Trace alpha-particle detection system for water networks: from direct detection in liquid phase to element identification

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CONTEXT

In emergency situations: how to identify and probe water contamination from alpha emitters?

We want

- A reliable and reusable device
- Cleanable
- Enabling spectroscopy at high resolution
- Fast (max a few 10s of minutes)
- Enabling quantification of actinides
- Available for water, but also drinks
- Low energy, a field trial device.

Several actinides are solely alpha emitters

APPROACH

Electrochemistry on top of a silicon detector

Patented WO 2012045872 (2010)
BDD diamond is grown on Si from a Canberra PIPS

- 1/ Preconcentration of actinides
- 2/ Counting time.
  → Typ 30Bq/l detected in 10 min

- The detection limits only depend on the acquisition time
- Identification of the traces possible
- Cleaning of the sensor is automatic at the end of the measurement

→ Thank you for your attention...

... Little time to discuss signal issues in polyX...
Probing the transient response of poly-X diamond to improve the stability of diamond devices under pulsed periodic excitation.

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Requirements

- OK SC CVD should be close to ideal,
  (but unfortunately not defect free!)

- But … what about
  • large area
  • availability
  • very thin layers
    e.g. for alpha detection or membranes for synchrotrons
  • cost
  • Autonomy for production

→ Still a chance for polyX materials?
  → Essentially very uniform over large areas!
The role of defects

CVD materials, as well as high quality IIa type diamonds inherently exhibit defect levels

- of interest for TL dosimetry
- stable at RT

Lot of literature available...

Impurities, Dislocations, Vacancies etc

- highly detrimental for IC
- unstability
polyX materials characteristics

Experiments performed under 6 MeV photon beams (medical accelerator)
Comparing a diamond device to a reference gas ionisation chamber
Typ. dose rate is = 3Gy/min

Basics of signal formation

$X, \beta, \gamma, +V$

$e^-, h^+$
$X, \beta, \gamma + V$

Deep traps (for holes)
$X, \beta, \gamma$

$+V$ → Deep traps (for holes)

$\rightarrow$ Pumping

$+V=0$

$\rightarrow$ Deep traps (for holes)

$\rightarrow$ Pumping
$\gamma$, $\beta$, $\gamma$

Deep traps (for holes)

Pumping

Shallow traps (for holes)

Progressively emptied
Deep traps (for holes) → Pumping

Shallow traps (for holes) → Progressively emptied

\[ V = 0 \]
Deep traps (for holes) → Progressively emptied

Shallow traps (for holes) → Progressively emptied

Pumping
"overshoot"

Deep traps (for holes)

Pumping

Shallow traps (for holes)

Progressively emptied

Same discussion on electrons...

Deep traps (for holes)

Pumping

Shallow traps (for holes)

Progressively emptied
It comes:
- The ON state is related to an equilibrium between carrier trapping and de-trapping:
- Sensitivity is strongly affected by transiting charges → Thus to fluency!
- Equilibrium also varies with dose levels → Non linearities!
- Stability is strongly varying with the device temperature:
  → This is one way to improve the signal stability: work at temperatures at which shallow levels are emptied.
  → OK but not always applicable

Illustrative case

Probing the response under a medical accelerator:
- 6 MeV photon beam
- Polycrystalline diamond (very defective!)
- Dose rate is 3Gy/min
Explaining the poor device characteristics?

Experiments performed under 6 MeV photon beams.
Comparing a diamond device to a reference gas ionisation chamber
Typ. dose rate is = 3Gy/min

And sub-linearities?

$E_Q$ is only created by the carriers transiting through the device
$\rightarrow$ Therefore the greater the signal the greater $E_Q$

$\rightarrow$The lower the fluency, the lower the signal :
$\rightarrow$ the lower the trapped charge,
$\rightarrow$ higher signals after stabilisation  ($E_Q$ vanishes)
Effect of the E field

At low E fields, the overshoot is predominant, and vanishes at high E fields.

See A. Rose, Concepts in Photoconductivity (1963)
Response to a pulsed excitation

Tests on the SAPHIR accelerator (Saclay)
Pulsed X-rays, 17MV accelerator
Pulses are 2µs long, at 25 Hz

Pulsed height spectra under DC bias

(= Histograms of the voltage pulses )

Bias is 0.5 V/µm

Each 5 sec
Pulsed height spectra under DC bias
(= Histograms of the voltage pulses)

Pulsed height spectra under DC bias

Bias is 0.5 V/µm

Overshoot

Bias is 1 V/µm

Each 5 sec
Emptying defects at 0V bias

Pulsing the bias → Using one "lost" pulse to further empty traps

Mode 1/2

Emptying defects at 0V bias

Photocurrent (nA)

Time (µs)
It comes:

- Unstable effects are *very* commonly observed in polyX devices
- The most determinant influence of shallow defect levels (typ 0.3 to 0.6 eV; the ones emptied close to RT)
- They affect all materials! (from 1E8 to 1E13 defects/cm³)

Solutions proposed:
- Heat the device (Patent WO2006024661)
- Use light to detrap shallow carriers between events
- 0V-bias the device and irradiate between two events (most convincing) (Patent FR243507 D25440 AV)

Thank you for your attention...

(I stop now...)