R&D of Halides Scintillation Crystals and their Recent Trends

ハログン化物シンチレーターの開発と最近の動向

March 9, 2015

Shiro Sakuragi  Union Materials Inc.

桜木史郎
ユニオンマテリアル株式会社
Content

1、Introduction

2、Status of SrI$_2$(Eu) and CeBr$_3$ Scintillator

3、Preparation of SrI$_2$(Eu) Crystal by the “Liquinert Process”

4、Scintillation Properties of SrI$_2$(Eu)

5、Future of Halides Scintillators
### 1. Introduction

**R&D of Scintillators in UM**

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>ISSP, University of Tokyo Horiba</td>
</tr>
<tr>
<td>1978</td>
<td>12 years 8 years</td>
</tr>
<tr>
<td>1986</td>
<td>UM設立</td>
</tr>
<tr>
<td>2000</td>
<td>半導体材料・Semiconductor</td>
</tr>
<tr>
<td>2015</td>
<td>29 years</td>
</tr>
</tbody>
</table>

**Metal Halides**
- 物性研究・Solid State Physics
- シンチレーター・Scintillator
- 赤外線材料・IR Optics

**Pure CsI**
- 櫻木・橋本・窪田

**R&D of Scintillator**
- Shaped NaTl(Tl) and CsI(Tl)
- Scintillation crystal

---

**Letter to the Editor**

**A NEW SCINTILLATION MATERIAL: PURE CsI WITH 10 ns DECAY TIME**

Shinzou KUBOTA 1), Shirou SAKURAGI 2), Satoshi HASHIMOTO 3) and Jian-zhi RUAN (Gen) 1)

1) Rikkyo University, Nishi-Ikebukuro 3, Tokyo, 171, Japan
2) Union Material Inc., Tone-machi, Katasoma, Ibaraki, 270-12, Japan
3) Kyoto University of Education, Fukakusa, Fushimi

Received 10 November 1987

---

**Figure 1. Emission spectra of pure CsI**

- Borosilicate window
- Fused silica window
- standard bialkali

**SrI2(Eu) single crystals in quartz ampoules**

---

North-Holland, Amsterdam

---

*Image of emission spectra of pure CsI*
65 years
Long history of iodides scintillators

NaI(Tl)  1950  Saint-gobain Crystals, Others

CsI(Tl)  1985  HORIBA, BDH  8,000 Detectors for Cornell Univ.
CLEO II calorimeter

Synchrotron

8000 pieces of CsI(Tl) scintillator

γ-ray Detector for Electron-Positron Synchrotron of Cornell University
HORIBA Cornell Project 1985~1988

Cornell University

WILSON SYNCHROTRON LABORATORY
CLEO II  Calorimeter

HORIBA

Purification Furnaces for CsI(Tl)

Crystal Growing Furnaces for CsI(Tl)
S,Stone and S.Sakuragi
Example of crystal growth by “Liquinert Process”

1985 Horiba Ltd.,

Csl(Tl) scintillator for CLEO II calorimeter of Cornell University

R&D: 1984
First delivery Tapered scintillators : 5 pieces

Second delivery: 200 pieces 1985

Final delivery: 4000 pieces 1988

Φ 70x400L ingot
Towards for high performance halides scintillators

<table>
<thead>
<tr>
<th>Crystal</th>
<th>Year</th>
<th>Company</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>LaBr₃(Ce)</td>
<td>2000</td>
<td>Saint-gobain Crystals</td>
<td>USA</td>
</tr>
<tr>
<td>CeBr₃</td>
<td>2012</td>
<td>Hellma Crystals (Germany)</td>
<td></td>
</tr>
<tr>
<td>SrI₂(Eu)</td>
<td>2012</td>
<td>Radiation Monitoring Devices Inc, (USA)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>Union Materials Inc., (Japan)</td>
<td></td>
</tr>
</tbody>
</table>
R&D Trend of SrI₂(Eu) and CeBr₃ Scintillator

SrI₂(Eu)  2003~2013  • US
Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, Fisk University and Radiation Monitoring Devices Inc.
  2003~: Systematic study for halides scintillator materials.
  • RMD

CeBr₃  2005~2012  • EU
Delft University of Technology  • Eu Space Agency
  • Hellma Materials, Schott AG, Scionix BV

SrI₂(Eu)  2012  • Japan
  • Tohoku University, JST Project
  • Union Materials Inc.
  • Many other companies
Advantages & Disadvantages between Three kinds of New Halides Scintillators

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>SrI₂(Eu)</td>
<td>① Light yield ⋅⋅⋅⋅⋅⋅85,000 Ph/MeV</td>
<td>① Hygroscopic nature ⋅⋅⋅⋅⋅⋅Very high</td>
</tr>
<tr>
<td></td>
<td>② Energy resolution ⋅⋅⋅⋅⋅⋅3% at 662KeV</td>
<td>② Self-absorption effect of Eu</td>
</tr>
<tr>
<td></td>
<td>③ Self-activity ⋅⋅⋅⋅⋅⋅Non</td>
<td>③ Long decay time ⋅⋅⋅⋅⋅⋅⋅⋅⋅⋅1 μ sec</td>
</tr>
<tr>
<td></td>
<td>④ Low melting point ⋅⋅⋅538°C</td>
<td>④ High difference of T.E.C.</td>
</tr>
<tr>
<td></td>
<td>⑤ Cleavage plane ⋅⋅⋅⋅⋅⋅Non</td>
<td>⑤ Density ⋅⋅⋅⋅⋅⋅4.6g/cm³</td>
</tr>
<tr>
<td>CeBr₃</td>
<td>① Short decay time ⋅⋅⋅⋅⋅⋅25nsec</td>
<td>① Hygroscopic nature ⋅⋅⋅⋅⋅⋅Very high</td>
</tr>
<tr>
<td></td>
<td>② Self-activity ⋅⋅⋅⋅⋅⋅Non</td>
<td>② Melting point ⋅⋅⋅722°C</td>
</tr>
<tr>
<td></td>
<td>③ Energy resolution ⋅⋅⋅⋅⋅⋅4% at 662KeV</td>
<td>③ Raw material ⋅⋅⋅⋅⋅⋅Expensive</td>
</tr>
<tr>
<td></td>
<td>④ Light yield ⋅⋅⋅⋅⋅⋅60,000 Ph/MeV</td>
<td></td>
</tr>
<tr>
<td></td>
<td>⑤ Cleavage plane ⋅⋅⋅⋅⋅⋅Non</td>
<td></td>
</tr>
<tr>
<td>LaBr₃(Ce)</td>
<td>① Short decay time ⋅⋅⋅⋅⋅⋅20nsec</td>
<td>① Hygroscopic nature ⋅⋅⋅⋅⋅⋅Very high</td>
</tr>
<tr>
<td></td>
<td>② Energy resolution ⋅⋅⋅⋅⋅⋅3% at 662KeV</td>
<td>② Self-activity ⋅⋅⋅⋅⋅⋅Yes</td>
</tr>
<tr>
<td></td>
<td>③ Light yield ⋅⋅⋅⋅⋅⋅65,000 Ph/MeV</td>
<td>③ Cleavage plane ⋅⋅⋅⋅⋅⋅Yes</td>
</tr>
<tr>
<td></td>
<td>④ Density ⋅⋅⋅⋅⋅⋅5.3g/cm³</td>
<td>④ Melting point ⋅⋅⋅788°C</td>
</tr>
<tr>
<td></td>
<td>⑤ Raw material ⋅⋅⋅⋅⋅⋅Expensive</td>
<td>⑤ Raw material ⋅⋅⋅⋅⋅⋅Expensive</td>
</tr>
</tbody>
</table>
## 2, Status of SrI\(_2\)(Eu) and CeBr\(_3\) Scintillators

### Comparison between SrI\(_2\)(Eu) and CeBr\(_3\)

<table>
<thead>
<tr>
<th></th>
<th>M.P. (℃)</th>
<th>Density (g/cm(^3))</th>
<th>Hygroscopic nature</th>
<th>Emission wave length (nm)</th>
<th>Light yield (Pho./Mev)</th>
<th>Energy Resolution (662Kev)</th>
<th>Decay time (ns)</th>
<th>Light yield Proportionality 5~1000Kev</th>
<th>Self activity</th>
<th>Crystal diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SrI(_2)(Eu)</strong></td>
<td>538</td>
<td>4.6</td>
<td>Very</td>
<td>430</td>
<td>80000</td>
<td>&lt;4% (Depending on Eu concentration)</td>
<td>&lt;5%</td>
<td>Non</td>
<td></td>
<td>50mm</td>
</tr>
<tr>
<td><strong>CeBr(_3)</strong></td>
<td>772</td>
<td>5.10</td>
<td>Very</td>
<td>370</td>
<td>45000</td>
<td>&lt;5%</td>
<td></td>
<td>Non</td>
<td></td>
<td>75mm</td>
</tr>
</tbody>
</table>

A high light yield is mandatory to improve the energy resolution.
Reference: “Sintillators with high-energy-resolution and low-intrinsic-activity” F. Quarati, et.al.
Good light yield proportionality

Recent data of CeBr3 Scintillator from Delft University of Technology
Scintillation and detection characteristics of high-sensitivity gamma-ray spectrometers

F.G.A. Quarati a,b,*, P. Dorenbos a, J. van der Biezen c, Alan Owens c, M. Selle d, L. Parthier e, Y. Schotanus f

a Faculty of Applied Science, Department of Radiation Science & Technology, Delft University of Technology, Mekelweg 15, 2629JB Delft, The Netherlands
b Prøsepe BV, Heilige Geestweg 65, 2201JF Noordwijk, The Netherlands
c European Space Agency, ESA/ESTEC, Keplerlaan 1, 2201AZ Noordwijk, The Netherlands
d Helima Materials GmbH, Moritz von Rolsterstraße 1, 07745 Jena, Germany
e SCHOTT AG, Advanced Materials, Hattenbergstrasse 10, 55122 Mainz, Germany
f Scionix Holland BV, Regulierenring 5, 3581LA Bunnik, The Netherlands

A R T I C L E   I N F O

Article history:
Received 10 June 2013
Received in revised form 2 August 2013
Accepted 4 August 2013
Available online 15 August 2013

Keywords:
Cerium-bromide
Lanthanum-bromide
Scintillator gamma-ray spectrometers
Detection sensitivity
Low count rate
Planetary remote sensing

A B S T R A C T

Crystal growth and detector fabrication technologies have reached such a state of maturity that high-quality large-volume CeBr₃ scintillators can now be produced with dimensions of 2" × 2" and well above. We present a study of CeBr₃ samples of various dimensions and show that they have a number of advantages over equivalently sized LaBr₃:5%Ce for gamma-ray spectroscopy applications requiring high detection sensitivity.

At the present time, the achieved energy resolution of CeBr₃ is about 4% FWHM at 662 keV, i.e. 25% worse than that of LaBr₃:5%Ce. However, thanks to the drastically reduced intrinsic activity, CeBr₃ gamma-ray detection sensitivity is about 1 order of magnitude better than that of LaBr₃:5%Ce at energies of 1461 keV and 2614.5 keV, which are relevant for the detection of ⁴⁰K and ²⁰⁸Tl (²³²Th), respectively.

In this communication, we report on several aspects of CeBr₃ gamma-ray spectrometers, such as scintillation characteristics, non-proportionality of the response, gamma-ray detection performances up to 3 MeV and radiation tolerance.
© 2013 Elsevier B.V. All rights reserved.
1”x1”, 2”x2” CeBr3

Energy resolution

Table 1
Summary of light yield (LY) and energy resolution measurements with bare and encapsulated CeBr3 crystals. The measurement systematic error for the yields is ±10% relative to the value and for the energy resolutions is ±0.15% absolute.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Photo-electron yield (phe/MeV)</th>
<th>Absolute light yield (photon/MeV)</th>
<th>Energy resolution at 662 keV %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CeBr3 bare samples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#4 (2 mm thick)</td>
<td>17,000</td>
<td>59,000</td>
<td>4.1</td>
</tr>
<tr>
<td>#5 (3 mm thick)</td>
<td>17,500</td>
<td>60,000</td>
<td>4.2</td>
</tr>
<tr>
<td>#6 (3 mm thick)</td>
<td>19,000</td>
<td>66,000</td>
<td>3.7</td>
</tr>
<tr>
<td>DU001 (0.5” × 1”)</td>
<td>16,500</td>
<td>57,000</td>
<td>4.3</td>
</tr>
<tr>
<td>Bare sample average</td>
<td>17,500</td>
<td>60,000</td>
<td>4.1</td>
</tr>
<tr>
<td>CeBr3 encapsulated samples</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SBG 388 (1” × 1”)</td>
<td>13,000</td>
<td>45,000</td>
<td>4.2</td>
</tr>
<tr>
<td>SFC 269 (1” × 1”)</td>
<td>11,500</td>
<td>40,000</td>
<td>4.4</td>
</tr>
<tr>
<td>SFC 270 (1” × 1”)</td>
<td>12,500</td>
<td>43,000</td>
<td>4.2</td>
</tr>
<tr>
<td>SFC 271 (1” × 1”)</td>
<td>13,000</td>
<td>45,000</td>
<td>4.4</td>
</tr>
<tr>
<td>SFC 272 (1” × 1”)</td>
<td>13,500</td>
<td>47,000</td>
<td>4.7</td>
</tr>
<tr>
<td>SFC 273 (1” × 1”)</td>
<td>13,500</td>
<td>47,000</td>
<td>4.5</td>
</tr>
<tr>
<td>SBF 431 (2” × 2”)</td>
<td>12,500</td>
<td>43,000</td>
<td>4.3</td>
</tr>
<tr>
<td>SFB 307 (2” × 2”)</td>
<td>12,500</td>
<td>43,000</td>
<td>4.2</td>
</tr>
<tr>
<td>SFB 308 (2” × 2”)</td>
<td>12,500</td>
<td>43,000</td>
<td>4.1</td>
</tr>
<tr>
<td>Encapsulated sample</td>
<td>12,000</td>
<td>45,000</td>
<td>4.3</td>
</tr>
<tr>
<td>average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LaBr3:5%Ce encapsulated sample</td>
<td>19,000</td>
<td>66,000</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Fig. 1. Picture of two of the CeBr3 encapsulated samples used in this study, left 1” × 1” sample SFC 273 (proton irradiated) and right 2” × 2” sample SBF 307.
CeBr$_3$ Emission spectrum

![Emission spectrum graph](image)

Fig. 2. X-ray excited emission of CeBr$_3$ and LaBr$_3$:5%Ce. For CeBr$_3$, the emission of three samples with increasing thicknesses is presented. The spectra are area normalized.

Decay time

![Decay time graph](image)

Fig. 3. Scintillation decay time under $^{137}$Cs excitation for both CeBr$_3$ and LaBr$_3$:5% Ce samples of several volumes. The two lines are interpolating logarithmic functions to guide the eyes. The 30 mm × 8 mm CeBr$_3$ sample represents a deviant data point (open diamond data symbol) which is attributed to its particular aspect ratio.
Energy resolution of 2”x2”

Photon energy dependence of Energy resolution

Fig. 5. Pulse height spectra of $^{137}$Cs collected with 2” x 2” spectrometers based on CeBr$_3$, LaBr$_3$:5%Ce and NaI(Tl).

Fig. 7. Energy resolution FWHM as function of photon energy for 2” x 2” spectrometer based on CeBr$_3$ and LaBr$_3$:5%Ce. The lines are the best fitting function of Eq. (2).
Pulse height spectra of $^{152}$-Eu with 2”x2”

Intrinsic activity spectra with 1”x1”

Fig. 6. Pulse height spectra of $^{152}$Eu collected with 2” x 2” spectrometer based on CeBr$_3$, LaBr$_3$:5%Ce and NaI(Tl).

Fig. 9. Intrinsic activity spectrum of 5 CeBr$_3$ spectrometers with dimension of 1” x 1”.
3. Preparation of SrI$_2$(Eu) Crystals by the “Liquinert Process”

Difficulties in preparation process of halides crystals

① Hygroscopic nature

- Solubility in water
  - NaCl: 36g/100gH$_2$O
  - LiBr: 143g/100gH$_2$O
  - NaI: 159g/100gH$_2$O
  - CeBr$_3$: (150g)/100gH$_2$O
  - SrI$_2$: 178g/100gH$_2$O

Sticking problem of crystal to crucible
Harmful chemical reaction caused by water vapor

Crystal growth of NaI(Tl) in quartz containing small amount of water

\[ \text{Wetting and sticking material} \]

\[ \text{700℃, Water vapor} \]

\[ \text{NaI} + \text{H}_2\text{O} = \text{NaOH} + \text{HI} \]

\[ 2\text{NaOH} + \text{SiO}_2 = \text{Na}_2\text{SiO}_3 + \text{H}_2\text{O} \]

Chemical resultant \( \Rightarrow \text{Na}_2\text{SiO}_3 \) (Sodium silicate)

Wetting and sticking material
Perfect removal technology of water from growth environment

Reactive-gas Atmosphere Processing

Example:
NaI(Tl) RAP gas • • • CI4:Carbon tetra-iodide

\[ \text{CI}_4 + \text{H}_2\text{O} = \text{COI}_2 + 2\text{HI} \]

\[ \text{COI}_2 + \text{H}_2\text{O} = \text{CO}_2 + 2\text{HI} \]

Water is converted to other materials through RAP reaction. As the result, we can get Liquinert condition.
Appearance of sphere melt by perfect removal of water

・・・ “Liqinert Melt” ・・・

“Liqinert” : Representation of the sphere shape and non-wetting melt at high temperature

撥水性・・・金属、半導体などの無機物質液体が高温で濡れないで球状を呈すること

Repellent nature・・・ Representation of the sphere shape of water at around room temperature

撥水性・・・水・油、常温付近液体が濡れないで球状を呈すること

Liqinert melt

Atmosphere

θ:\text{contact angle}

melt

θ \sim 18°

Θ

0°

crucible

Wetting melt

Atmosphere

θ < 90°

melt

θ : contact angle

crucible
“Liquinert Process” of SrI$_2$(Eu)

Dehydration under vacuum; Removal of 99.99% of water
RAP treatment; Perfect removal of water

Liquinert SrI$_2$(Eu)

Characteristic feature:
Clear and transparent melt, round shape melt surface,
No floating scum, No inclusion
Crystal Growth by Vertical Bridgman method

SrI$_2$(Eu) Single Crystals  $\Phi 25$ mm x $\sim 70$ mm  4 ingots

November, 2013
UM Progress in R&D work of SrI$_2$(Eu) in 2014

Φ 1.5” Single Crystal

Φ 2” Single Crystal

Φ 1.5” Detector

No floating scum

Φ 1”, Improved Energy Resolution
2014年 RMD社（米）のSrI₂(Eu)

1.5” SrI₂(Eu) Single Crystal

Radiation monitoring instrument with 1.5”SrI₂(Eu) scintillator

SrI₂(Eu) Detectors

γ-ray spectra of many RI
SrI₂(Eu) Scintillation Products by the “Liquinert Process”

**SrI₂(Eu) Single Crystals**

- Φ25mm x ~70mm 4 ingots
- November, 2013

**Encapsulated SrI₂(Eu) Detector**

- Φ25x25mm

**Advantages**

- High quality
- High material yield
- High performance
Scintillation properties of UM SrI$_2$(Eu) detector

① Energy spectra for Cs–137

SrI$_2$(Eu) FWHM = 3.4%
NaI(Tl) FWHM = 6.4%

662 keV

Scintillator: SrI$_2$(Eu) UM131001
MCA: LEA / LEMCA1B
Analysis Software: LEA / Becquerel Monitor Plus
PMT: Hamamatsu / R6231
2 Energy spectra of the soil from Souma, Fukushima

福島県相馬市土壤100g, 100g soil from Souma, Fukushima
5. Future of Halides Scintillators

- Slow decay material:

  SrI$_2$(Eu) will be applicable to medical (SPECT) and isotope identification use.

- Fast decay material:

  CeBr$_3$ will be applicable to medical (PET), High Energy and Space Physics.

- SrI$_2$(Eu) and CeBr$_3$ have the basic problem, heavy hygroscopic nature.

- The development of easy and compact mounting technology of SrI$_2$(Eu) and CeBr$_3$ crystals is very important for wide spreading of these new materials.
Thank you for your attention

March 9, 2015

Shiro Sakuragi
Union Materials Inc.
# Three kinds of New Halides Scintillators

<table>
<thead>
<tr>
<th>Crystal</th>
<th>NaI(Tl)</th>
<th>CsI(Tl)</th>
<th>SrI₂(Eu)</th>
<th>LaBr₃(Ce)</th>
<th>CeBr₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>3.67</td>
<td>4.51</td>
<td>4.59</td>
<td>5.29</td>
<td>5.10</td>
</tr>
<tr>
<td>Melting Point (°C)</td>
<td>651</td>
<td>621</td>
<td>538</td>
<td>788</td>
<td>722</td>
</tr>
<tr>
<td>Radiation Length (cm)</td>
<td>2.59</td>
<td>1.86</td>
<td>1.95</td>
<td>1.88</td>
<td>1.96</td>
</tr>
<tr>
<td>Molière Radius (cm)</td>
<td>4.13</td>
<td>3.57</td>
<td>3.40</td>
<td>2.85</td>
<td>2.97</td>
</tr>
<tr>
<td>Interaction Length (cm)</td>
<td>42.9</td>
<td>39.3</td>
<td>37.0</td>
<td>30.4</td>
<td>31.5</td>
</tr>
<tr>
<td>Refractive Index a</td>
<td>1.85</td>
<td>1.79</td>
<td>?</td>
<td>1.9</td>
<td>2.3</td>
</tr>
<tr>
<td>Hygroscopicity</td>
<td>Yes</td>
<td>Slight</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Luminescence b (nm)</td>
<td>410</td>
<td>550</td>
<td>435</td>
<td>356</td>
<td>371</td>
</tr>
<tr>
<td>Decay Time b (ns)</td>
<td>245</td>
<td>1220</td>
<td>1100</td>
<td>30</td>
<td>17</td>
</tr>
<tr>
<td>Light Yield b,c (%)</td>
<td>100</td>
<td>165</td>
<td>221</td>
<td>130</td>
<td>122</td>
</tr>
<tr>
<td>d(LY)/dT b (%/°C)</td>
<td>-0.2</td>
<td>0.4</td>
<td>&lt;-0.1</td>
<td>0.2</td>
<td>-0.1</td>
</tr>
</tbody>
</table>

## Remarks

- **2001年以降**
  - 核物質(U, Pr)の探査用γ線検出素材

- 半導体結晶(Ge,CdTe)に代わる高分解能ハライド結晶の開発

出展:CIT.Net PP資料
② Large differences of TEC in SrI₂ Crystal

Crystal structure: Orthorhombic

Lattice Constants;
\[ a = 15.268 \text{Å}, \quad b = 8.235 \text{Å}, \quad c = 7.896 \text{Å} \]

Thermal Expansion coefficient (°C)

<table>
<thead>
<tr>
<th>Lattice</th>
<th>Coefficient of Thermal Expansion (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>1.552 \times 10^{-5}</td>
</tr>
<tr>
<td>b</td>
<td>2.164 \times 10^{-5}</td>
</tr>
<tr>
<td>c</td>
<td>0.924 \times 10^{-5}</td>
</tr>
<tr>
<td>Volume</td>
<td>4.662 \times 10^{-5}</td>
</tr>
<tr>
<td>Density</td>
<td>-4.596 \times 10^{-5}</td>
</tr>
</tbody>
</table>

Large differences of TEC between \textit{lattice b} and \textit{c} of SrI₂ crystal

Cracking Problem on cooling down process