Radioluminescent clad optical fibre X-ray sensor

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An optical fibre X-ray sensor using cladding to core coupling of radioluminescent emissions from X-ray phosphors is presented. The sensor is tested using a line source normally used in the pre-ionisation of an excimer laser and is calibrated against a pendosimeter and the emission intensity of a scintillating block.

Introduction: Optical fibre sensors based on cladding luminescence have been reported widely. In these sensors the luminescent stimulation may come from side illumination [1, 2] or from the evanescent wave of guided mode in the core [3] but the general principle of the luminescent emission intensity being relative to the measurand is the same. In all of these sensors the emission from the cladding is coupled to the core via the evanescent field of guided modes which has been shown theoretically [4]. The device presented in this Letter is based on the same principle of cladding luminescent intensity but the core coupling mechanism is different from [4]. In this sensor there was no light launched into the fibre via its aperture to create the conditions for coupling in the evanescent field at the core cladding interface but instead it relies wholly on scattering at the core cladding interface caused by surface roughness of the core.

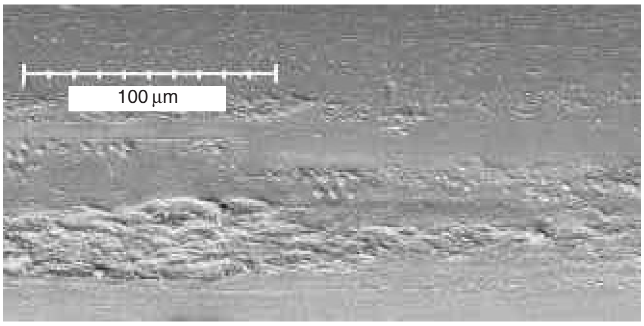

Fig. 1 *Polymer fibre surface after cladding removal*

Sensor: A 1 mm diameter polymer fibre is stripped of its cladding by a combination of chemical and mechanical methods. This process produces a roughness on the surface of the bare fibre core that can be seen in the SEM micrograph of Fig. 1. The inactive fibre end face is coated with aluminium foil to prevent core coupling by this route. The sensitive part of the fibre is then coated with an epoxy which has been doped with a radioluminescent phosphor and subsequently (after curing) with another aluminium coating to prevent cladding stimulation by ultraviolet emissions from stray plasma discharges in the experimental apparatus. The epoxy's transmission characteristics and refractive index have been carefully selected to allow maximum transmission of the generated luminescence (625 nm) and to maintain the positively guiding properties of a conventional optical fibre. A schematic diagram of the sensor is shown in Fig. 2. When X-rays stimulate the cladding material a visible emission is generated. Part of this emission is scattered to the fibre core as a positively guided mode whereupon it propagates through the core. The active sensor end face is coupled to a conventional polymer optical fibre which transmits the signal to a photomultiplier for conversion to an electrical signal.

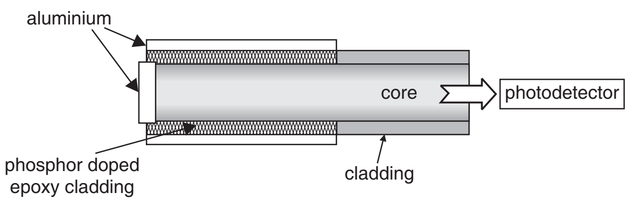

Fig. 2 *Luminescent clad X-ray sensor*

Experiment and results: The X-ray source [5] used in this experiment is a line source with a length of 80 cm. The source produces X-ray pulses with a FWHM duration of about 50 ns. To determine the response of the sensor it is placed along the axis of the out-coupling window of the source. A multimode polymer fibre is used to connect the sensor to a photomultiplier (Hamamatsu R331) which was placed in a shielded room to reduce electromagnetic interference. A gain of the order of 10^6 was required for the photomultiplier, indicating that low light intensity was coupled into the fibre core. For calibration two other X-ray detectors were used. The first detector consists of a plastic scintillator cube (Nuclear Enterprise NE102A) of 1 cm^3. A hole was drilled in the scintillator block and a fibre was inserted to collect some of the scintillating emission. The second detector was a pen dosimeter (Physiotechnie SEQ6, 100 mRad full scale) which was used to measure the cumulative dose of a set of X-ray pulses. In separate measurements it has been verified that the source is emitting homogeneously in the region where the detectors were placed [5]. The results from this experiment are shown in Fig. 3. The signals shown in this graph are an average of several pulses and are plotted against the average dose as recorded on the pen dosimeter. The data points represent the peak height from the X-ray fibre sensor and the scintillator signal integral. The voltage of the X-ray source and therefore the current, the X-ray signal and the dose vary at maximum ±10% from shot to shot. The standard deviation over a range of shots is calculated to be 5% and the error bars included reflect this. The experimental results are shown in Fig. 3.

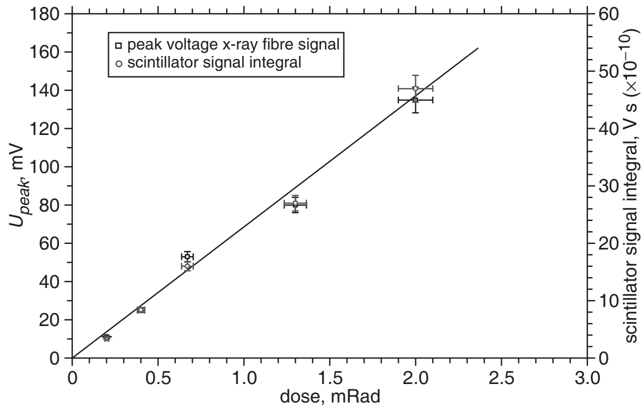

Fig. 3 *Sensor output and scintillator signal against X-ray dose*

Conclusion: A novel X-ray detection mechanism has been demonstrated. The sensor operates using the imperfections which arise on the surface of polymer fibres when they are stripped of their cladding and therefore offers spatially integrated measurement over its entire length. From a linear regression analysis its shows a maximum deviation from linearity of 7%. The sensor offers the advantages of immunity from electromagnetic interference and electrical isolation which are nessessary in some hostile environments associated with X-ray generation. Further potential development of this device includes its expansion into a multi-point network utilising phosphors with different emission wavelengths and a spectrally resolved output.

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