University of BRISTOL
Bristol Composites Institute

Spectroscopy – Driven Application & Interphase Effect of Luminescent Composites

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ICCM23 International Conference
Belfast Northern Ireland

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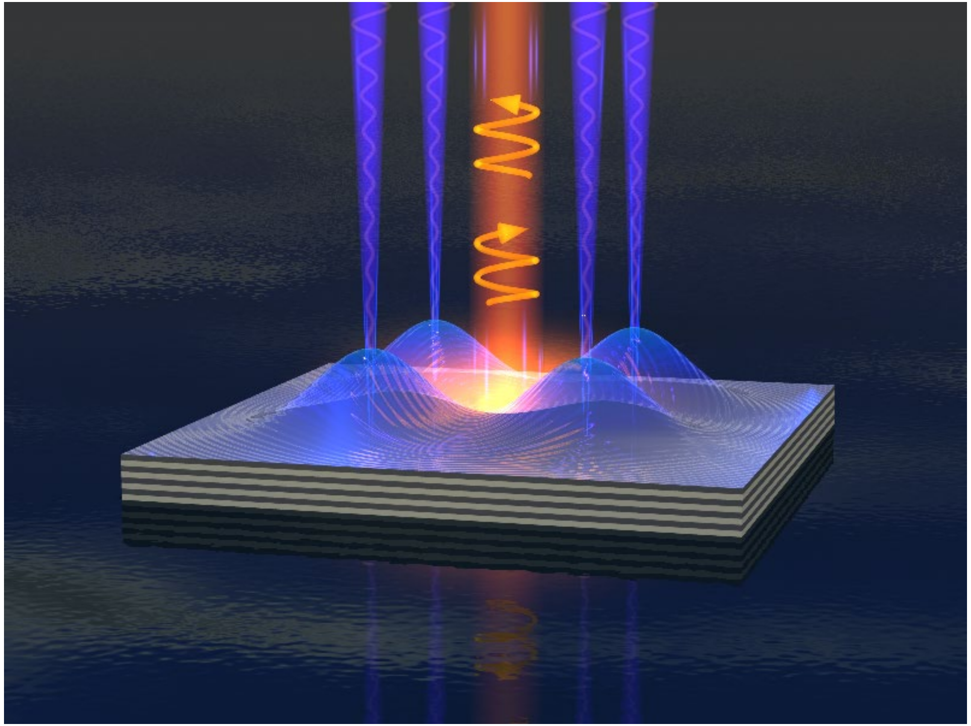
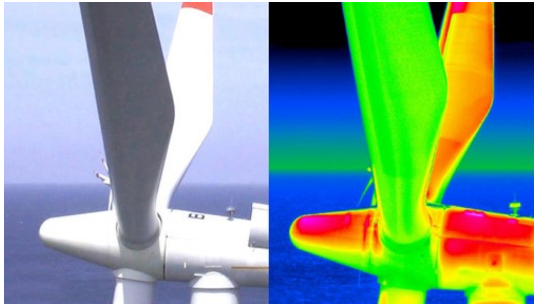
Introduction



Light Emitting?

Structural Health System



https://www.bam.de/_SharedDocs/EN/Images/energy-inspection-of-rotor-blades-2.jpg?__blob=normal

Composite Sensor

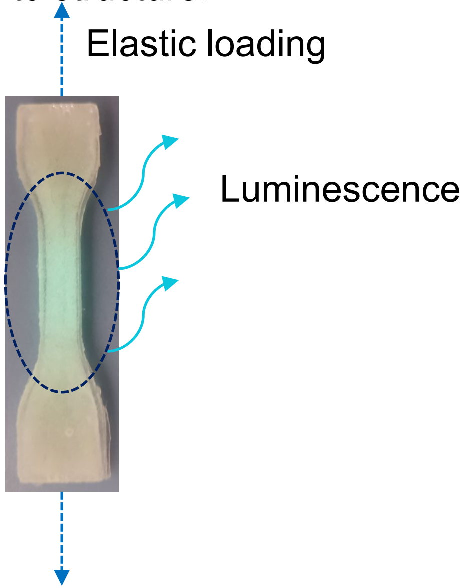
https://www.environmentalengineering.org.uk/wp-content/uploads/media/Polariton-fluid-emits-clockwise-or-anticlockwise-spin-light-by-applying-electric-fields-to-a-semiconductor-chip.png

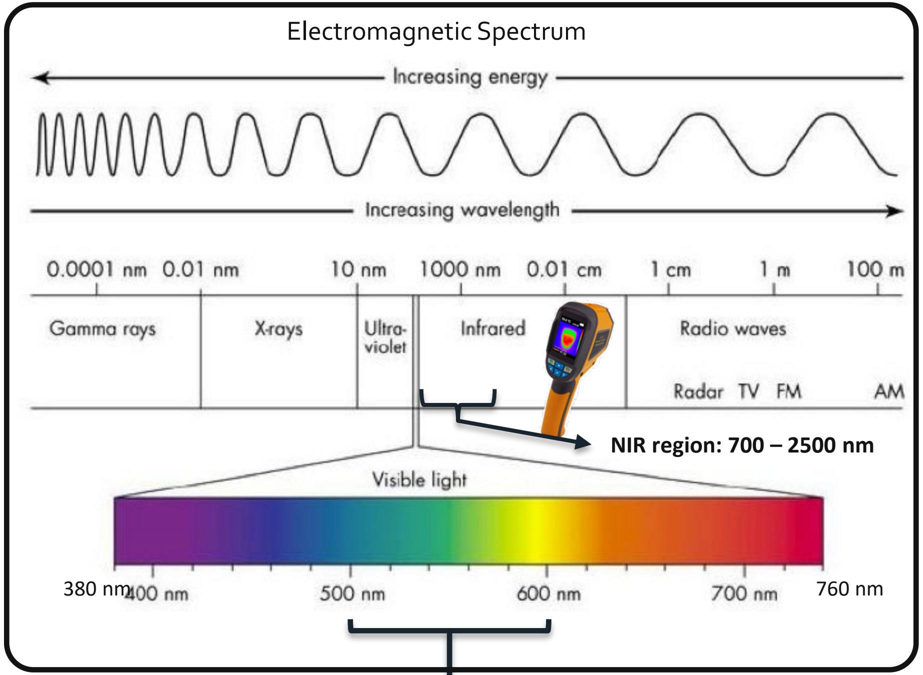
Mechanoluminescence (ML)
- Deformation mechanoluminescence (DML or DL)
  - Fracto-ML (FML)
  - Plastico-ML (PML)
  - Elastico-ML (EML)
- Tribo-mechanoluminescence (TML or TL)
  - Electrically induced TML
  - Chemically induced TML
  - Thermally induced TML

Classification of different types of mechanoluminescence.

H. Zhang, et al., *Recent development of elastico-mechanoluminescent phosphors*, Journal of Luminescence. 207 (2019) 137–148. doi:10.1016/j.jlumin.2018.10.117.

EML is a type of luminescence induced by elastic deformation applied to structure.





$SrAl_2O_4: Eu^{2+}, Dy^{3+}$

Strontium aluminate, europium and dysprosium doped (SAOED)

- Emission Color: Long persistent green phosphor (500 – 600 nm)
- Storage: Room temperature
- Form : Powder
- MW : 209.11 g/mol , MP : > 1200 °C
- Formula : $Sr_{0.95}Eu_{0.02}Dy_{0.03}Al_2O_4$
- Activation wavelength band: 200 – 450 nm (365 nm optimal condition)

EM waves

Material

Sensing

Objective

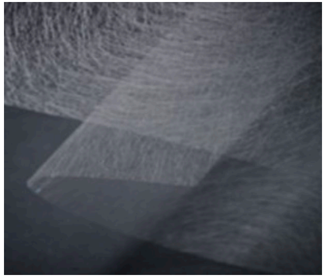
To investigate a valid EML phenomenon to monitor structural health condition (strain sensing).

- Indication of quantitative data from EML sensing to interpret structural health monitoring.
- Indication of interaction force between EML phosphors and elastomeric resin.
- Correlation to cyclic loading applied to samples and IR temperature change.
- Comparison of mechanical properties such as tensile strength and modulus of samples under the cyclic loading.

Potential application:
Structural self-monitoring by functional elastomeric components under the repetitive loading.

Materials

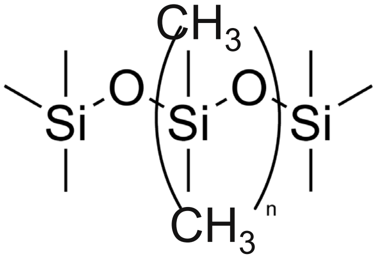
Polyetherimide veil



Technical Fibre Products Ltd.

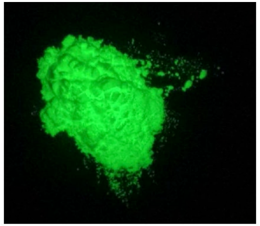
- To increase fracture toughness
- To trap ML phosphors in the matrix resin

PDMS (Polydimethylsiloxane)



- To be a potential application for functional elastomeric components
- To figure out structural health of the elastomeric matrix

Luminescent phosphors

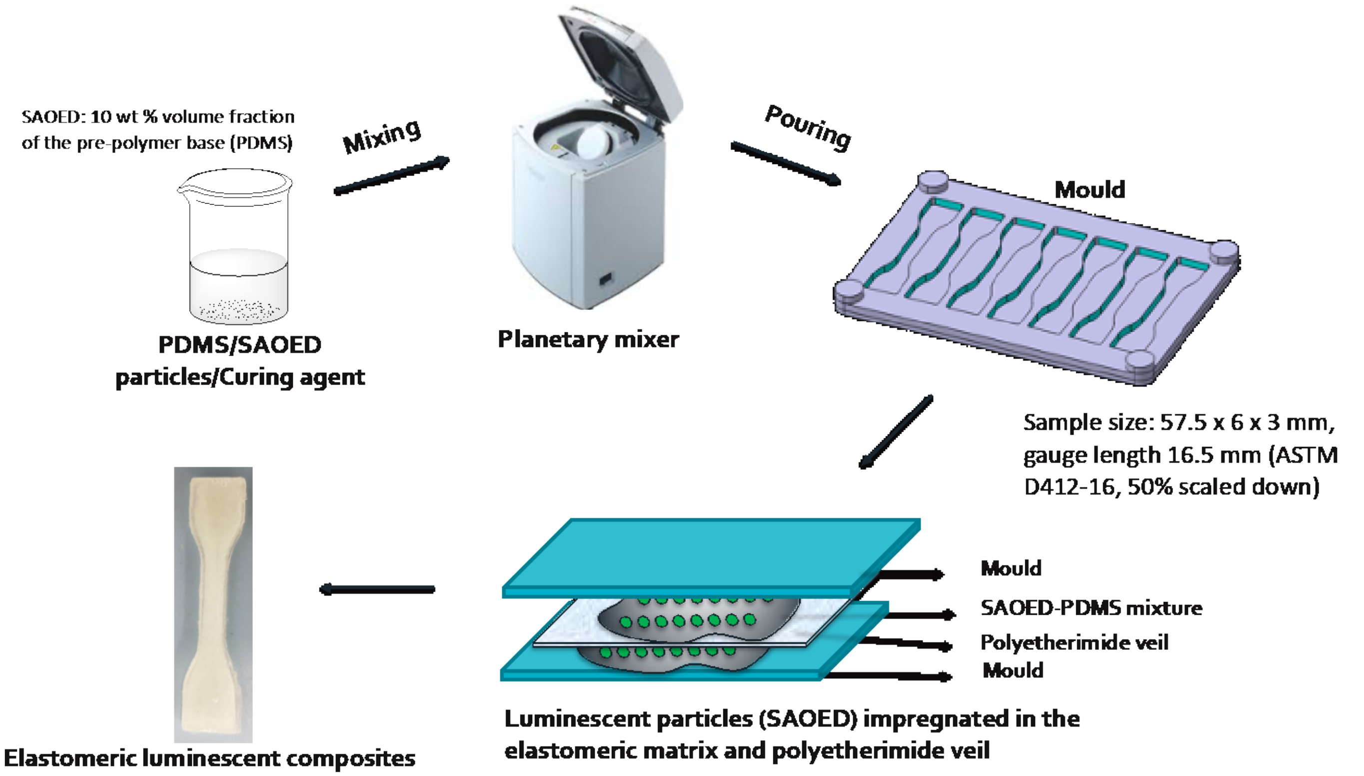


Sigma Aldrich

$SrAl_2O_4$: Eu^{2+}, Dy^{3+}

- To investigate structural health monitoring

Manufacturing



Characterisation

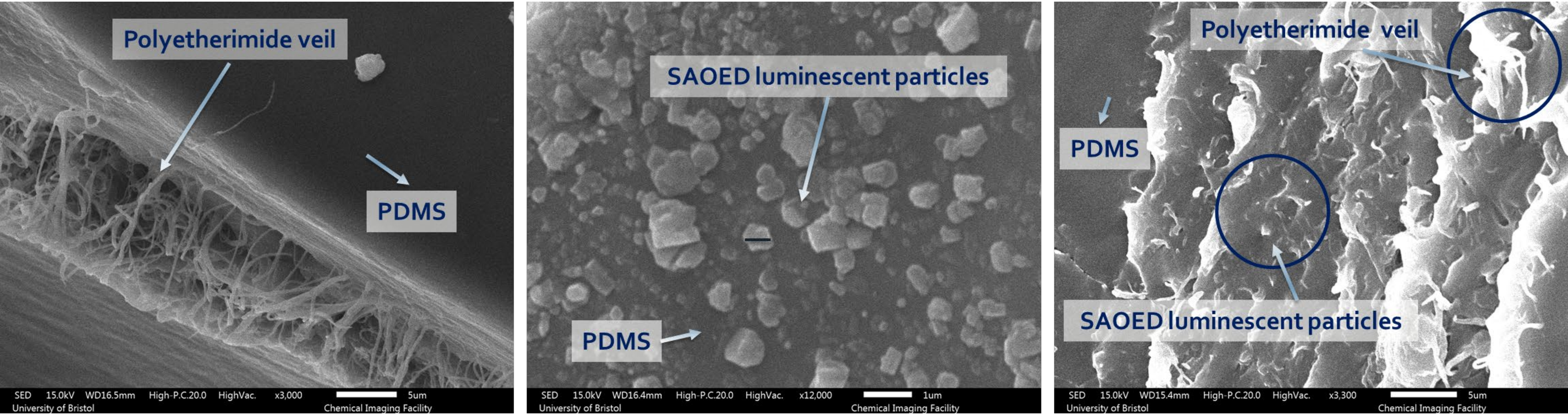
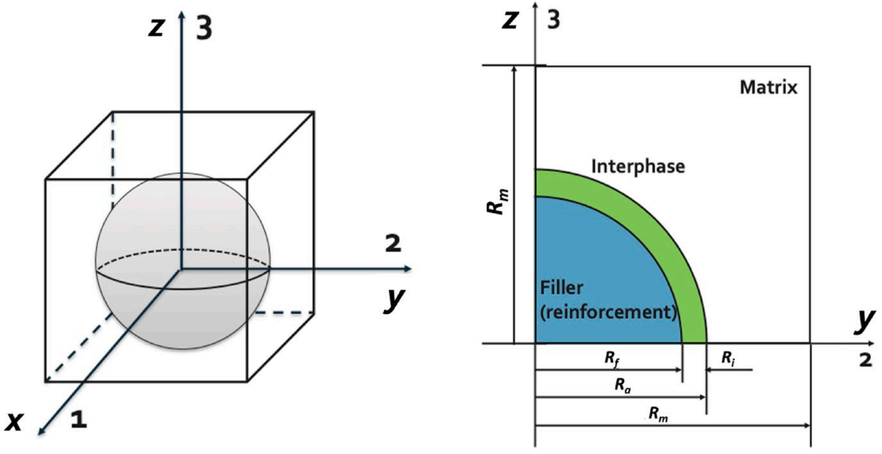


Fig. Scanning electron microscopy (SEM) images of EML/PEI veil composites.

Modified Micromechanical Modelling

Halpin-Tsai (HT)	Modified HT
$E_R = \dfrac{1 + \eta\zeta V_f}{1 - \eta V_f}$ $\eta = \left(\dfrac{E_f}{E_m} - 1\right) \Big/ \left(\dfrac{E_f}{E_m} + \zeta\right)$ $\zeta = 2\left(\dfrac{l}{t}\right) + 40V_f^{10}$	$E_R = \dfrac{1 + \zeta\eta_f V_f + \zeta\eta_i V_i}{1 - \eta_f V_f - \eta_i V_i}$ $\eta_f = \left(\dfrac{E_f}{E_m} - 1\right) \Big/ \left(\dfrac{E_f}{E_m} + \zeta\right)$ $\eta_i = \left(\dfrac{E_i}{E_m} - 1\right) \Big/ \left(\dfrac{E_i}{E_m} + \zeta\right)$ $V_i = \left[\left(\dfrac{R_f + R_i}{R_f}\right)^3 - 1\right] V_f$



$$E_i(\alpha, R) = (\alpha E_f - E_m)\left(\frac{R_m - R_a}{R_a - R_f}\right)^n + E_m$$

Fig. Schematic design of filler inclusion in a matrix.

Modified Micromechanical Modelling

Mori-Tanaka (MT)	Modified MT
$\mathbb{C}^c = \mathbb{C}^m + V_f\langle(\mathbb{C}^f - \mathbb{C}^m)\mathbb{A}^f\rangle\left(V_m\mathbb{I} + V_f\langle\mathbb{A}^f\rangle\right)^{-1}$ $\mathbb{A}^f = \left[\mathbb{I} + \mathbb{S}(\mathbb{C}^m)^{-1}(\mathbb{C}^f - \mathbb{C}^m)\right]^{-1}$ $S_{1111} = S_{2222} = S_{3333} = \frac{7 - 5v_f}{15(1 - v_f)}$ $S_{1122} = S_{2233} = S_{3311} = S_{1133} = S_{2211} = S_{3322} = \frac{5v_f - 1}{15(1 - v_f)}$ $S_{1212} = S_{2323} = S_{3131} = \frac{4 - 5v_f}{15(1 - v_f)}$	$\mathbb{C}^c = \mathbb{C}^m + \left[(V_f + V_i)(\mathbb{C}^i - \mathbb{C}^m)\mathbb{A}^{fi} + V_f(\mathbb{C}^f - \mathbb{C}^i)\mathbb{A}^f\right] \times \left[V_m\mathbb{I} + (V_f + V_i)\mathbb{A}^{fi}\right]^{-1}$ $\mathbb{A}^{fi} = \mathbb{I} - \mathbb{S}\left\{\frac{V_f}{V_f + V_i}\left[\mathbb{S} + (\mathbb{C}^f - \mathbb{C}^m)^{-1}\mathbb{C}^m\right]^{-1} + \frac{V_i}{V_f + V_i}\left[\mathbb{S} + (\mathbb{C}^i - \mathbb{C}^m)^{-1}\mathbb{C}^m\right]^{-1}\right\}$

Results

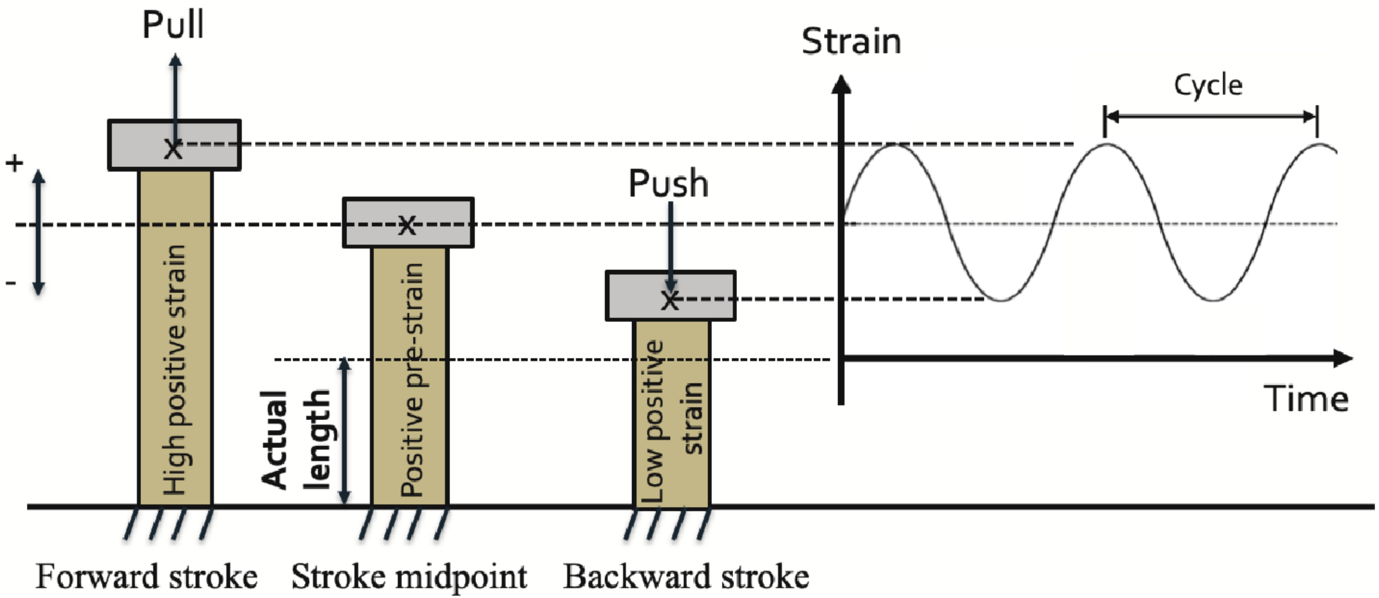


Fig. Cyclic loading.

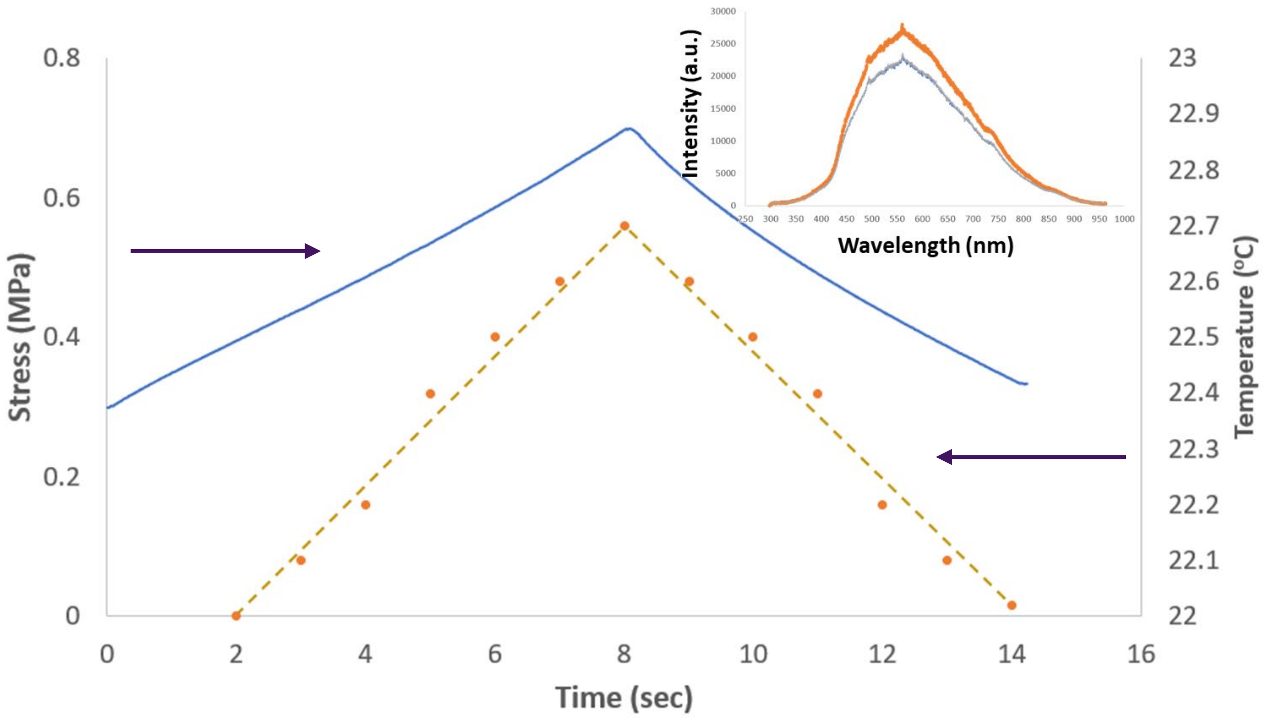


Fig. Mechanical behaviour, thermal effect, and spectral changes along with cyclic loading (One loop of normalised data).

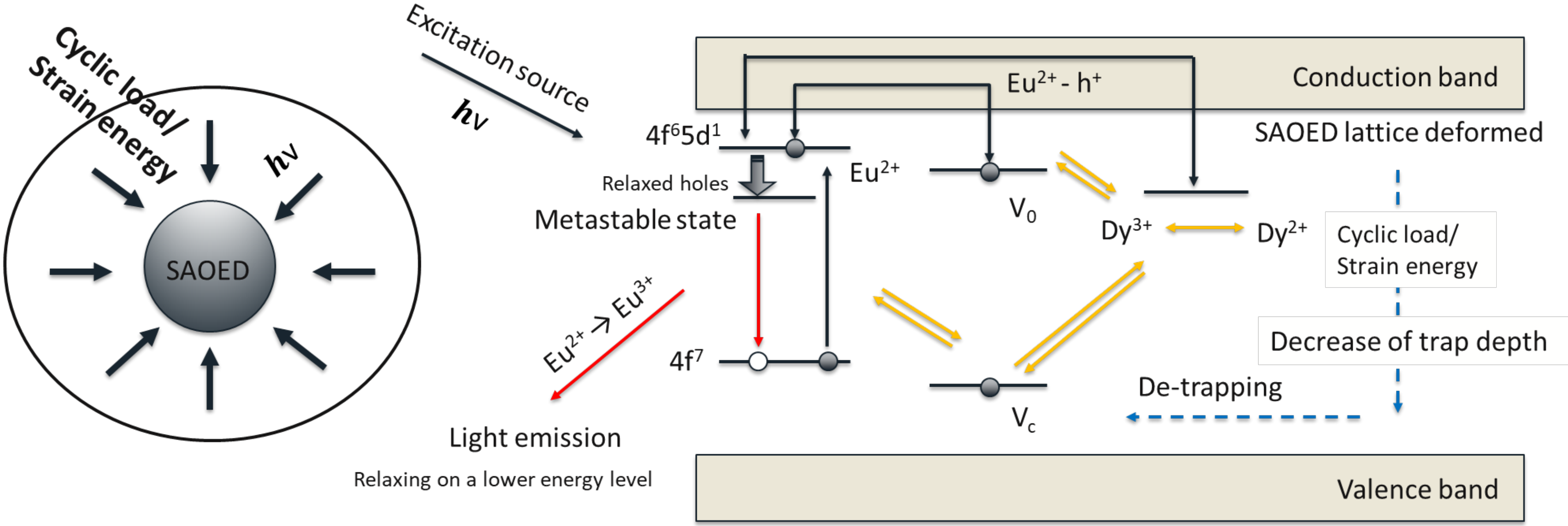
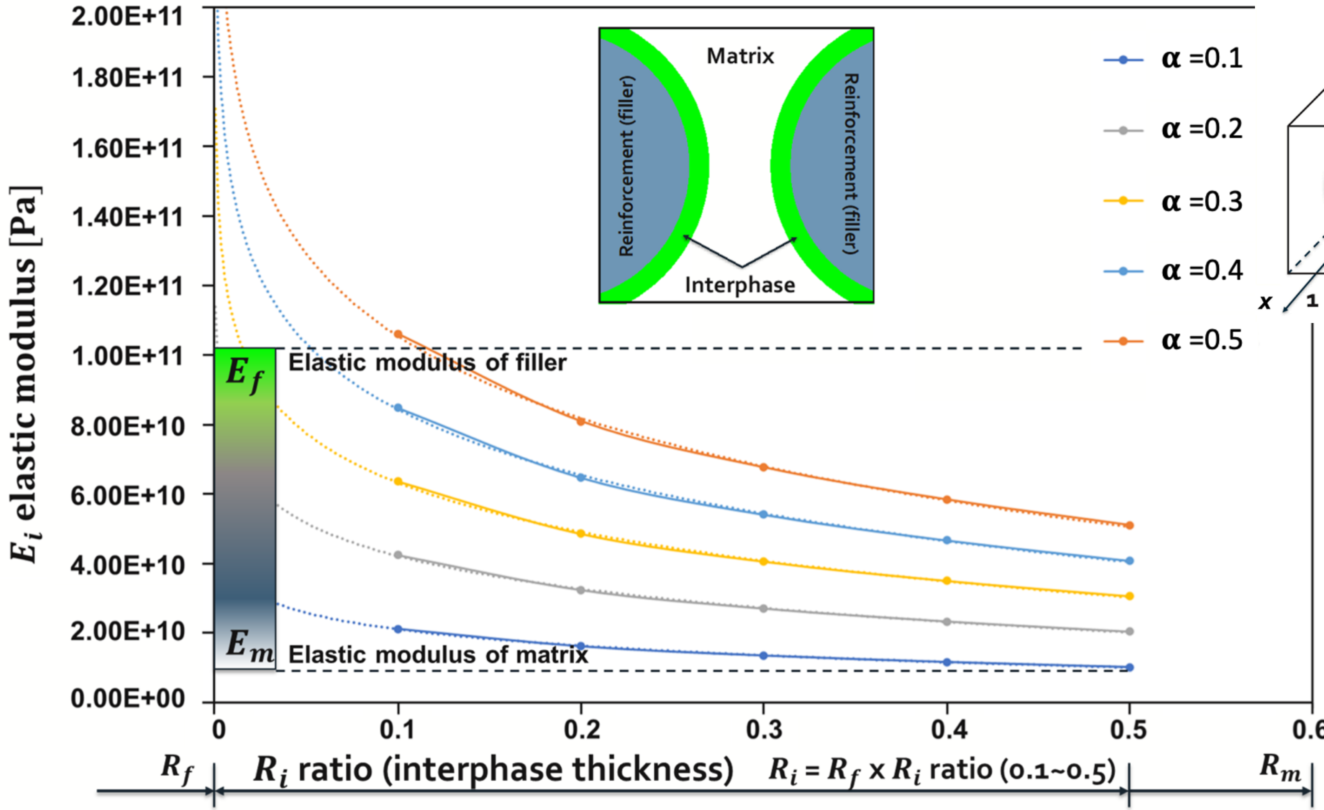
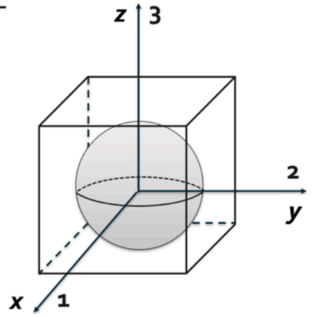
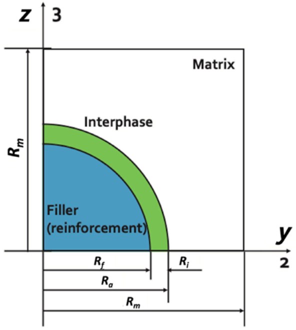


Fig. EML mechanism of the polyetherimide veil incorporated with phosphors in a matrix.



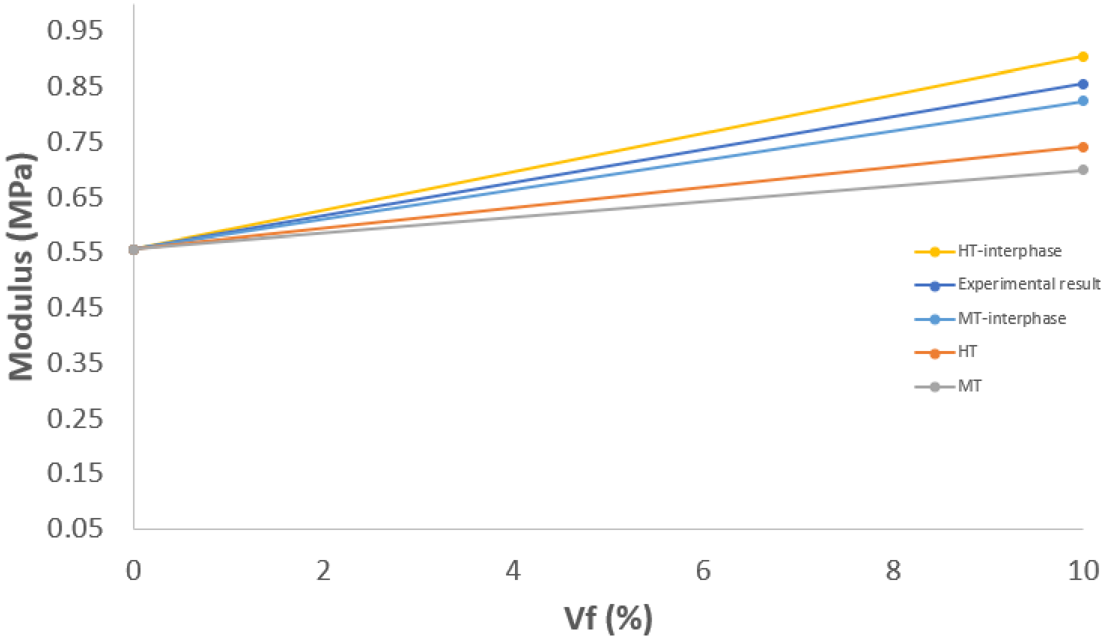




Properties	PDMS (matrix)	SAOED (particles)
Young's modulus	0.556 MPa	102 GPa [1]

[1] Yamada *et al.*, "Ab initio calculations of the mechanical properties of $SrAl_2O_4$ stuffed tridymite." (2007): 126103.

Fig. Interphase elastic properties as a function of thickness in the interphase region.



Properties	PDMS (matrix)	SAOED (particles)
Young's modulus	0.556 MPa	102 GPa
Poisson's ratio	0.45	0.23
Ref.	From experiment	[1]

[1] Yamada *et al.*, "Ab initio calculations of the mechanical properties of $SrAl_2O_4$ stuffed tridymite." (2007): 126103.

Fig. Young's modulus of composites with comparing micromechanical models and an experimental result.

Conclusions

- EML phosphors in a transparent matrix exhibit strain-driven monitoring behaviour.
- Phosphor particles increase elastic modulus and luminescence with cyclic loads.
- Strain sensing is applicable for repeated use in mechanical response.
- EML information is readable at higher cyclic loading.
- The strain sensing exhibits linear and durable characteristics as a sensor.

Acknowledgements

- This work was supported by **Wind Blade Research Hub**, a collaboration between the *University of Bristol* and the *Offshore Renewable Energy Catapult*.

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