PbI_2 as a direct semiconductor for use in radiation imaging detectors

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Fluorescent & Scintillation Products
for Industry, Science & Medicine

6th iWoRiD
International Workshop on Radiation Imaging Detectors

Overview

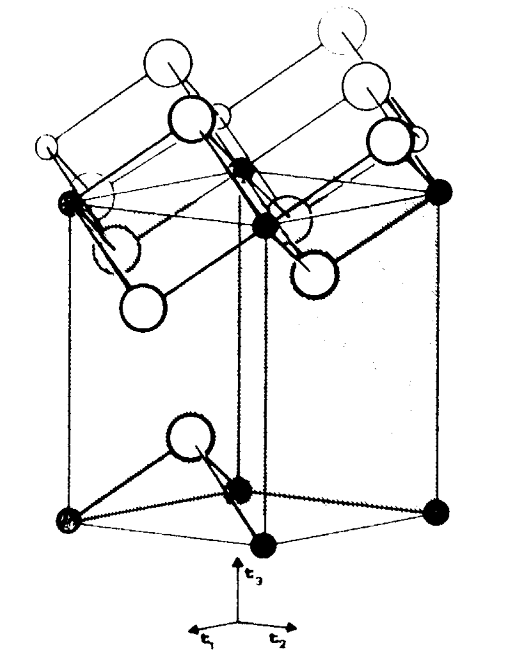
- Motivation
- Why PbI_2?
- Material Processing
- Optical Spectroscopy
- Electrical Characteristics
- Perspectives
- Conclusion

Motivation

- Inexpensive ($10-20/sq.in) deposition on an a-Si active matrix flat panel imager (AMFPI)
- Target market – Medical x-ray fluoroscopy (visualisation on catheter and stent based procedures in primarily in thoracic areas)
- Direct detection reduces AMFPI costs by eliminating the photodiode component and significantly cutting extensive processing steps (e.g. GE/NIST)
- To reduce dark current value to $<10\ nA/cm^2$
- To reduce image lag for the high frame rate (30 fps) fluoroscopy applications

Why PbI_2?

- layered semiconductor, anisotropic
- hexagonal close packed (HCP)
- av. absorption coeff. 57 cm^{-1}
- k edges (88; 33.1)
- density, $6.2 g/cm^3$
- band gap, 2.55eV - indicates that devices should operate a low leakage currents at high temperature.
- carrier mobilities
  - electrons 8 $cm^2/V\,s$
  - holes 2 $cm^2/V\,s$
- $\mu\tau$
  - electrons 10^{-5} cm^2/V
  - holes 2.10^{-6} cm^2/V
- conversion efficiency approx.240 e^-/keV (~5 eV/e^-)

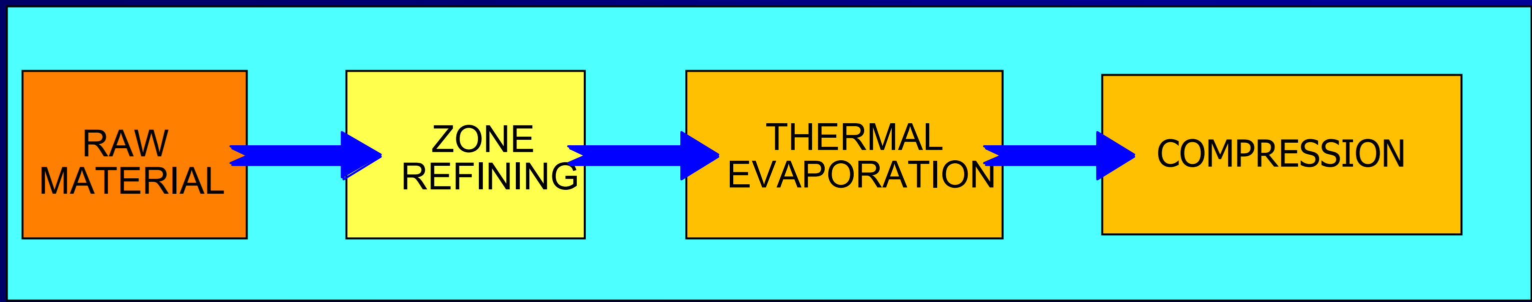


→ conversion efficiency x5 CsI:Tl, Gd_2O_2S:Tb
x10 a-Se

Who has investigated lead iodide ......and for what application?

- Nuclear spectrometers
  - Radiation Monitoring Devices, Inc (RMD) Watertown, MA, US - K.Shah et al (1990's -)
  - Tohoku University, Japan - T.Shoji et al (1990's -)
  - Hebrew University of Jerusalem, - M. Roth et al (1980's -)
  - Fisk University, Nashville, TN, US - A. Burger (1980's -)
  - University of Bari, Italy - C. Manfredotti (1977)
  - SiemensAG, Erlangen, Germany - S. Roth and W.R. Willig (1971)
- Advanced solid state batteries (Ionic Conductivity)
  - Sandia National Labs, Albuquerque, NM, US - G.A. Samara(1970's/80's)
  - University of Illinois, Urbana-Champaign, IL, US - J. Oberschmidt (1970's/80's)
- Image recording and high resolution photography
  - University of Bristol, UK - A.J. Forty et al (1950's-1960's)

A process for manufacture of PbI_2 thick films



<u>Purification (zone refining)</u>

- initial high quality feedstock
- high level of purification (ppb)

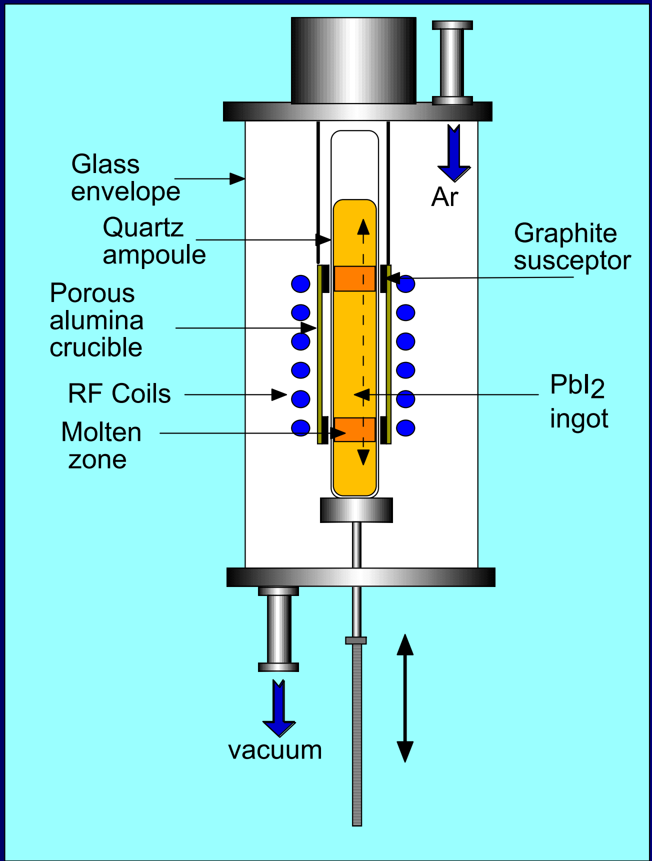
<u>Thick film deposition</u>

- semiconductor cleanliness
- control of polycrystallinity
- control of stoichiometry

<u>Compression</u>

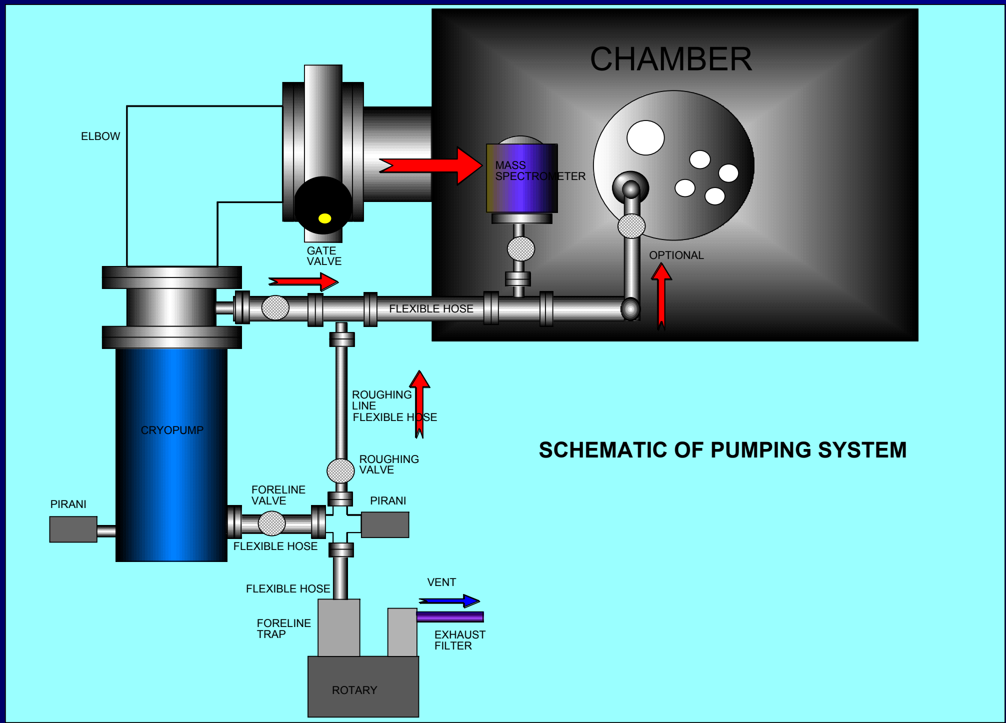
- even compression, contact method
- what effects does it have on structure and polytype formation (XRD). Spectroscopy

Zone refining



- RF heating enables larger diameter quartz ampoules to be used; therefore larger batches of purified PbI_2
- Encapsulating chamber allows vacuum or inert gas environment; therefore can be used for removing volatile components prior to zoning when ampoule is not enclosed
- Evolving design of graphite susceptors to optimise zoning process.

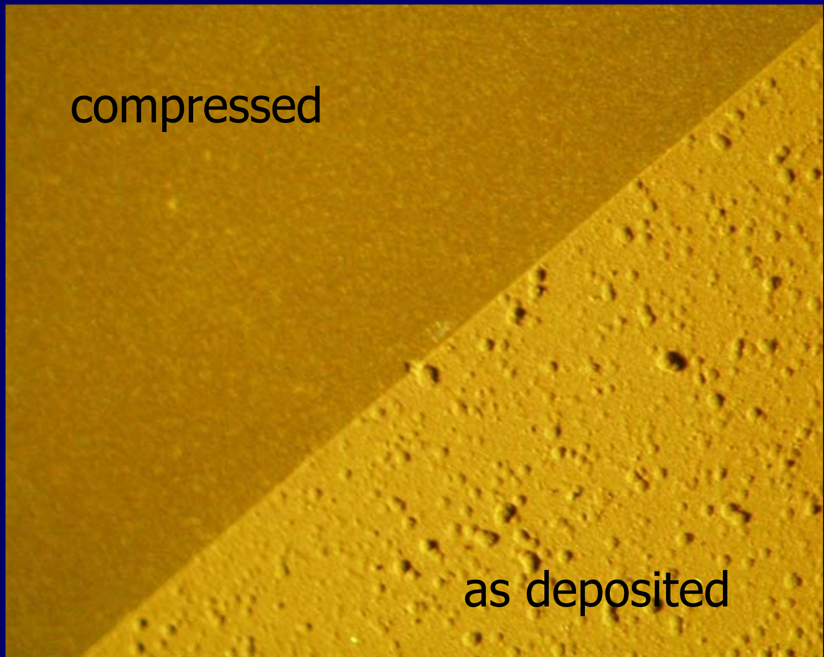
Deposition system



• Large area deposition system for PbI2 on amorphous silicon flat panels

- box system w24” x h30” x d30”
- front door, allows easy access and maintenance of source, shields, substrate mounting, etc.
- allows large panel deposition
- cryopump for clean pumping
- mass spectrometer for process control and quality/reproducibility monitoring
- side mounted pumping for ease of access to source heat, feedthroughs, substrate.
- provision for additional gas lines, iodine compensation, annealing, etc.
- provision for high pressure analysis with differentially pumped mass analyser
-

Surface morphology of lead iodide films

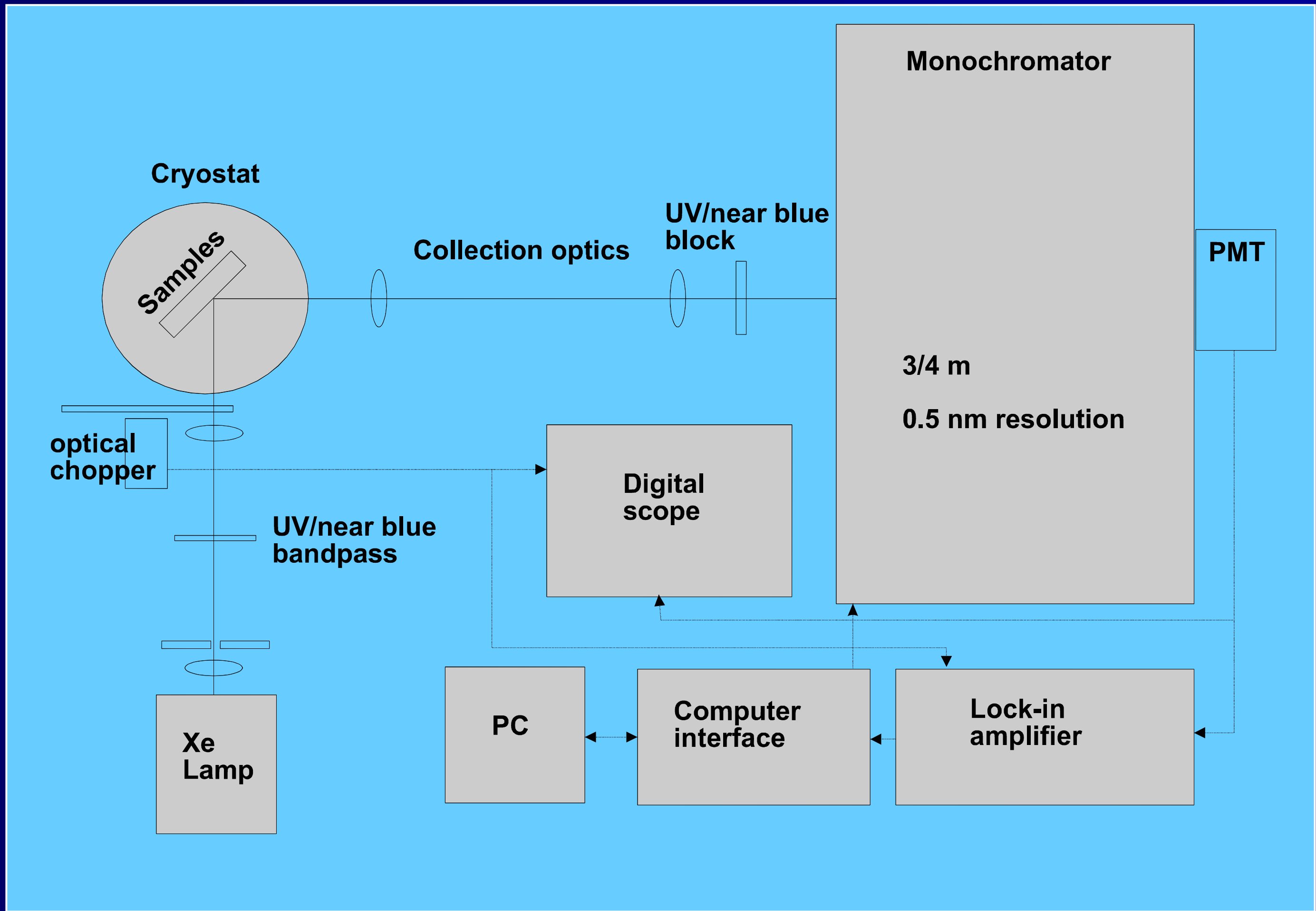


Film thickness variable
100 – 500 μm

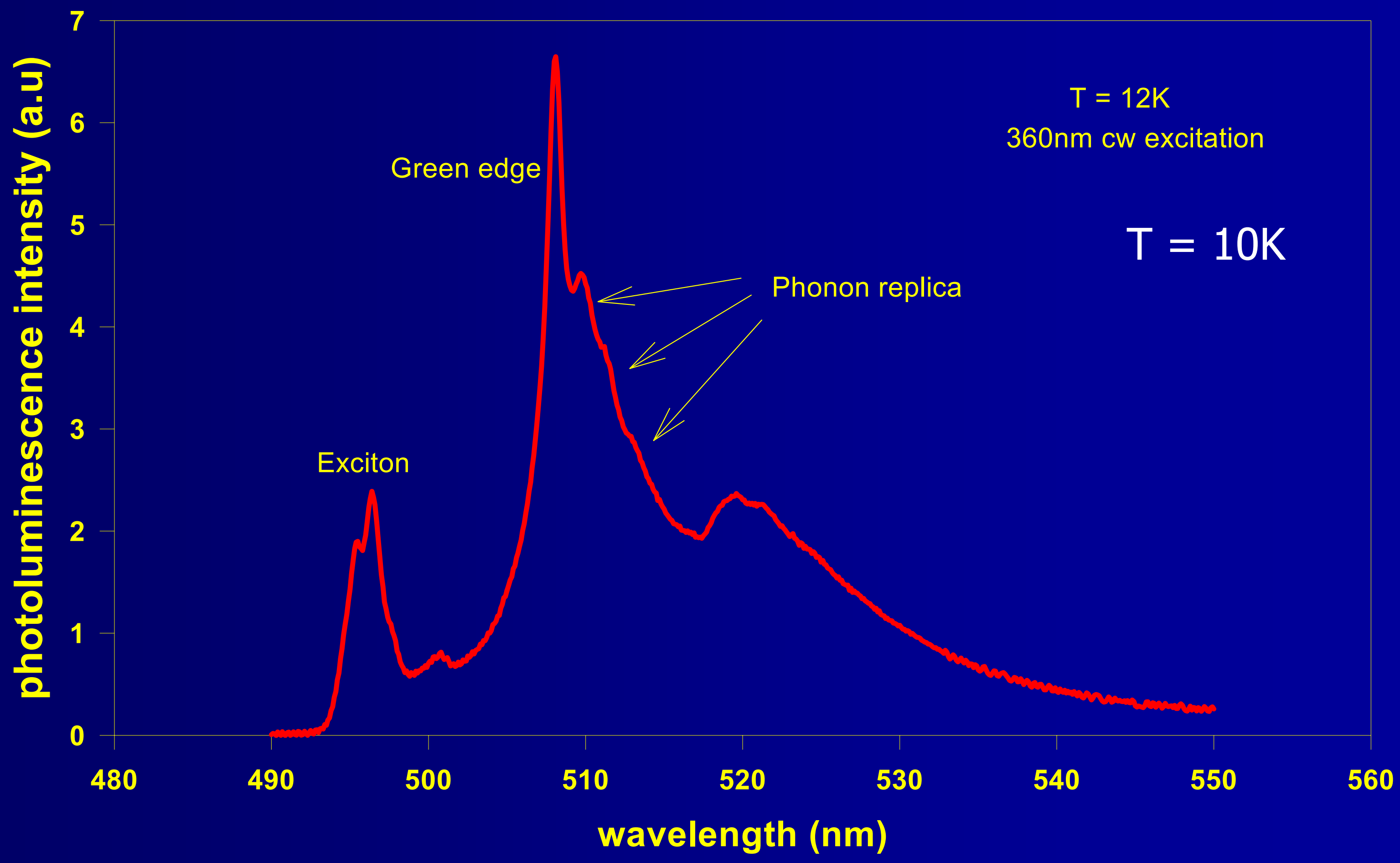
Compression
Increases density
Reduce voids
Increases microcrystallite contact

What effect does compression have on the optical and electrical characteristics of the layer?

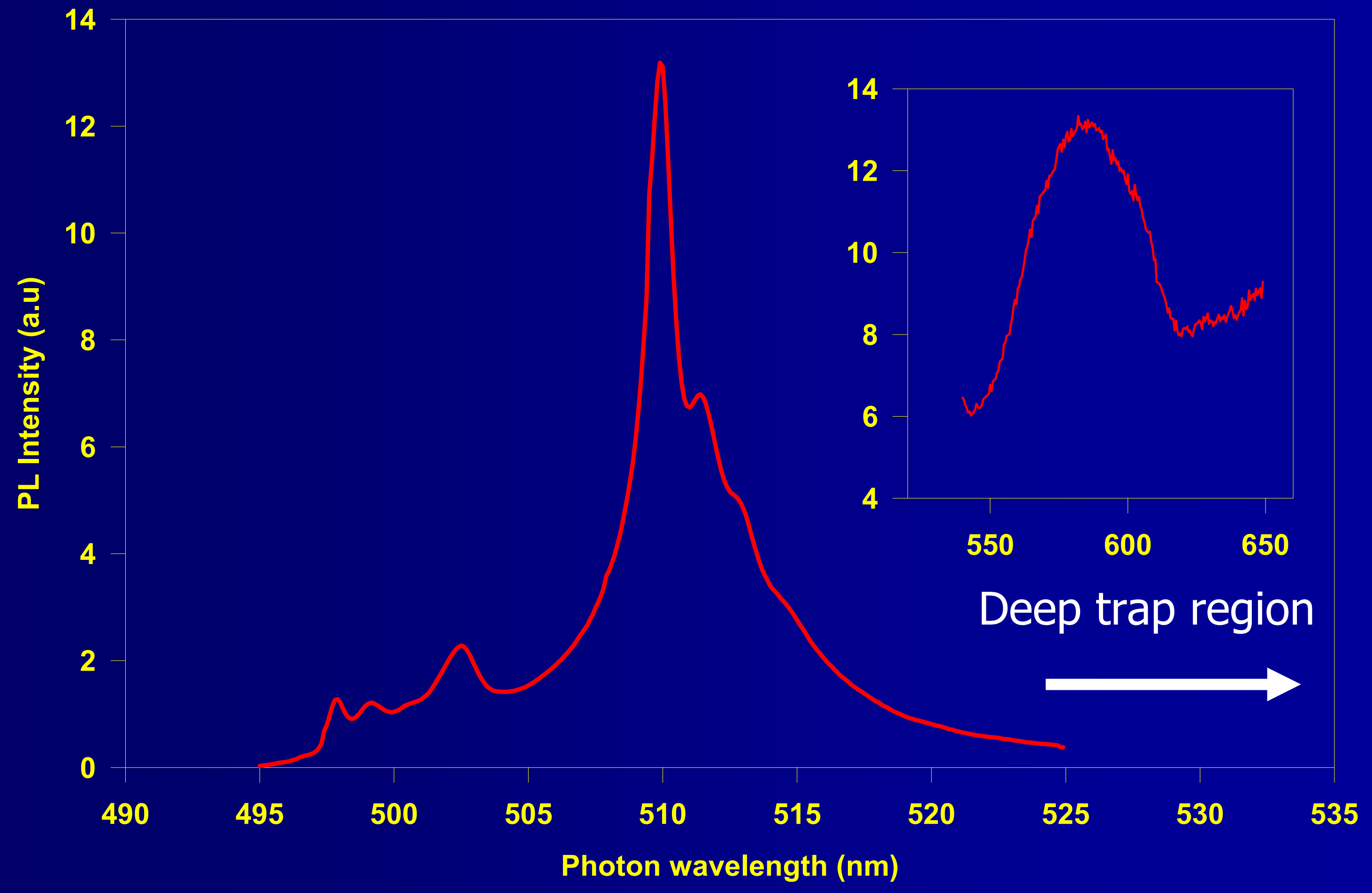
Low temperature (10K) photoluminescence



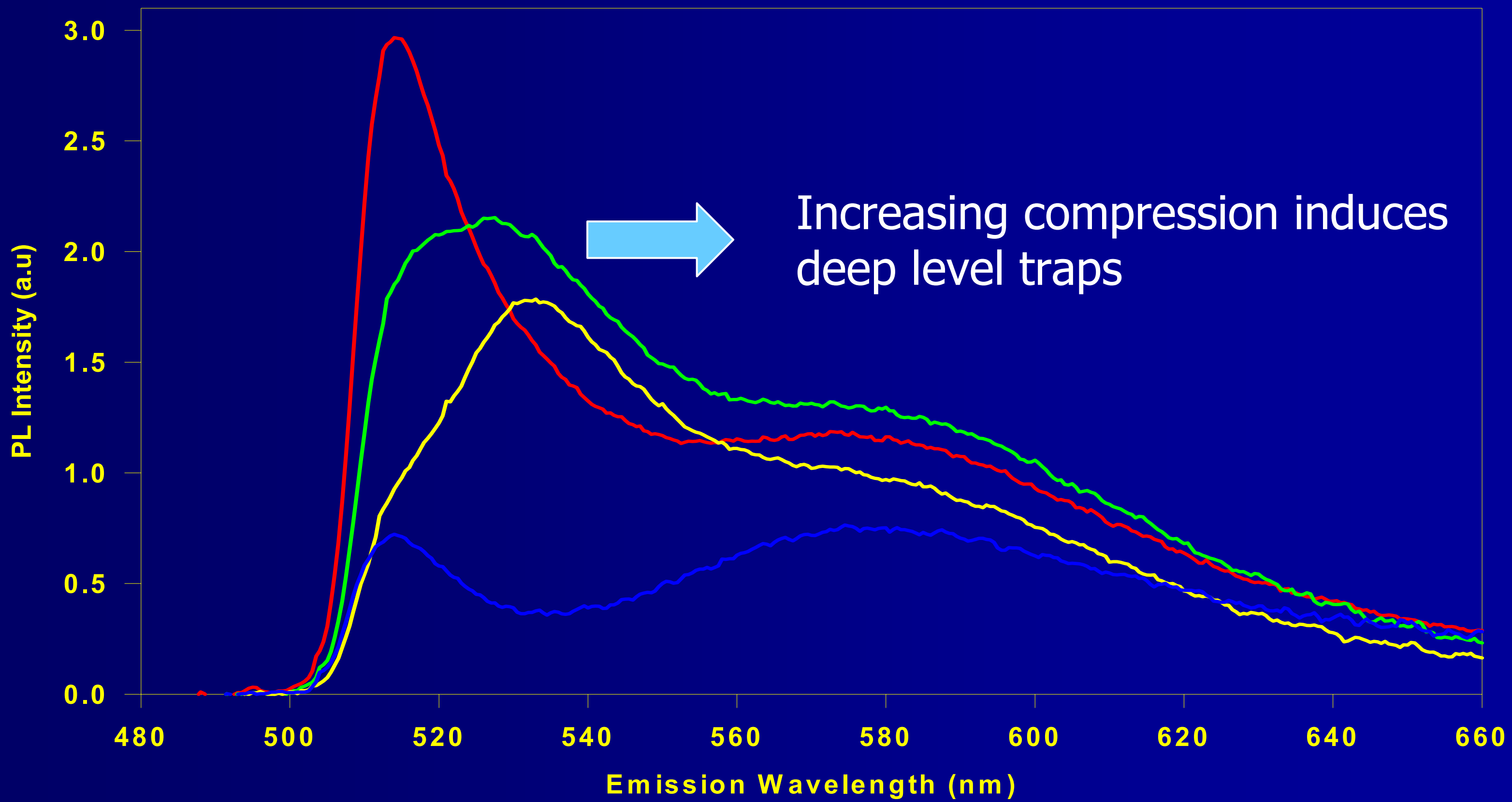
Photoluminescence spectra of high quality lead iodide (zone refined) I



Photoluminescence spectra of high quality lead iodide (zone refined) II

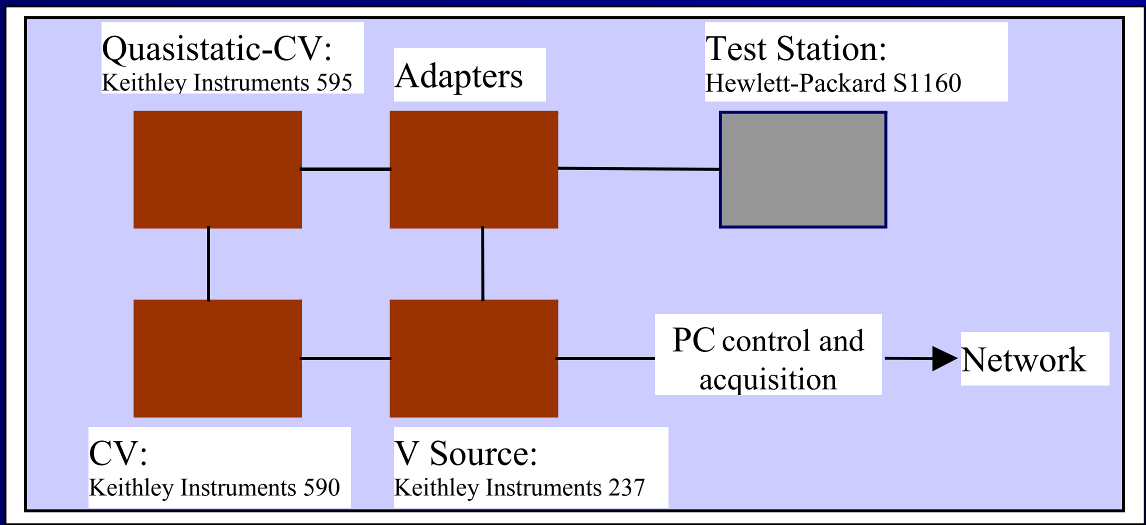


Low temperature photoluminescence of compressed PbI_2



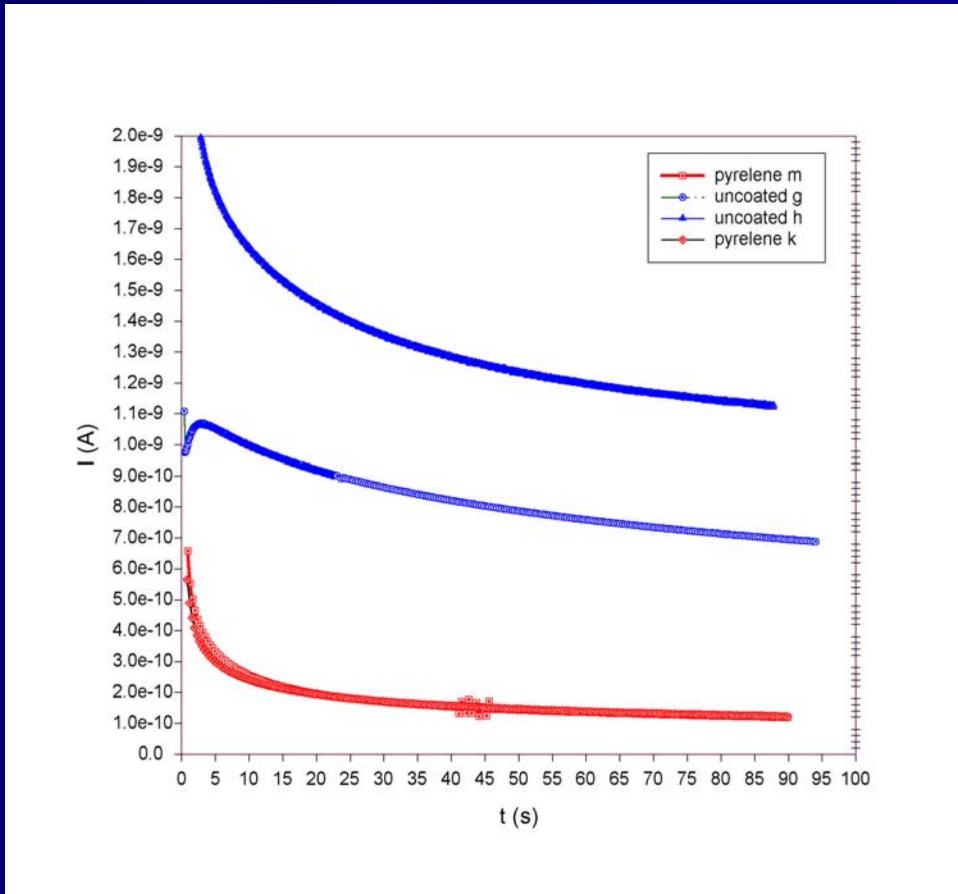
Electrical measurements

- Dark current
- I-t
- I-V
- C-V



Dark current measurements

I (A)



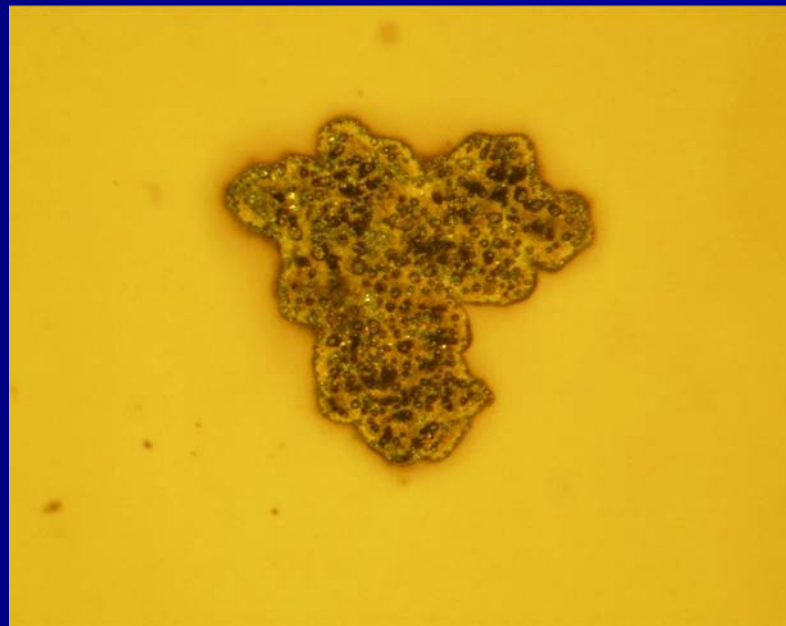
Time (s)

Post-processed PbI_2
1 nA/cm²

Dielectric interlayer (Parylene)
100 pA/cm²

Semiconductor contacts

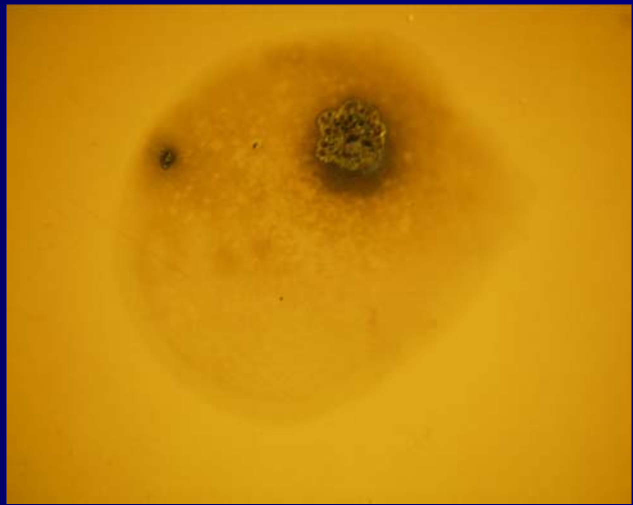
graphite



PbI_2 breakdown
from underside of contact

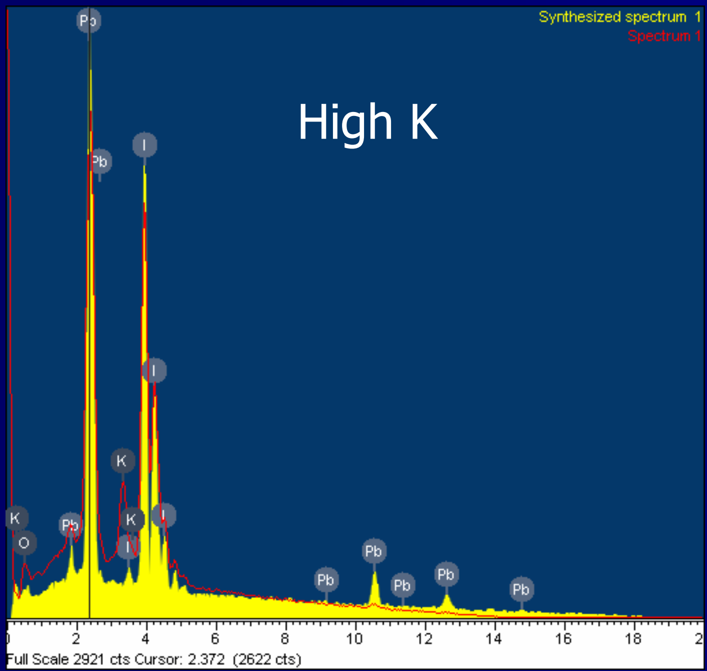
Material choice dictates contact stability, e.g. Ag promotes rapid failure; Au, Te and colloidal graphite

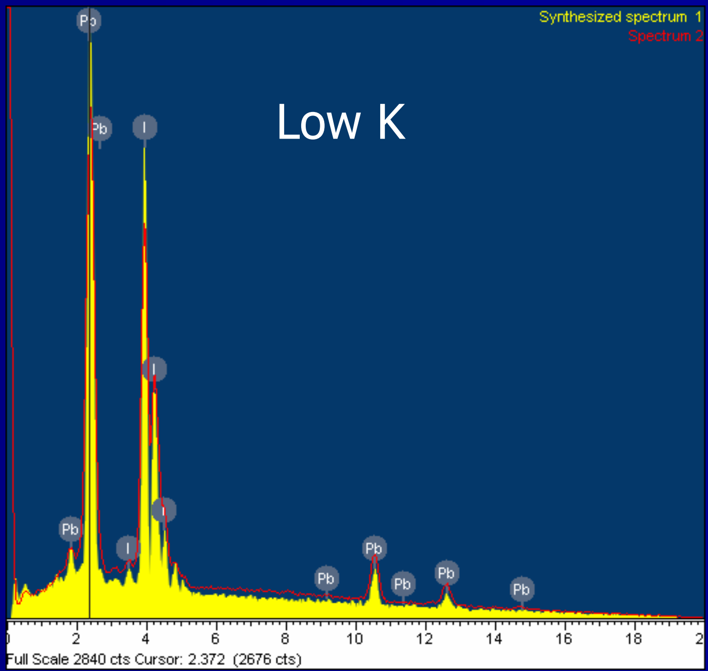
Other failure modes



- Device drive conditions (V/cm^{-1})
- Operational temperatures
- Other material impurities

EDX spectra of films





Contact stability in conditions with minimal potassium contamination

Perpectives

- Project ceased due to reorganisation of key account partner
- Further work is required to optimise contact technology and drive characteristics
- IP for process in progess
- Key account partner being sought for taking project development to the next stage

…any offers???

Conclusions

Cost effective large area deposition achieved

Compression proven to be ineffective for high quality imaging layers

excessive deep level trapping resulting in image lag

Dark current targets achieved and exceeded

Optimum drive conditions and ultimate performance not yet established

Acknowledgements

Dr Bhaswar Baral – materials growth

Dr Xuefeng Liu – electrical characterisation

Dr Derek Day – (formerly of Varian Medical Systems, Sunnyvale, CA)

analysis of electrical data

Terry Brown -

(Metal Crystal and Oxides Ltd, Harston, Cambridge, UK)

for advising on, and supplying, RF zone refining system

Thank you for listening
….any questions?

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