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

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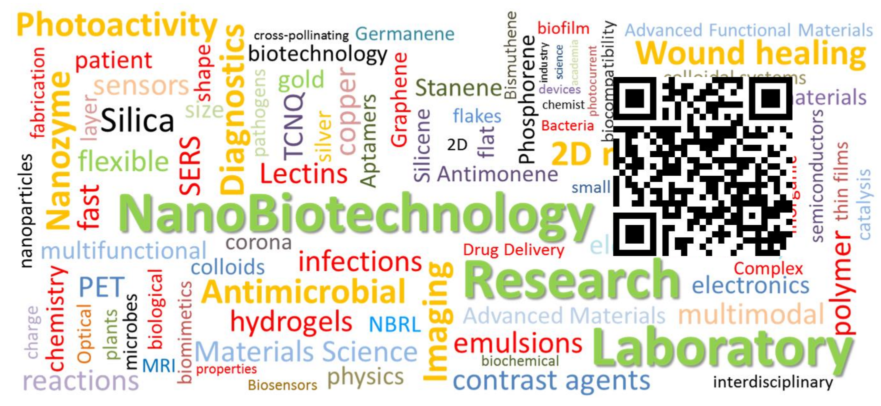


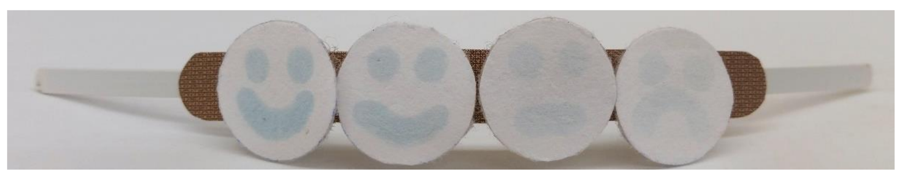
Introduction

The sun's ultraviolet radiation (UVR) is both the main cause of skin cancer and the best natural source for vitamin D. → UVR is important.

UVR is neither visible to humans nor related to temperature. Therefore, people are not able to see or feel UVR. → UVR monitoring technology is needed.

UVR is classified into UVA, UVB and UVC. They can cause remarkably different effects on biological entities. → Spectrally-selective UVR monitoring is required.

People with different skin phototypes have diverse levels of UV tolerance. → **Customized skin color-specific and spectrally-selective UVR monitoring system for practical mass usage is in demand.**



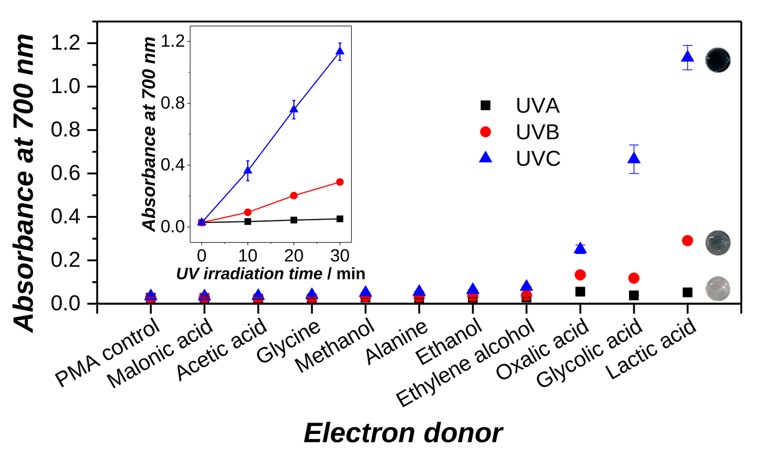
UV exposure limit for people with different skin color

Skin type		I	II	III	IV	V	VI
Skin color		Very fair	Fair	Medium	Olive	Brown	Dark brown
MED	UVB ($J \cdot m^{-2}$)	200-300	250-350	300-500	450-600	600-1000	1000-2000
	UVA ($J \cdot m^{-2}$)	200-350 ($x10^3$)	300-450 ($x10^3$)	400-550 ($x10^3$)	500-800 ($x10^3$)	700-1000 ($x10^3$)	>1000 ($x10^3$)

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

Development of the photoactive ink

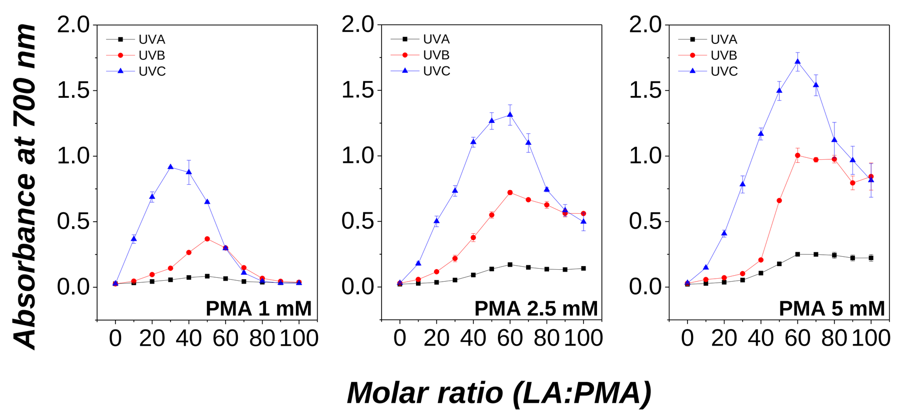
➤ Selection of the ink components



Comparison of the ability of different e⁻ donors in reducing phosphomolybdic acid (PMA) on excitation with UVA, B and C for 30 min.
Inset: UVR exposure time-dependent response of PMA in the presence of lactic acid (LA).
Concentration: PMA 1 mM; e⁻ donor 10 mM.
UVR intensity: 15 $W \cdot m^{-2}$.

PMA + LA

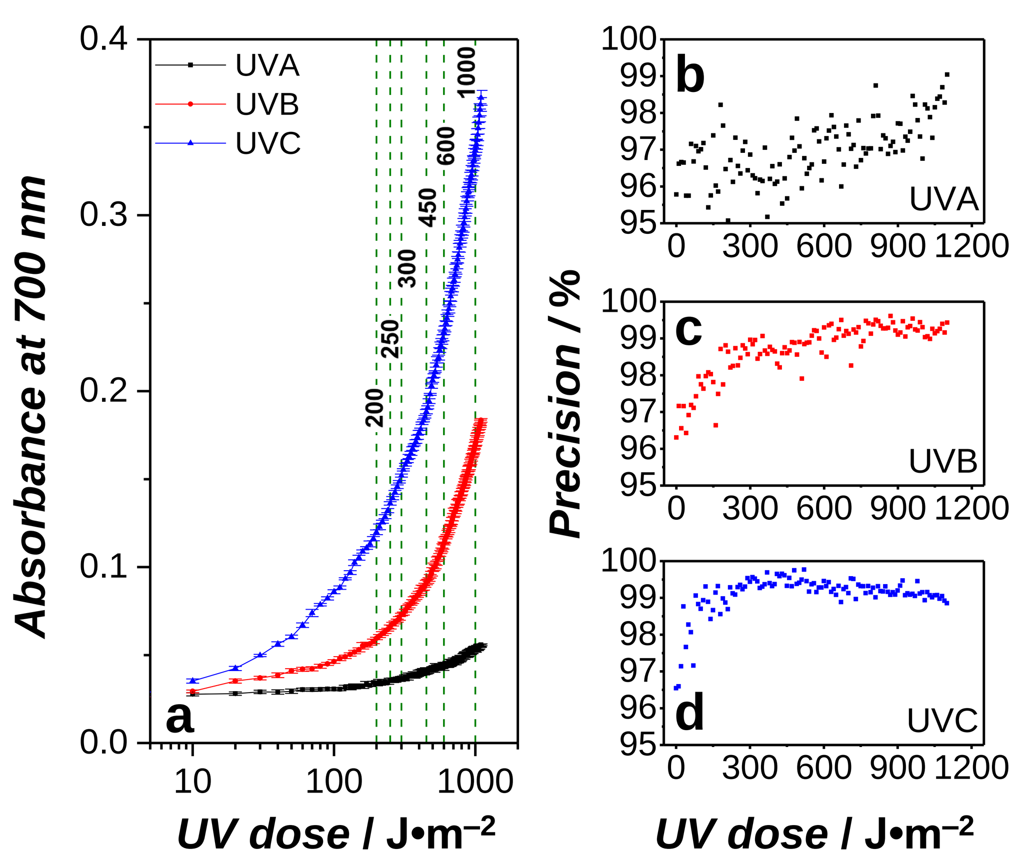
➤ Selection of the ink composition



Influence of the concentration of PMA 1 mM, 2.5 mM, and 5 mM, and LA:PMA Molar ratios on sensor response measured from absorbance at 700 nm after exposing samples for 5 min.
UVR intensity: 15 $W \cdot m^{-2}$.

5 mM PMA + 300 mM LA

Ultrasensitive UV sensing in solution-based system

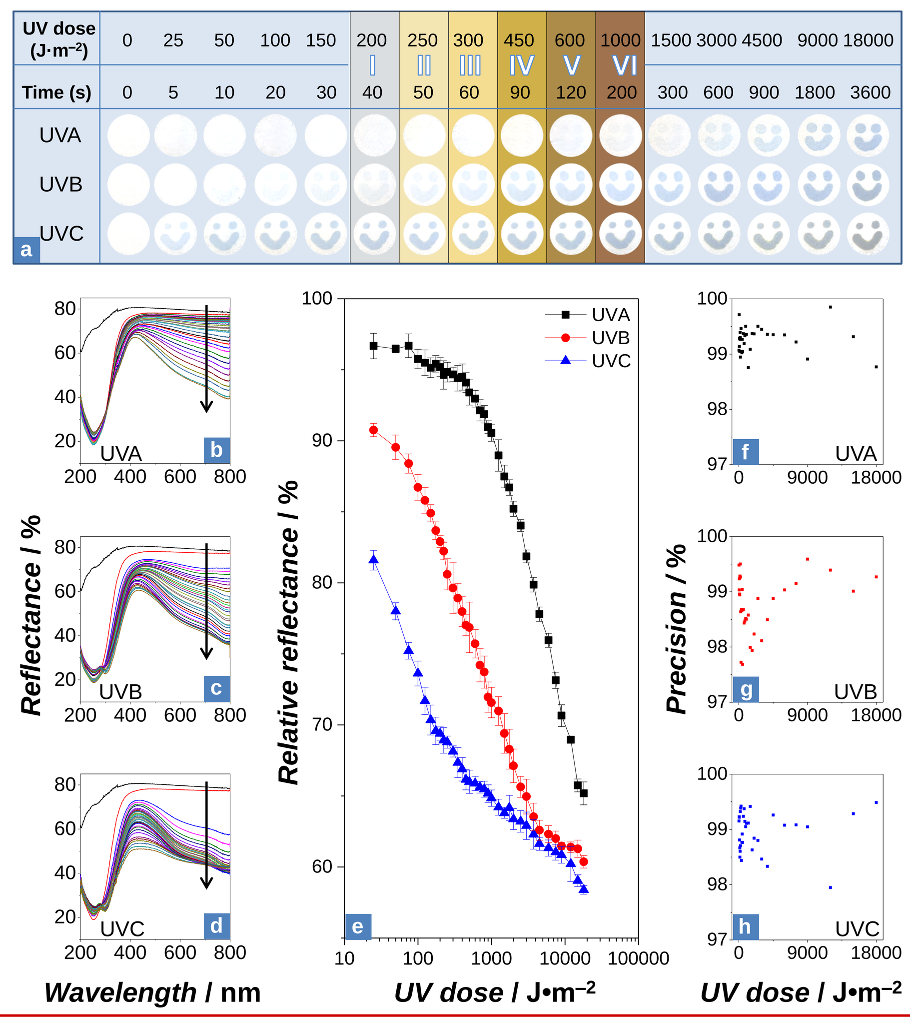


(a) UVR dose-dependent colorimetric response of PMA-LA photoactive ink demonstrating the sensor's ability to differentiate UVA, B and C even at extremely low dosages, as reflected from logarithmic X-axis. The highlighted responses correspond to the UVB MED for type I to VI skin.

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 $J \cdot m^{-2}$ increments, as calculated from the data presented in (a).

Naked-eye UV detection on paper-based system



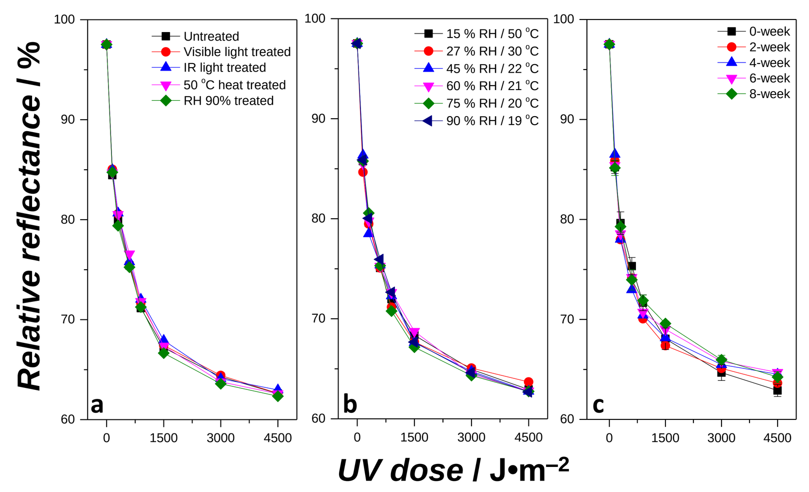
(a) Photographs of three paper-based UV sensors with increasing exposure time and corresponding cumulative effective dose of UVA, B, and C. The sensor response at the UVB MED doses of skin types I-VI is highlighted.

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

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

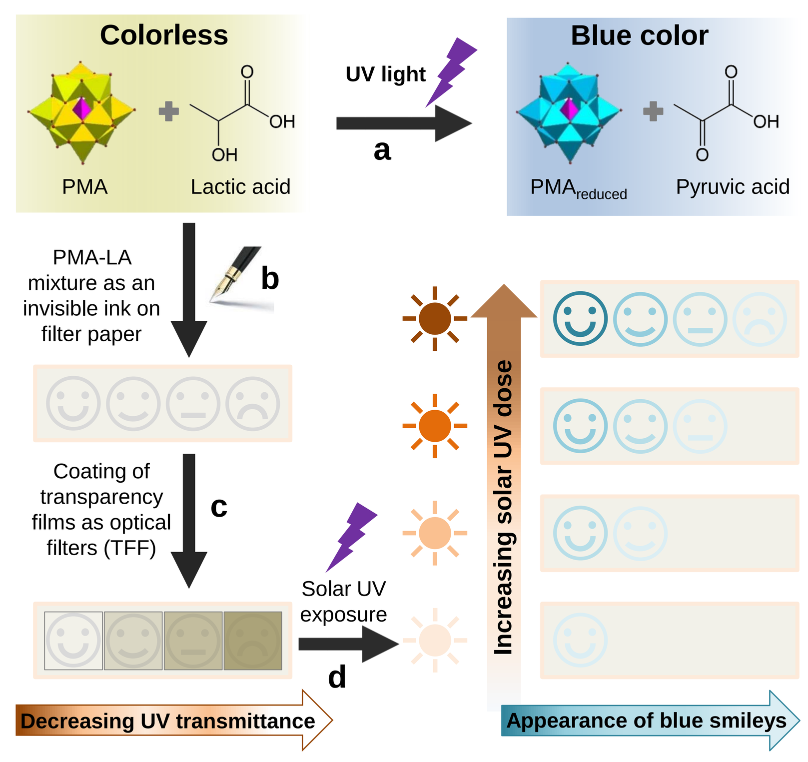
(f-h) Precision of PMA-LA smiley sensors at each of the tested UV doses, as calculated from the data presented in (e).

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 UVB 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



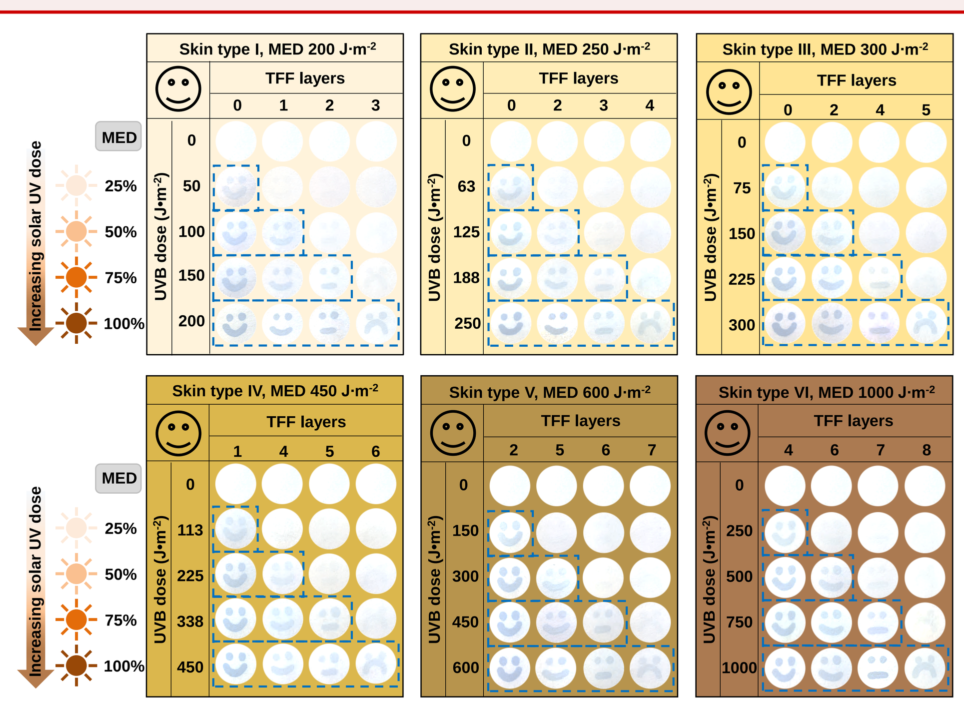
(a) The aqueous solution containing PMA is reduced by UVR in the presence of LA to produce a blue product.

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

(c) These smileys are coated with increasing number of transparency film filters (TFF) that increasingly reduce the UV transmittance 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, assuring 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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