Skin color-specific and spectrally-selective naked-eye dosimetry of UVA, B and C radiations

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Introduction

The sun’s ultraviolet radiation (UVR) is both the main cause of skin cancer and the best natural source for vitamin D. UVR monitoring technology is needed. UV dose is important.

UV is neither visible to humans nor related to temperature. Therefore, people are not able to see or feel UVR.

UV is classified into UVA, UVB and UVC. They can cause remarkably different effects on biological entities.

People with different skin phototypes have diverse levels of UV tolerance.

UV exposure limit for people with different skin color

<table>
<thead>
<tr>
<th>Skin type</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin color</td>
<td>Very fair</td>
<td>Fair</td>
<td>Medium</td>
<td>Olive</td>
<td>Brown</td>
<td>Dark brown</td>
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<tr>
<td>MED (J/m²)</td>
<td>200-300</td>
<td>250-350</td>
<td>300-500</td>
<td>450-600</td>
<td>600-1000</td>
<td>1000-2000</td>
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<tr>
<td>UVA</td>
<td></td>
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<td>UVB</td>
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<tr>
<td>UVC</td>
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</table>

Minimal erythematous dose (MED) is defined as the lowest threshold dose that may produce sunburn.

Development of the photoactive ink

- Selection of the ink components
- Selection of the ink composition

Comparison of the ability of different \( \varepsilon ^{-} \) donors in reducing phoshomolybdic acid (PMA) on excitation with UVA, B and C for 30 min.

Inst. UVR exposure time-dependent response of PMA in the presence of lactic acid (LA). Concentration: PMA 1 mM; \( \varepsilon ^{-} \) donor 10 mM. UVR intensity: 15 W m⁻².

Influence of the concentration of PMA 1 mM, 5.5 mM, and 5.5 mM and LA/PMA Molar ratio on sensor response measured from absorbance at 700 nm after exposing samples for 5 min. UVR intensity: 15 W m⁻².

PMA + LA

5 mM PMA + 300 mM LA

Ultrasensitive UV sensing in solution-based system

(a) UV dose-dependent colorimetric response of PMA-LA photoactive ink demonstrating the sensor’s ability to differentiate UVA, B and C even at extremely low dosages, as reflected from logarithmic X-axis. The highlighted response corresponds to the UBV MED for type I to VI skin.

Each data point represents an average of colorimetric response obtained from 12 independent sensors and associated standard deviation.

(b-d) Precision of PMA-LA sensors at each of the UV doses at 10 J m⁻² increments, as calculated from the data presented in (a).

Naked-eye UV detection on paper-based system

(a) Photographs of three paper-based UV sensors with increasing exposure time and corresponding cumulative effective dose of UVA, B, and C. The sensor response at the UBV MED dosages of the skin types I-VI is highlighted.

(b-d) Reflectance spectrums of smileys on exposure to UVA, B, and C respectively with increasing UV doses.

(e) UV dose-dependent response showing PMA-LA smiley sensor’s ability to differentiate UVA, B, and C even at extremely low dosages.

(f-h) Precision of PMA-LA smiley sensors at each of the tested UV doses, as calculated from the data presented in (e).

High durability and stability

(a) The paper-based UV sensors show high durability after pre-exposing them to different ambient mimicking environmental conditions for one hour.

(b) The paper-based UV sensors show stable UV sensing performance while simultaneously exposing them to a wide range of relative humidity and ambient temperature conditions.

(c) The PMA-LA ink employed to prepare smiley sensors remains stable for at least over 8 weeks.

Design of the paper-based solar UV dosimeters

(a) The aqueous solution containing PMA is reduced by UVR in the presence of LA to produce a blue product.

(b) The PMA-LA mixture acts as an invincible ink to paint four smileys on a strip of filter paper.

(c) These smileys are coated with increasing number of transparency film fibers (TFF) that increasingly reduce the UV transmission on smileys from left to right.

(d) After solar UV exposure, blue smileys start to appear on the paper strip sensor from left to right, such that the appearance of 1 to 4 blue smileys represents 25, 50, 75 and 100% of safe exposure thresholds, respectively.

Customized skin color-specific UV dosimeters

Performance of six customized sensors in simulated solar light, assuming that sensors meet the wide-ranging UVB MED thresholds of people with different skin colors. The skin-phototype specificity is achieved by an appropriate combination of the smiley paper discs coated with different TFF layers (0–8) in a single sensor that allows dose-dependent modulation of sensor response.

Conclusion

Ease in fabrication due to a simple printable ink and readily-available low-cost household components;

- Paper-based sensors offering multi-format wearable potential;

- High spectral selectivity allowing UVA, B and C selective monitoring;

- High sensitivity allowing naked-eye dosimetry without the requirement of a technological interface;

- Robust sensors with high specificity, durability and stability across different environmental conditions;

- Customisable for people with different skin phototypes.

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