MINIATURE RADIATION DOSIMETER FOR IN VIVO RADIATION MEASUREMENTS

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The use of ionizing radiation from various sources for the treatment of tumors is widespread. Some 250,000 individuals will start radiation treatments each year. At present, it is not common practice to instrument the patient with dosimeters, although there are passive dosimeters like thermal luminescent dosimeters (TLDs) which are available. There are no commercial devices for in vivo, real time, dosimetry of patients. The dose to be given the patient is determined from computer modelling and the calibration of the radiation sources.

We will describe a miniature dosimeter which has been mounted in a 1 mm catheter. The active device is a radiation sensing field effect transistor (hereafter called a RADFET) which can be used in either an active or passive mode.^{1 2} The RADFET in a catheter is designed to be used during implant radiation therapy of the breast, prostate, cervix, among other modalities.

The RADFET operates in a fashion similar to the chemically sensitive field effect transistor (CHEMFET). Ionizing radiation produces electron-hole pairs in the gate dielectric (SiO_2) of the MOSFET. In the specially prepared SiO_2 of the RADFET, there is a great excess of hole traps over electron traps. The applied gate voltage sweeps the electrons out leaving a net positive charge of trapped holes. The net charge is proportional to the total dose received by the RADFET. The charge is measured by the threshold voltage shift of the RADFET. A new circuit, with some similarities to circuits used for CHEMFETs, will be described for making differential measurements of the threshold shift as a function of radiation dose. The threshold shift of a RADFET as a function of radiation dose is given in the Figure. The sensitivity of the RADFET is defined as the slope of the response in the Figure, and it is seen to decrease at the higher dose levels. The decrease in sensitivity is caused by the internal space charge build-up inside the gate oxide which increases electron-trapped hole recombination and inhibits electron diffusion to the contacts. The dashed line in the Figure is a fit to the data by the formula:

$$\Delta V_{th} = A(1 - \exp(-B \cdot \text{dose})), \text{ where for these devices}$$

$$A = 4.05 \text{ volts and } B = 3.39 \times 10^{-5} \text{ rad}^{-1}$$

This formula can be used to convert the RADFET readings into dose in rads. The sensitivity of the RADFET in a catheter is found to be unaffected by the temperature over a wide range in temperature (experimentally, -180C to 100C), and when it is operated with the proper drain to source current, the threshold voltage does not change with temperature.

Figure Caption: The change in threshold voltage of a RADFET as a function of the dose in rads. The solid line through the data points is a guide to the eye and the dashed line is from a formula given in the text.

The RADFET has several advantages over the commonly used TLDs. The RADFET can be monitored continuously using very low power and voltage and thus can give the dose rate as well as the total dose. The TLD needs to be inserted in a special reader after exposure and the information is erased during read-out; the threshold shift of the RADFET is relatively permanent within a few percent over many months. The RADFET is much smaller for the same sensitivity than the TLD chip. The silicon chip is extremely rugged, comparable to the TLD chip, but the wires and wire bonds are more vulnerable to mechanical effects. The RADFET can also be operated with no voltage bias during exposure, although the sensitivity is a little smaller than with a bias.

Because of the economics of microelectronic fabrication, RADFETs can be produced for a very low cost; single MOSFETs of the required sophistication are a dollar or less at retail. There does need to be development work on processing to obtain repeatable hole and electron trap concentrations in the oxide. For a range of sensitivities, RADFETs with different thicknesses of the gate dielectric need to be fabricated. The threshold voltage is a DC property of the device and care during fabrication is needed to prevent drift of the threshold voltage with time due to phenomena like ion contamination of the oxide. Because of the inherent advantages of RADFETs over other forms of radiation dosimetry, we expect to see increasing use of RADFETs in the future.

References:

1. R. C. Hughes, "Theory of Response of Radiation Sensing Field Effect Transistors," J. App. Phys., 58, 1375, 1985.
2. A. G. Holmes-Seidle, "The Space-Charge Dosimeter; General Principles of a New Method of Radiation Detection," Nuc. Inst. and Methods, 121,169, 1974.