MOSFET applications in brachytherapy

Joanna E. Cygler, Ph.D.

The Ottawa Hospital Cancer Centre, Ottawa, Canada
Carleton University, Dept. of Physics, Ottawa, Canada
University of Ottawa, Dept. of Radiology, Ottawa, Canada

MOSFETs

- **Metal Oxide Semiconductor** Field Effect Transistor
- Capable of dose measurements immediately after or during irradiation (on-line dosimetry)
- Can operate in active (positive bias on gate during radiation) or passive mode*

*not discussed here

Threshold voltage shift / $\Delta VT$

- $\Delta V_T$ is a function of absorbed dose
- That function is linear when the MOSFET operates in the biased mode during the irradiation
- Absorbed dose linearity region increases with the increase of the bias voltage

Soubra, Cygler, Mackay, Med. Phys. 21(4), 567-572, 1994

Types of MOSFET detectors

Unbiased single MOSFET
- Temperature dependence
- Instability of response
- Shorter dose linearity range than biased MOSFETs
- Frequently used as disposable detectors

Single bias, single MOSFET
- Temperature dependence
- Instability of response

Dual-bias, dual-MOSFET
- Two MOSFETs on same silicon chip operating at two different gate biases
- Better sensitivity, reproducibility, and stability than single MOSFET
- Minimal temperature effects
Commercial MOSFET systems

- BEST Medical (Thomson-Nielsen)
  - Mobile MOSFET system (single detectors and arrays)
  - Portable Dosimeter, based on dual-bias-dual-MOSFET technology

Mobile MOSFET system

Two physical detector sizes:
- standard (8 x 2.5 x 1.3 mm$^3$)
- microMOSFETs (3.5 x 1 x 1 mm$^3$)

Two detector active volumes (sensitivities):
- Standard (0.2 x 0.2 x 5 \times 10^{-4} mm$^3$)
- High (0.2 x 0.2 x 1 \times 10^{-3} mm$^3$)
Nominal sensitivities in high-energy photon beams of various TN detector/bias combinations.

<table>
<thead>
<tr>
<th>TN MOSFET type</th>
<th>Bias</th>
<th>Nominal sensitivity (mV/cGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard sensitivity</td>
<td>Standard</td>
<td>1</td>
</tr>
<tr>
<td>Standard sensitivity</td>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td>High sensitivity</td>
<td>Standard</td>
<td>3</td>
</tr>
<tr>
<td>High sensitivity</td>
<td>High</td>
<td>9</td>
</tr>
</tbody>
</table>

Energy dependence of detector response (diode and MOSFET)


MOSFET applications in brachytherapy

- Ideal for brachytherapy
- Small detector size (microMOSFET)
- Isotropic angular response
- Fits inside brachytherapy catheters or plastic tubes
- Anatomical locations: tumour, bladder, urethra, rectum, etc.
- Available as a single detector or five-detector-array with or without radio-opaque markers

MOSFET calibration set-up for LDR brachytherapy

Calibration should be performed
- for a given isotope
- ideally in water for two detector orientations

Modified after Bloemen-Van Gurp et al. 2009
**In vivo Measurements – prostate implants**

MOSFET reading taken every 1cm

Fluoroscopy image of the prostate after implant

**Use of MOSFET Detectors During Prostate Implant Procedure**

Calculated initial pre-plan (★) measured post implant (▲)

Cygler et al Radiotherapy and Oncology 80: 296-301; 2006
The radio-opaque marker of the array’s tip, helps with visualization under CT or fluoroscopy of MOSFETs’ positions relative to the internal bladder wall (at the lower edge of the Foley balloon).

**X-ray image of MOSFET array in the urethra during HDR prostate implant**

**Home-made MOSFET array for rectal dose measurement in HDR prostate brachytherapy**

*Courtesy of J. Wittych*
New developments: 4D dosimetry system - RADPOS*

- Combination of electromagnetic positioning sensor and MOSFET dosimeter
- Simultaneous measurements of dose and spatial position
- Software developed: allows to sample position and dose manually/automatically
- Real-time treatment verification tool
  - Patient and/or organ motion
  - Accuracy of delivered dose
- Can be used in brachytherapy


RADPOS in HDR brachytherapy

Special phantom constructed for treatment simulation. It could contain multiple plastic catheters positioned at well defined distances

RADPOS detector with a single MOSFET positioned in the centre of a thin plastic tube supported by two parallel acrylic plates (bottom and top)

The RADPOS detector was calibrated at 1 cm distance from the source, according to AAPM TG-43 protocol
1. RADPOS detector was calibrated according to AAPM TG-43 protocol, by sending the Ir-192 source into tube 1, to positions ranging from 8.0 to -8.0 cm in 0.5 cm steps.
2. Treatment delivered using catheters 1-5, dwell time 20 s.
3. Dose sampled every 10 s.

**Use of RADPOS in LDR prostate brachytherapy - rationale**

- Needle insertions
  - push prostate forward
  - cause prostate swelling

Presence of trans-rectal ultrasound probe deforms prostate and alters the position of OAR.

Removal of the ultrasound probe
- alters prostate shape and position of OAR
- Question: Can it also affect the seed separation and therefore possibly cause a change in dose distribution?
Modified RADPOS detector in LDR prostate brachytherapy

Modification of RADPOS probe - MOSFET array instead of single detector

- RADPOS probe was placed inside the urinary catheter during seed implantation

Cherpak, Cygler, E. Perry, "Real-time measurement of urethral dose and position during permanent seed implantation for prostate brachytherapy, Brachytherapy, 13, 169-177, 2014

Real time prostate brachytherapy

- RADPOS with MOSFET array inside urethra
- Effect of rectal US probe removal

Cherpak et al, Brachytherapy, 13, 169-177, 2014
Conclusions

- MOSFETs are suitable for in vivo dosimetry in brachytherapy
  - microMOSFETs are recommended to use
  - linear MOSFET array
- Careful calibration for appropriate energy range should be done
- Precise positioning of the detector is crucial - RADPOS can help
- RADPOS detector
  - Can perform temporal measurements of dose/position during treatment delivery
  - Can be used for identification of errors during HDR treatment delivery

Sample results

<table>
<thead>
<tr>
<th>Direction</th>
<th>Average displacement during treatment planning</th>
<th>Average displacement during implant procedure</th>
<th>Average displacement due to TRUS probe removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>x (right/left)</td>
<td>(0.0-0.6) mm</td>
<td>(0.1-2.5) mm</td>
<td>(0.1-2.0) mm</td>
</tr>
<tr>
<td>y (superior/inferior)</td>
<td>(0.0-0.6) mm</td>
<td>(0.4-5.9) mm</td>
<td>(0.3-8.7) mm</td>
</tr>
<tr>
<td>z (anterior/posterior)</td>
<td>(0.0-0.6) mm</td>
<td>(0.0-3.3) mm</td>
<td>(1.2-5.9) mm</td>
</tr>
<tr>
<td>$r = \sqrt{x^2 + y^2 + z^2}$</td>
<td>(0.3-4.6) mm</td>
<td>(1.4-5.1) mm</td>
<td>(1.4-9.7) mm</td>
</tr>
</tbody>
</table>

A.J. Cherpak, J.E. Cygler, C.E. Perry, "Real Time Measurement of Urethral Dose and Position Using a RADPOS Array during Permanent Seed Implantation for Prostate Brachytherapy" Brachytherapy, 2014
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Thank you