High-Dose Radiation Effects in Organic Thin-Film Transistors

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ABSTRACT

Organic thin-film transistors (OTFTs) are promising candidates for radiotherapy dosimetry due to their flexibility and real-time readout capabilities, but their long-term performance under high accumulated radiation doses remains unclear. OTFTs were irradiated to 1 and 2 kGy using a linear accelerator, and electrical performance was evaluated over a 20 Gy dose range. To investigate the origin of radiation-induced changes, pentacene and polystyrene were irradiated separately to 1 and 10 kGy using a cobalt-60 source and analyzed with X-ray photoelectron spectroscopy (XPS). Detector sensitivity remained unchanged up to 2 kGy despite a linear reduction in field-effect mobility of up to 12%. XPS revealed increased oxidation of pentacene and radiation-induced chemical changes in polystyrene consistent with the formation of acceptor-like defects, both explaining the observed mobility degradation. These results demonstrate that OTFTs maintain stable dosimetric performance after high accumulated doses while providing insight into material-level degradation mechanisms that can guide the development of more radiation-tolerant organic dosimeters.

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INTRODUCTION

Accurate radiation dose measurement is critical for the safe and effective use of ionizing radiation in cancer diagnosis and treatment. Since radiation interactions depend on material composition, ideal dosimeters should have properties similar to human tissue. However, many conventional dosimeters are fabricated from higher atomic number (high-Z) inorganic materials that differ from soft tissue, requiring correction factors for accurate dose determination [1].

Organic semiconductors are composed primarily of low atomic number (low-Z) elements, making them more tissue-equivalent while also enabling lightweight, flexible, and wearable radiation sensors. We have previously demonstrated that organic thin-film transistors (OTFTs) incorporating a polymer electret provide a linear radiation response under clinical irradiation conditions [2,3].

Despite these promising results, the long-term effects of accumulated radiation dose on OTFT performance remain unclear. This work investigates the high-dose stability of OTFTs and uses X-ray photoelectron spectroscopy (XPS) to identify radiation-induced material changes in the organic layers that may affect device performance.

METHODS AND MATERIALS

- OTFTs were fabricated with a 45 nm polystyrene electret and 50 nm pentacene semiconductor on silicon substrates (Fig. 1a and b)
- OTFTs were irradiated to accumulated doses of 1 and 2 kGy using a linear accelerator and device sensitivity was evaluated over a 20 Gy range
- For material studies, the organic layers (pentacene and polystyrene) were deposited onto ITO-glass and irradiated to 1 and 10 kGy using a Co-60 source
- XPS measurements were performed at the Elettra synchrotron to explore radiation-induced chemical changes in the organic materials

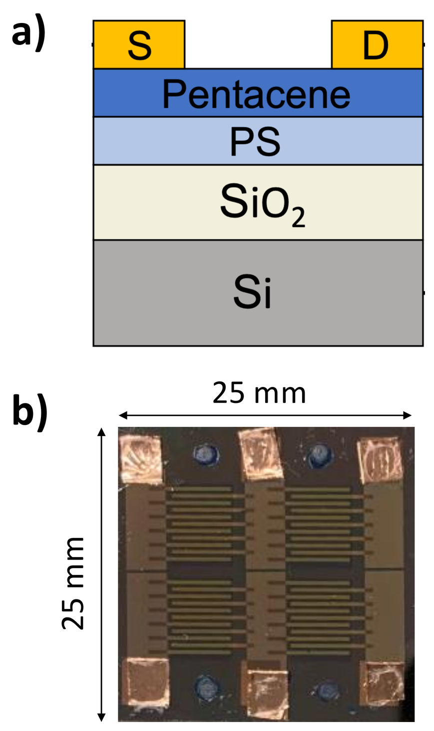

Figure 1. (a) Layered structure diagram and (b) top-view image of the OTFT with a polymer electret.

RESULTS

- OTFT current-voltage (I-V) curves shifted systematically with increasing dose (Fig. 2a). The voltage extracted at −1 μA remained linearly related to dose over a 20 Gy range before irradiation and after accumulated doses of 1 and 2 kGy ($R^2 > 0.98$), demonstrating preserved detector linearity after high-dose exposure (Fig. 2b)

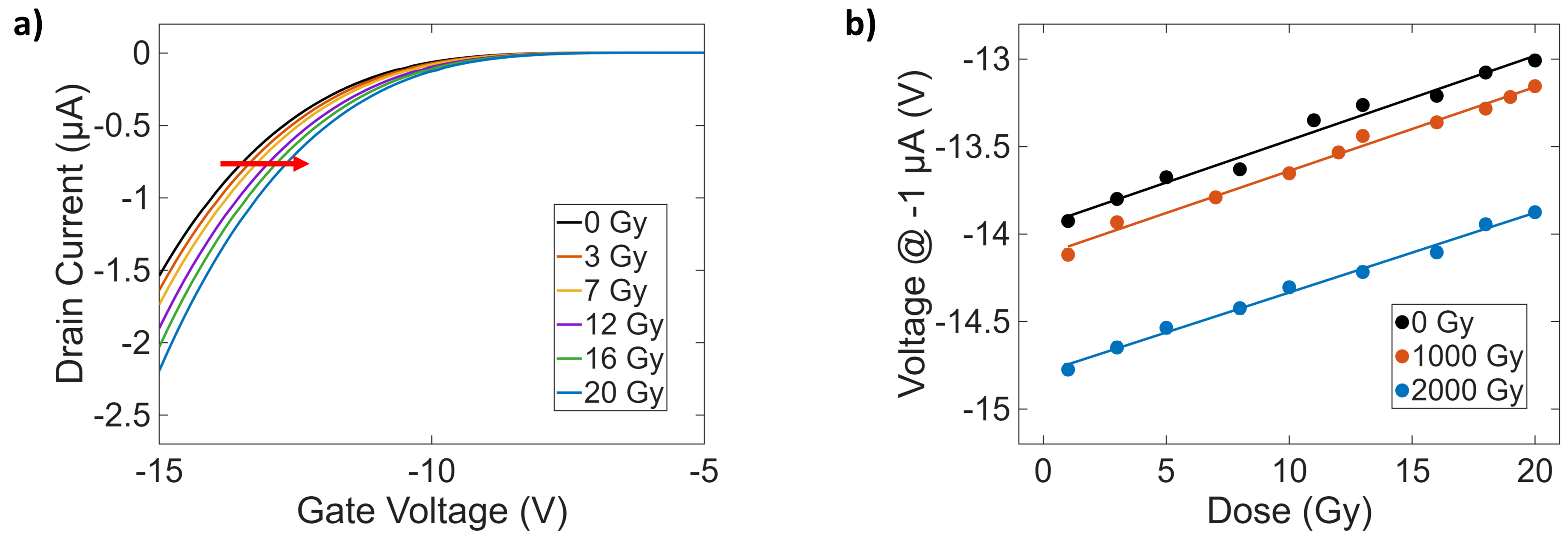

Figure 2. (a) Example of the data collected from the OTFT after irradiations. I-V curves are measured immediately after subsequent irradiations. Doses represent the accumulated dose to the device. (b) Gate voltage at −1 μA extracted from the transfer curves as a function of delivered dose before irradiation and after accumulated doses of 1 and 2 kGy.

- Detector sensitivity, extracted from the slope of the voltage-dose fits in Fig. 2b, remained stable within experimental uncertainty following accumulated doses of 1 and 2 kGy (Fig. 3a)
- Field-effect mobility, a measure of how easily charge moves through the transistor channel, decreased by approximately 12% after 2 kGy (Fig. 3b)

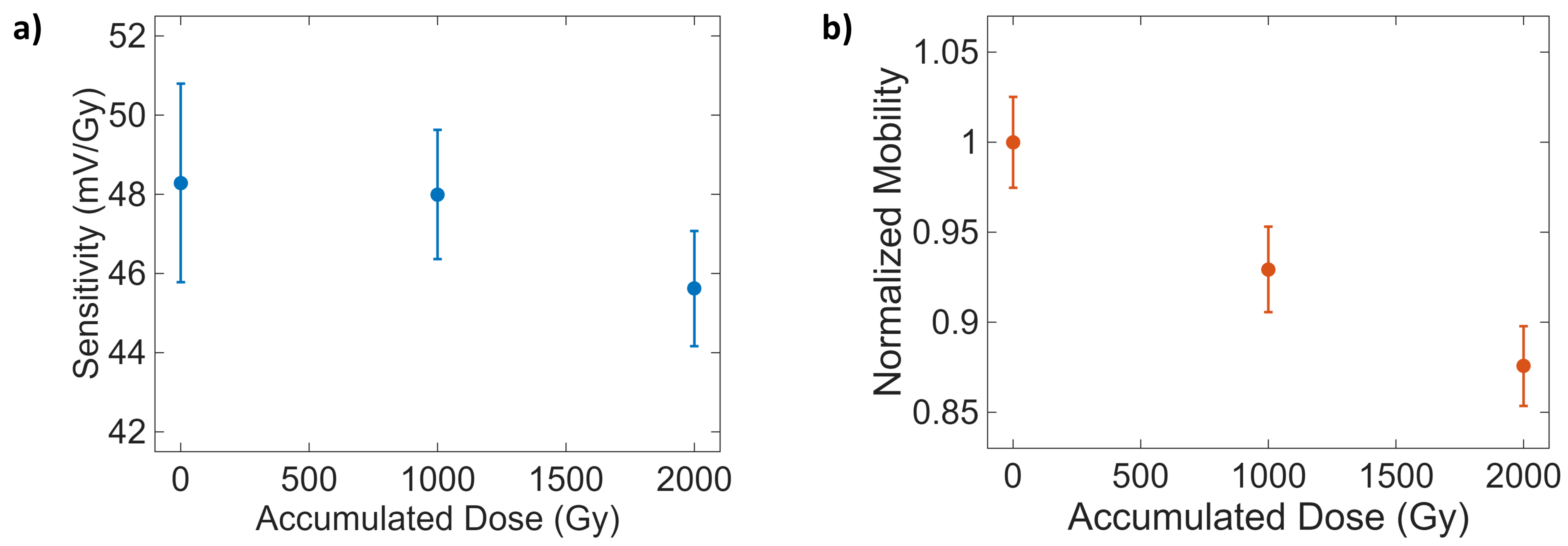

Figure 3. OTFT (a) sensitivity and (b) field-effect mobility as a function of accumulated dose. Error bars represent the uncertainty of the linear fit.

- XPS revealed increased carbon–oxygen bonding in pentacene after irradiation (Fig. 4a)
- In polystyrene, the carbon peak energy shifted with dose, consistent with radiation-induced acceptor-like defect formation (Fig. 4b)

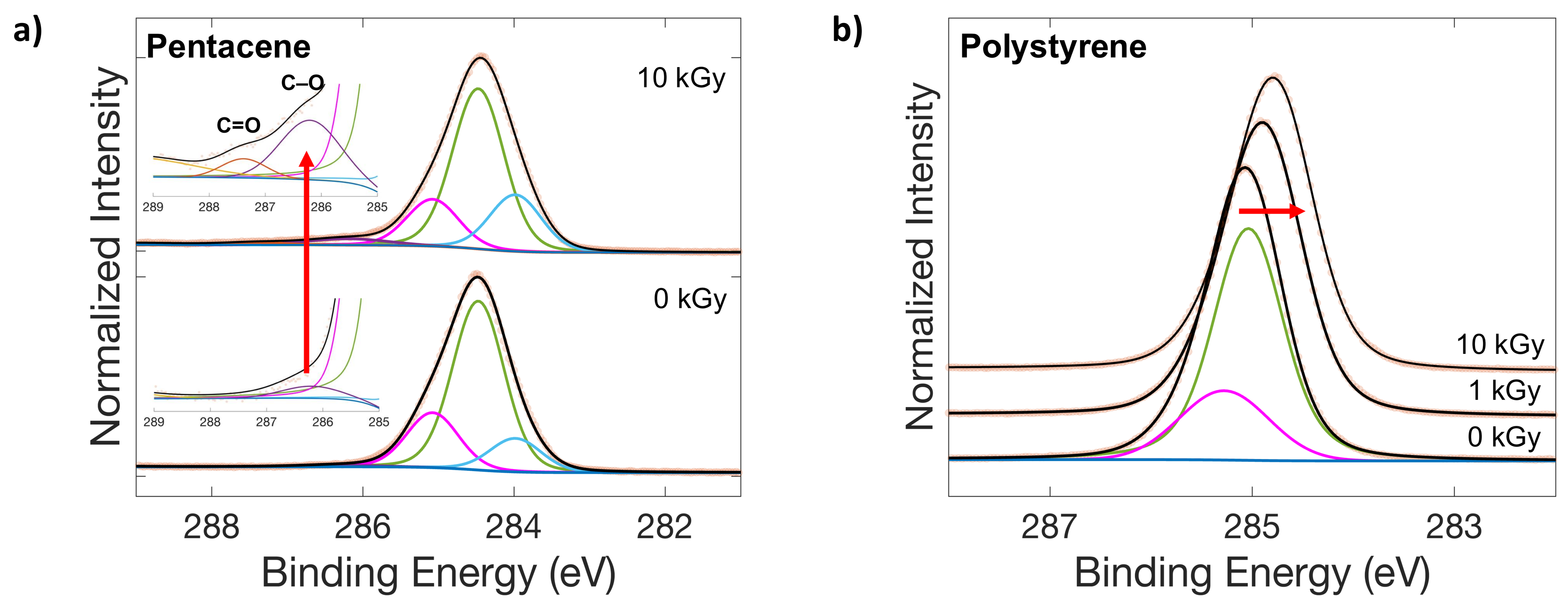

Figure 4. High resolution XPS spectra of: (a) pentacene C 1s core level (normalized to maximum) for pristine and 10 kGy irradiated samples. Insets show a magnified view of the carbon–oxygen bonding region; (b) polystyrene C 1s core level (normalized to maximum) for pristine, 1 kGy, and 10 kGy irradiated samples.

CONCLUSIONS

- OTFT dosimeters retained linearity and sensitivity after accumulated doses up to 2 kGy
- Radiation exposure caused a dose-dependent decrease in mobility without affecting detector sensitivity
- XPS revealed pentacene oxidation and acceptor-like defect formation in polystyrene, linking material-level changes to the observed mobility degradation in devices
- These findings provide insight into OTFT radiation response and support the development of more stable, radiation-tolerant organic dosimeters

ACKNOWLEDGMENTS & REFERENCES

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