CHARACTERISING THE PERFORMANCE OF HYDROGEN SENSITIVE COATINGS FOR NUCLEAR SAFETY APPLICATIONS

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Hydrogen Hazards in Nuclear Plant

- Intrinsic to many process and storage facilities handling nuclear material
- Released under normal operations and accident conditions
- Main sources of hydrogen in facilities handling nuclear material:
    i. Radiolysis of water or organic materials
    ii. Corrosion of metals (Mg, Zr, U)
- Typically maintained below 1% hydrogen significantly lower than LFL (4%)

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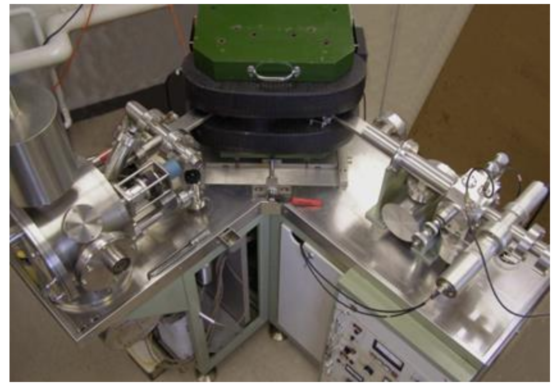
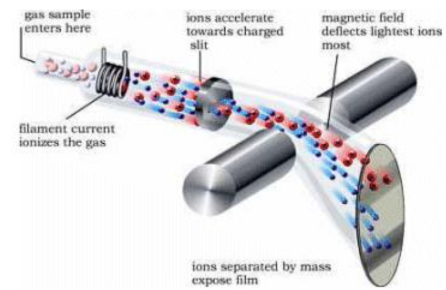
Traditional Hydrogen Detection

Commercially available sensors detect hydrogen via a change to the sensing element such as:

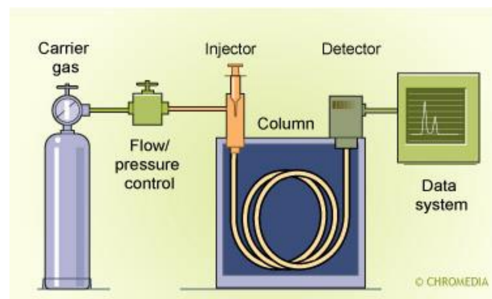
i. Temperature
ii. Refractive index
iii. Electrical properties
iv. Mass



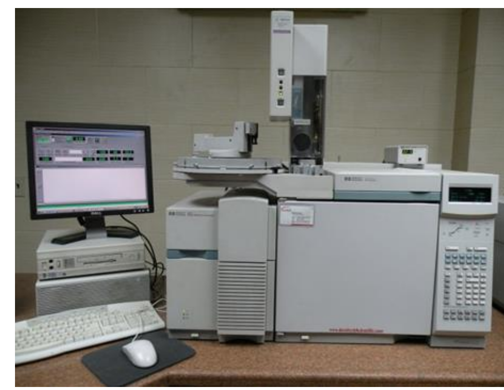
Mass Spectrometry



Portable Detection



Gas Chromatography



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New Hydrogen Sensor Development

Investigate the development of a sensor suitable for use on nuclear plant.

In general, the ideal sensor would:

- be inexpensive
- be simple and reliable
- be hydrogen specific and sensitive enough to detect below the LFL
- have a rapid response time
- have a long life span
- require no external power supply
- be radiation tolerant

Passive Hydrogen Sensors

Some transition metal oxides such as WO_3 and V_2O_5 have chemochromic properties. Their optical properties change with a change in oxidation state. Hydrogen will react with certain transition metal oxides altering the oxidation state, in turn, causing a colour change in the visible region.

Hence, transition metal oxides can be used as passive visual indicators for the presence of hydrogen

→ function under resilience conditions

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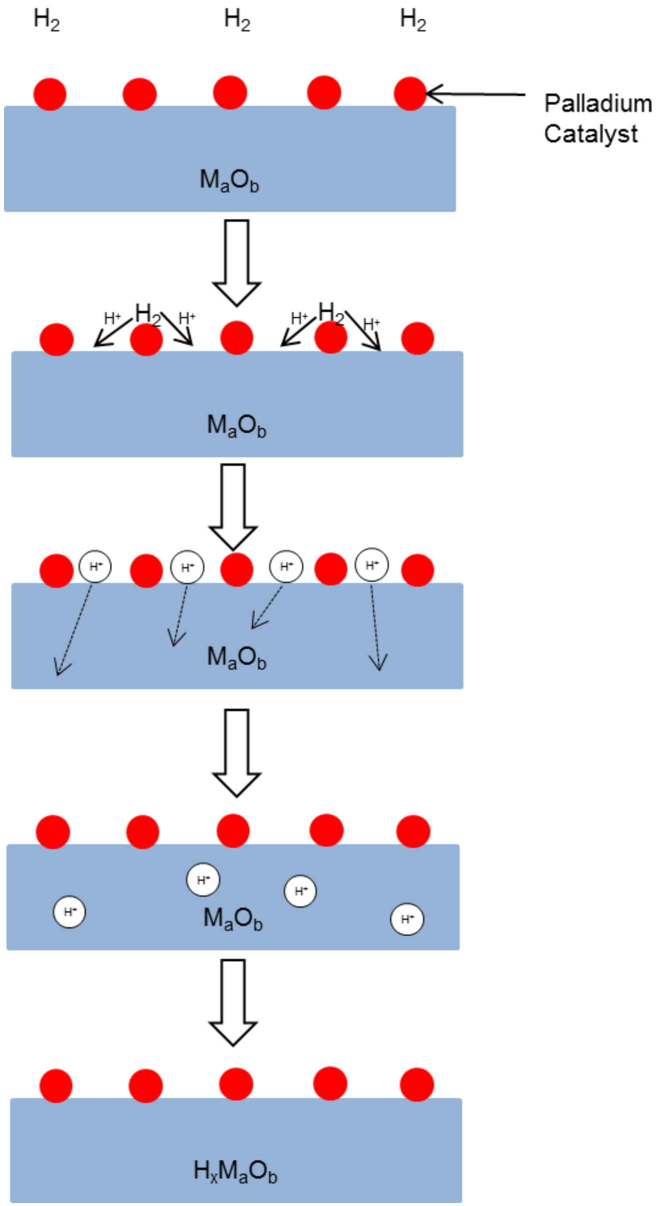
Hydrogen Sensing Mechanism



1. Film exposed to hydrogen
2. Transfer of hydrogen from gas phase to surface
3. Adsorption of hydrogen onto catalyst surface
4. Dissociation of adsorbed molecular hydrogen into atomic hydrogen
5. Diffusion of hydrogen atoms through Pd/M_aO_b interface
6. Insertion of H^+ ions into M_aO_b lattice
7. Reduction of metal ions and formation of metal bronzes $H_xM_aO_b$

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Hydrogen Sensing Mechanism

1. Double injection of e^- and H^+

$$V_2O_5 + xH^+ + xe^- \leftrightarrow H_xV_2O_5$$

$$\mathrm{V}^{x+} \qquad\qquad\qquad \mathrm{V}^{x-1+}$$

2. Reaction with chemisorbed oxygen species

$$O_2\ (gas) \rightarrow 2O\ (adsorbed)$$

$$O\ (adsorbed) + e^-\ (from\ V_2O_5) \rightarrow O^-$$

$$H_2 \rightarrow 2H\ (adsorbed)$$

$$2H\ (adsorbed) + O^- \rightarrow H_2O + e^-$$

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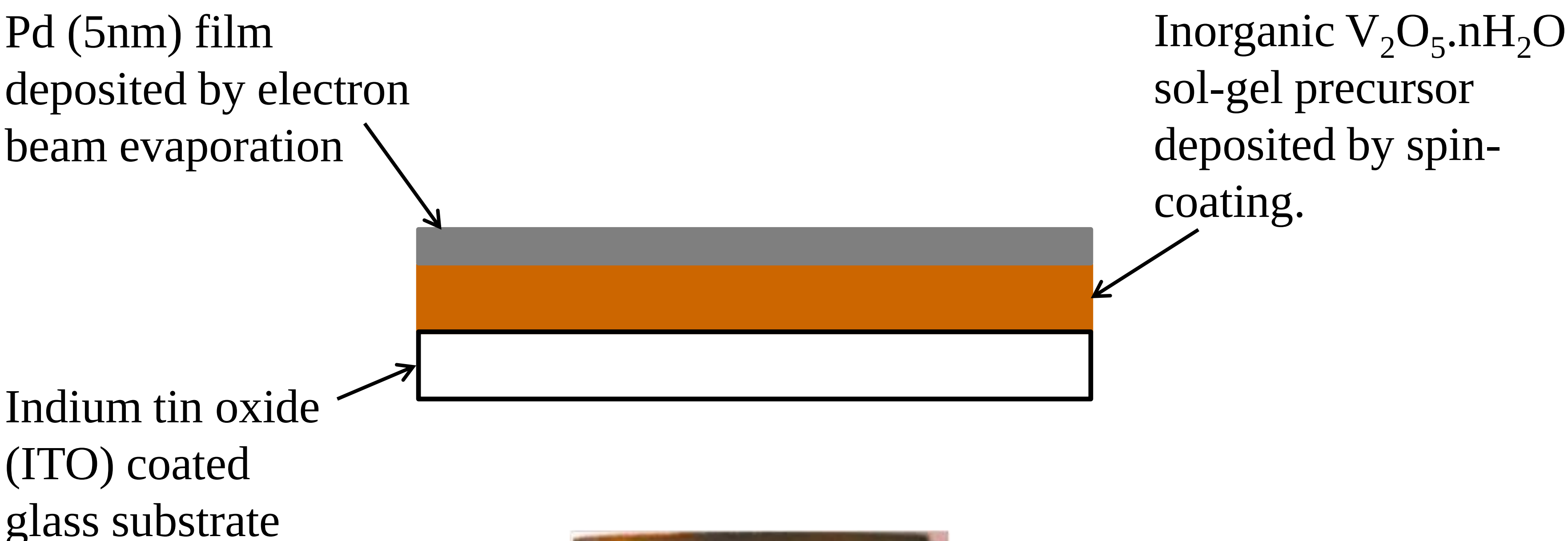
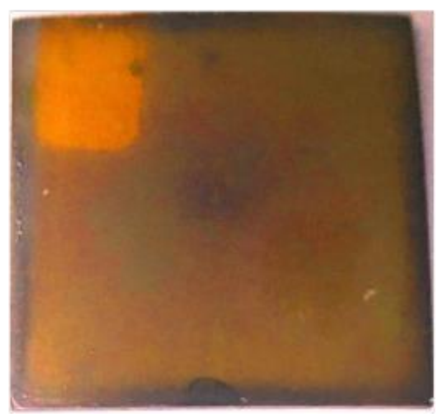
Experimental

Preparation of Pd-V_2O_5 film sensors





Experimental

Radiation Exposure

Samples are irradiated at the University of Manchester's Dalton Cumbrian Facility (DCF) using the Foss Therapy Services Model 812 Cobalt 60 self-shielded irradiator.

Absorbed dose rate of 200 Gy/min.
Total irradiation doses of 0, 5, 20, 50 kGy.

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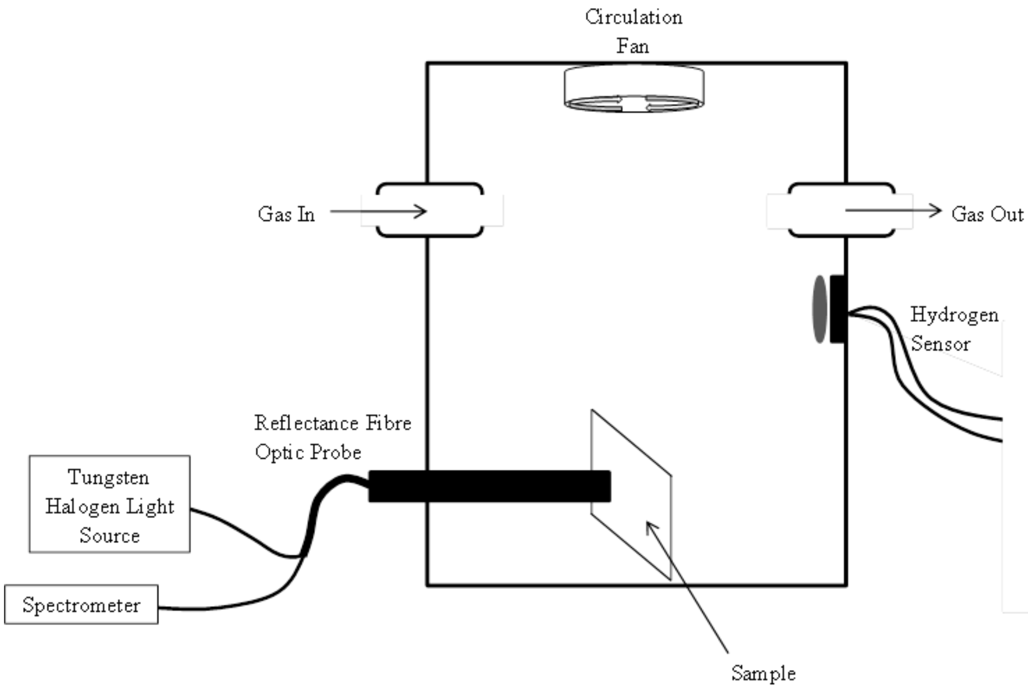
Experimental

Hydrogen Gas Sensing



→ 4 vol% H_2/N_2

→ 5 L/min flow rate

→ Room temperature

→ Diffuse optical reflectance measured using an Ocean Optics Flame-S-UV-NIR spectrometer at 45°

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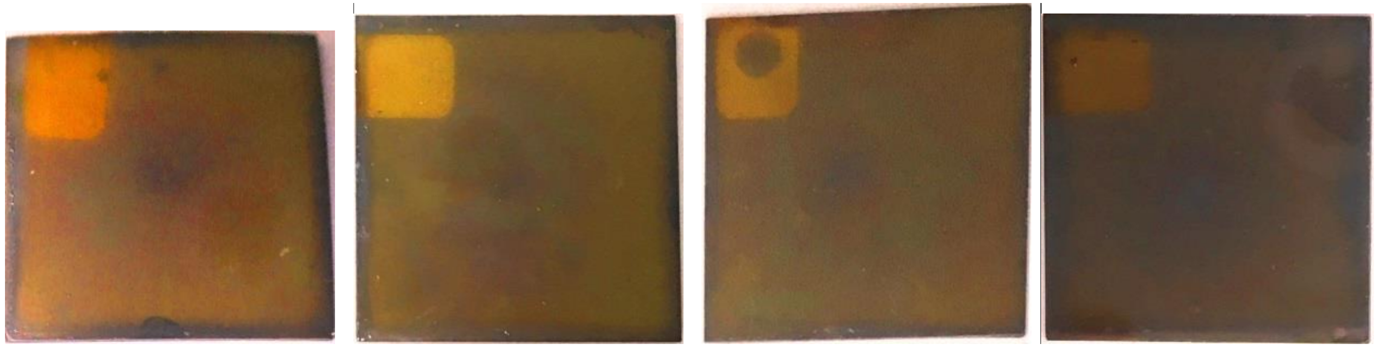
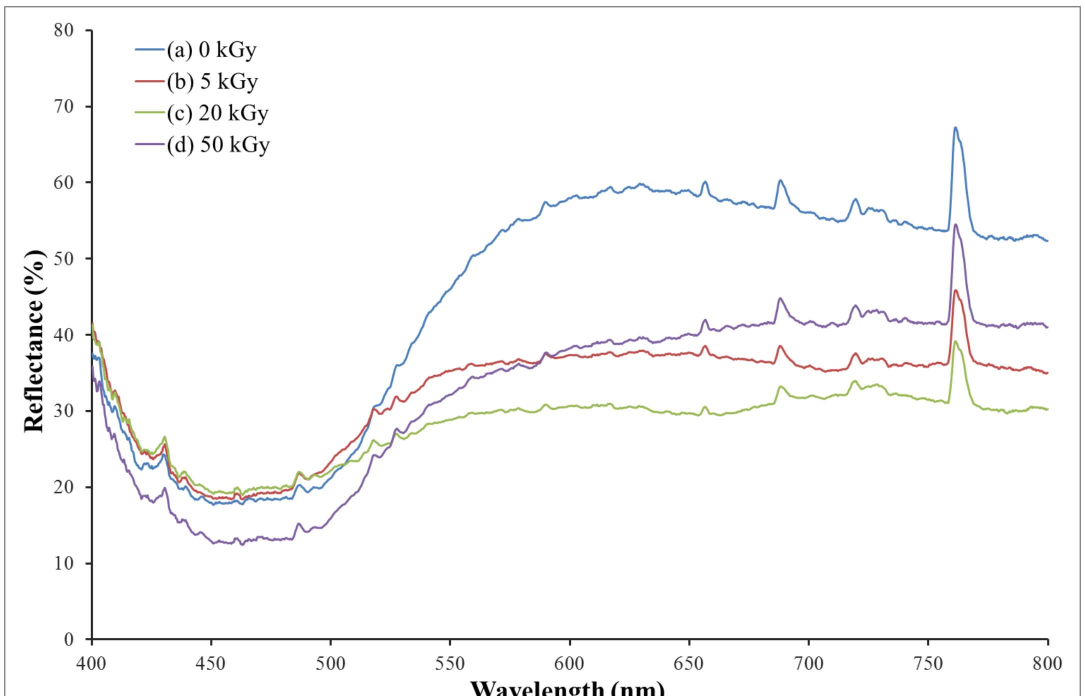
Effect of Gamma Irradiation

Initial Colour Change



Un-irradiated | 5 kGy | 20 kGy | 50 kGy



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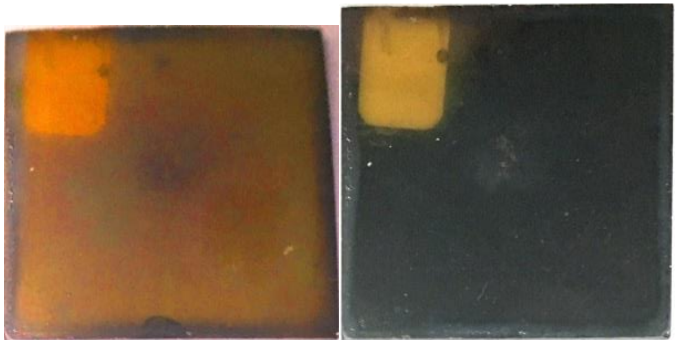
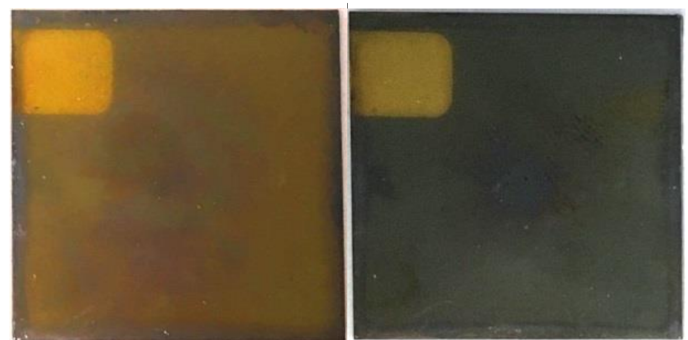
Effect of Gamma Irradiation

Hydrogen Sensing



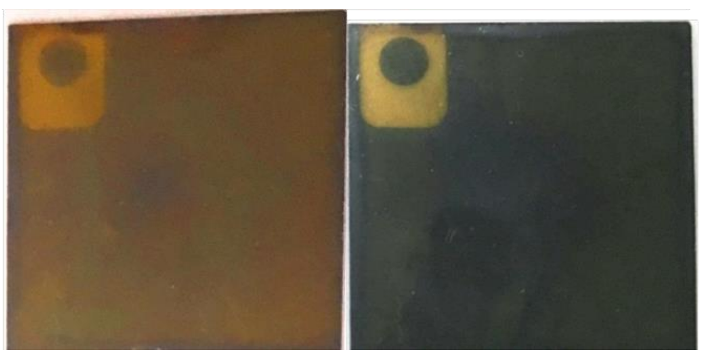
Before After

Un-irradiated



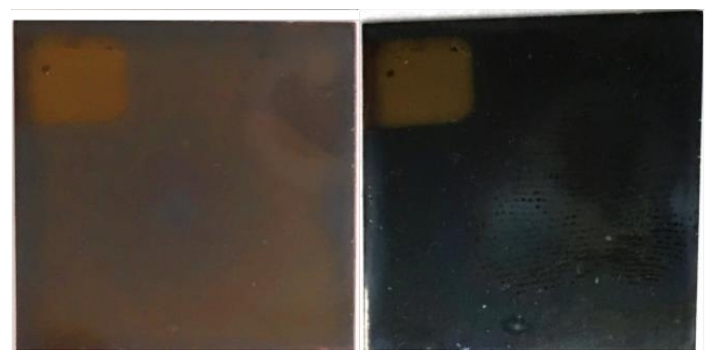
Before After

5 kGy



Before After

20 kGy



Before After

50 kGy

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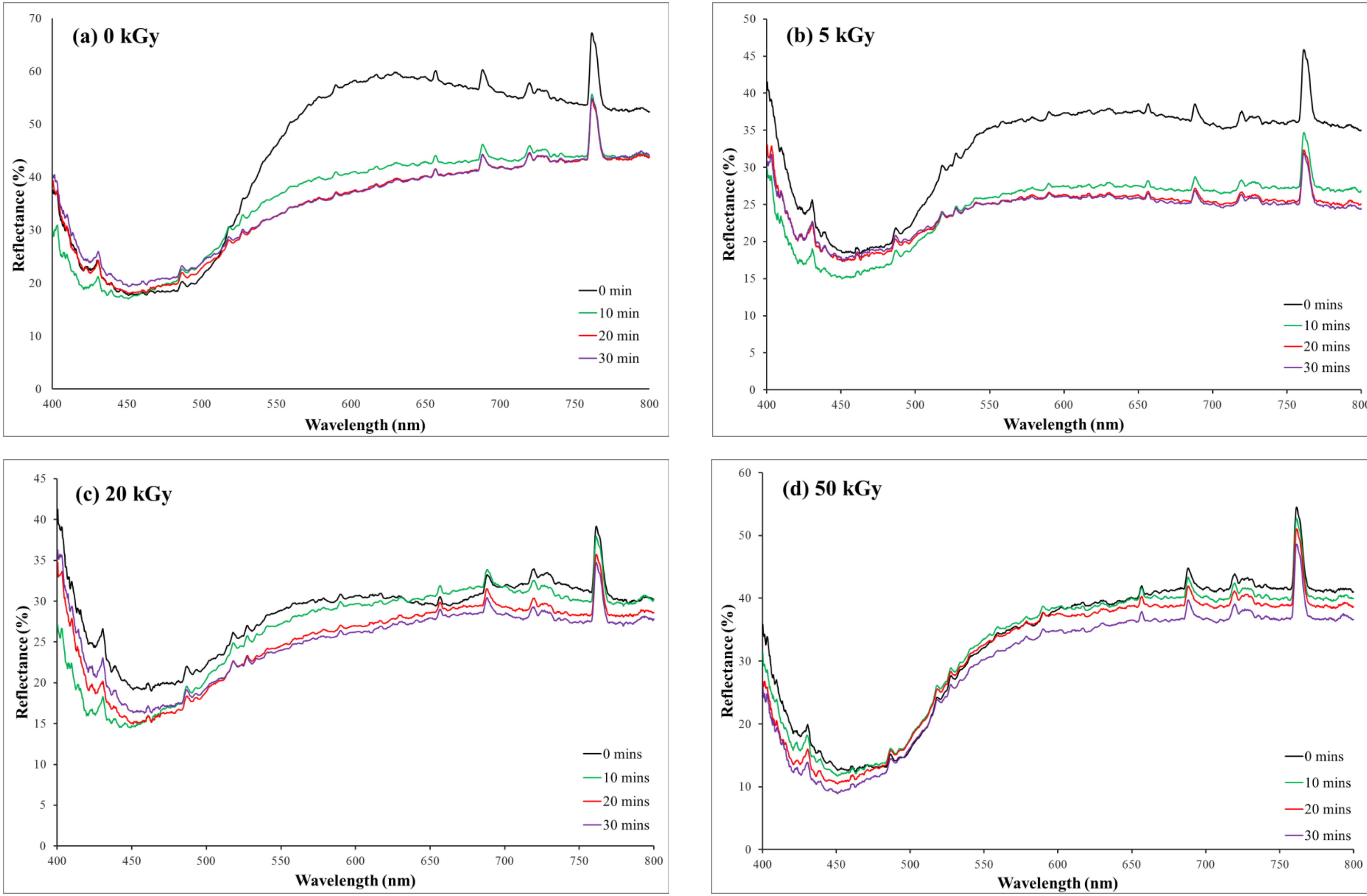
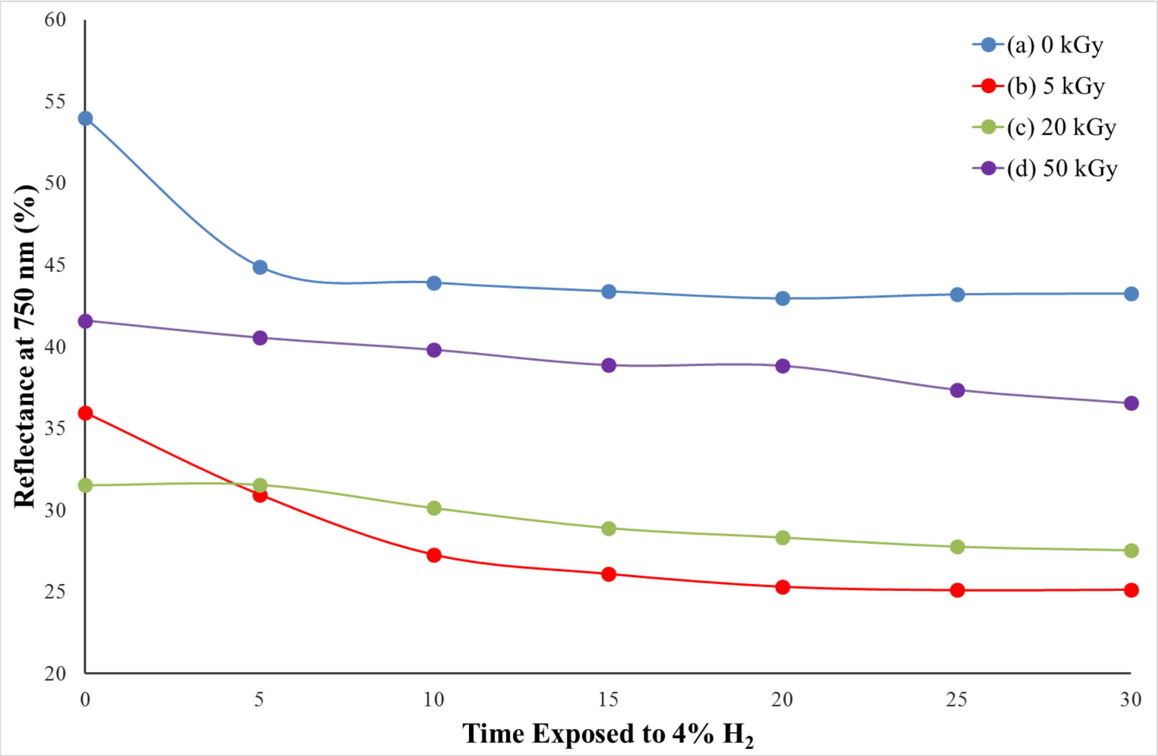
Effect of Gamma Irradiation

Hydrogen Sensing



Effect of Gamma Irradiation

Hydrogen Sensing



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Conclusion

- No degradation of thin films due to gamma irradiation
- Gamma irradiation darkens the Pd-V_2O_5 thin film sensors
- Rate of colour change decreases as gamma radiation dose increases

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Any Questions

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