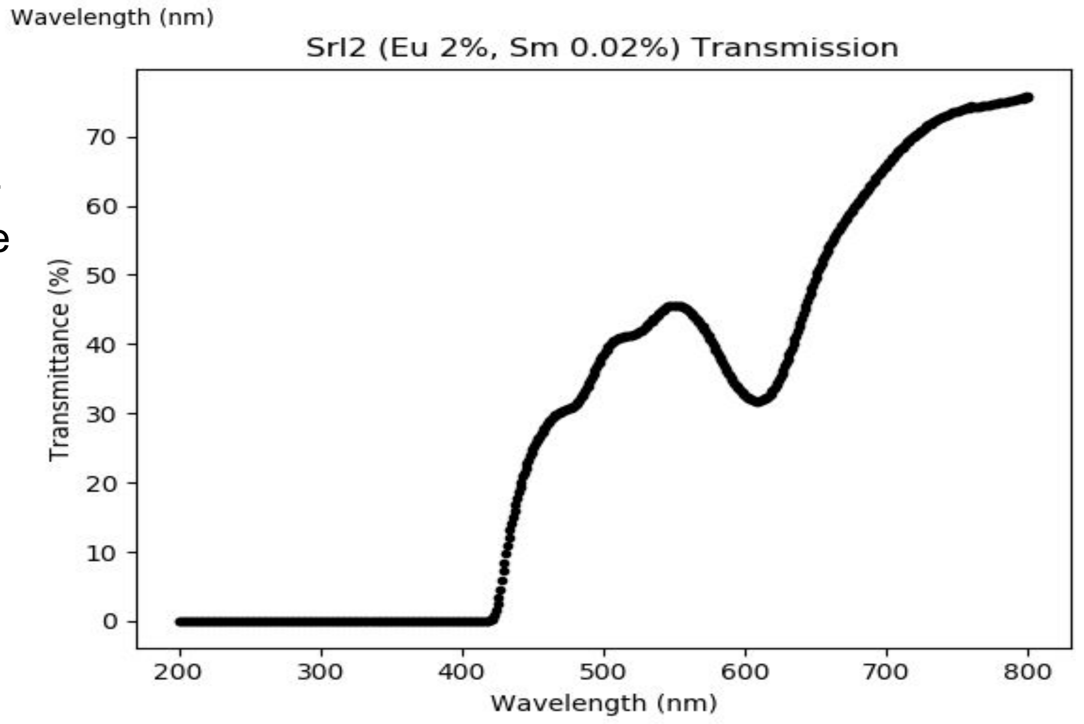


Figure 4. Radioluminescence spectrum of SrI_2(Eu2+ 2%, Sm2+ 0.02%)

RL spectrum shows the 420nm Eu2+ emission and 740nm Sm2+ emission

Figure 5. SrI_2(Eu2+ 2%, Sm2+ 0.02%) transmittance measurement plot:

Transmittance plot showing good optical transmission near the 740nm Sm2+ emission



SrI_2 doped with 2% Europium (control crystal):

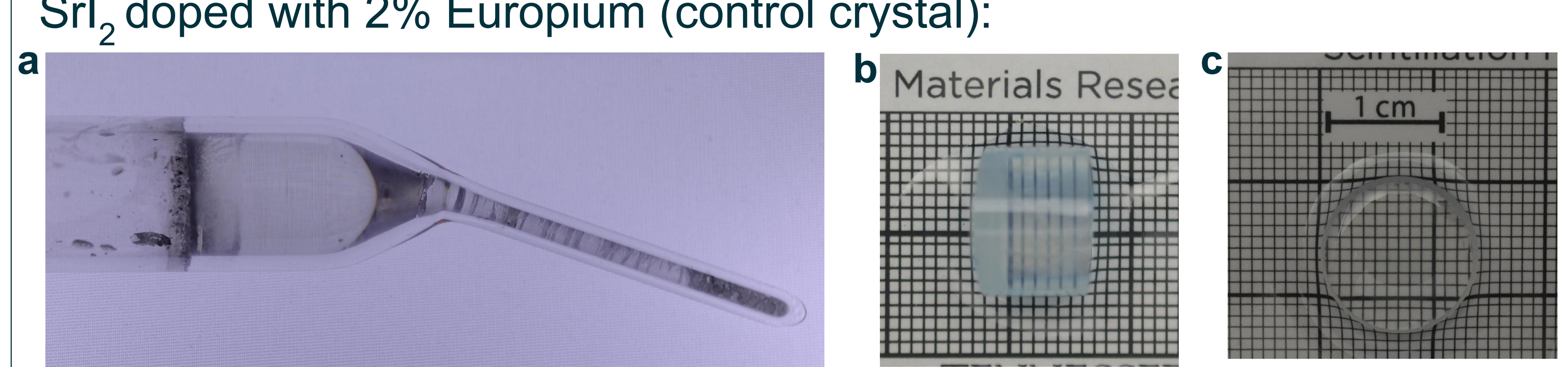


Figure 6. Pictures of SrI_2(Eu2+ 2%):
a: Full grown crystal before removing from quartz ampoule
b: Clear crystal boule after cutting off last-to-freeze and cone sections
c: 3 mm disk cut from boule shown in Figure 6.b and polished for measurements

Pulse Processing Chain for Detecting NIR Wavelengths

SiPM-based pulse processing chain

- Hamamatsu S13 series silicon photomultiplier
  18% PDE @740nm
  Optimum operating voltage of 56V
- TC-48-20 temperature controller
  Maintain SiPM at room temperature with a cooling fan
- CR-113 charge sensitive preamplifier
  1.5V electronic saturation limit
  Signal attenuators added between SiPM and CR-113 to keep signal within electronic limits
- Slight non-linear response of SiPM in energy introduced by signal attenuators

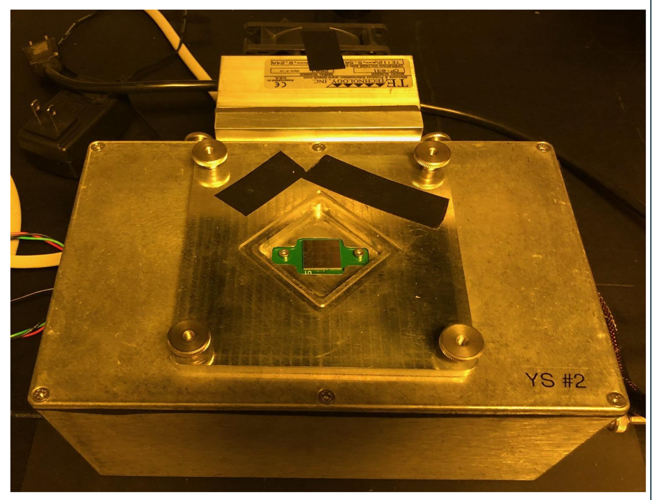


Figure 7. Picture of SiPM-based pulse processing setup

Table 1: Polynomial fit gives calibration curve to calculate energy resolution on energy axis using Cs137 and Na22 photopeaks for comparison with channel-based energy resolution to check effect of non-linearity on energy resolution

HV	Channel – based Energy Resolution	Difference in Energy Resolution (Channel vs Energy)
56 V	5.25%	0.4%

Initial testing of NIR scintillators with the SiPM-based setup

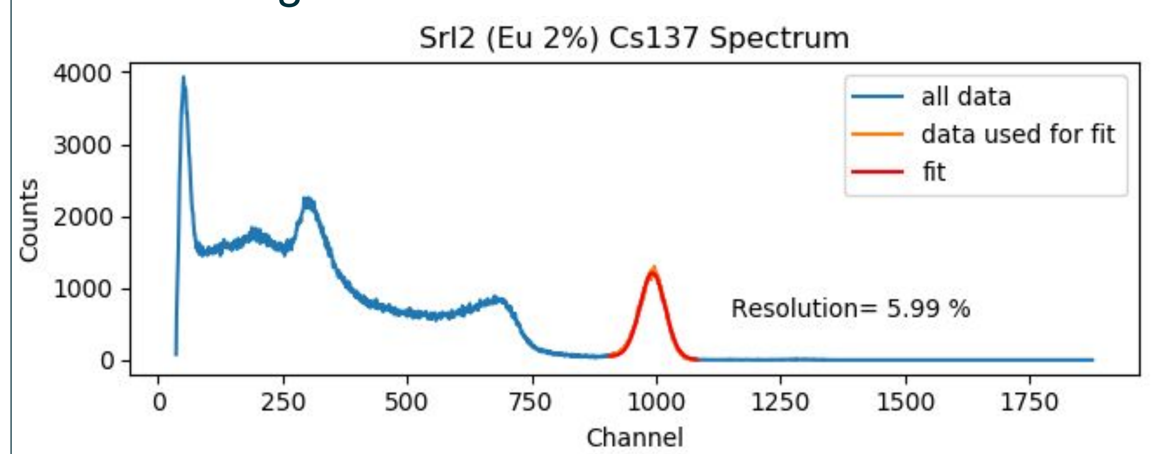


Figure 8. Cs-137 spectrum collected for a 3 mm disk from the SrI₂ (Eu 2%) crystal shown in Figure 6.c with a 5 dB signal attenuator

Conclusions and Future Work

- Completion of the characterization of the SiPM response shows that the slightly non-linear response in energy does not affect the energy resolution significantly
- Initial testing of the SrI₂(Eu 2%) and SrI₂(Eu 2%, Sm 0.02%) can be done on the SiPM setup (energy resolution measurements); Energy resolution measurements will be taken with a photomultiplier tube for comparison
- An avalanche diode (APD) based pulse processing chain is being implemented for comparison with the SiPM-based system and PMT measurements
- Literature search on NIR materials to plan the next scintillator growth composition

References

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2) Gamma spectrum comparison plot. N. Cherepy et. al. (2013). Instrument Development and Gamma Spectroscopy with Strontium Iodide. IEEE Transactions on Nuclear Science. 60. 2. p. 955-958
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4) Growth and Scintillation Properties of a New Red-Emitting Scintillator Rb2HfI6 for the Fiber-Reading Radiation Monitor. Kodama et. al. (2020)IEEE Transactions on Nuclear Science. 67.6.
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