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Electronic UV dosimeters

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Background/aims: The pathogenic role of ultraviolet (UV) in the development of skin cancer, skin ageing and immunosuppression makes it important to monitor human exposure to UV radiation. In a previous study we constructed UVB and UVC dosimeters based on a thermoluminescent phenomenon induced by UV in CaF_2:Dy and CaF_2 crystals. However, these dosimeters were insensitive to UVA radiation and readout was time-consuming. In the present study we aimed to develop an electronic dosimeter suitable for UVA, UVB and UVC. The principle of this dosimeter is a measure of accumulated electric current induced by UV on a photodetector.
Methods: Electric current induced by UV on a photodetector was accumulated in a Plessey's E-cell coulometer. A special reading device was constructed to quantify total charge of the coulometer. Sensitivity for UVA, UVB and UVC was achieved by the use of appropriate filters in front of the photodetector.
Results: The sensitivity of the electronic dosimeter increased with increasing wavelength of UV radiation; therefore, in UVB and UVC dosimeters the use of amplifiers was necessary. A linear response to UVA, UVB and UVC was achieved.
Conclusion: Dosimeters with a linear response to increasing doses of UVA, UVB and UVC have been constructed for personal monitoring of UV exposure.

Key words: ultraviolet radiation – electronic dosimeters – photodetection.

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PERSONAL dosimeters should provide information on the nature and magnitude of sun exposure. The information about human behaviour in sunlight in terms of ultraviolet (UV) exposure could be used in investigations of the role of UV in skin pathology and in population education.

In an attempt to construct a personal UV radiation UV dosimeter we have previously investigated the thermoluminescence of CaF_2:Dy and CaF_2 crystals induced by UV irradiation (1). We found that such dosimeters are useful for personal monitoring of short-wave UV irradiation, UVB and UVC. However, the major limitation of crystal-based dosimeters is that UVA exposure cannot be measured and the reading is complex. In this work we describe the construction of electronic dosimeters suitable for quantification of exposure to UVA (400–320 nm), UVB (320–280 nm) and UVC (280–200 nm). In principle, the UV light induces an electrical current in a photodetector element which is transmitted to an accumulator. The amount of accumulated electrical energy is proportional to the total energy of UV radiation reaching the photodetector. After the measuring period the dosimeter is connected to the reading instrument, enabling exact measurement of electrical energy. By application of different filters in front of the photodetector it is possible to select and measure the energy in a pre-defined wavelength band of the UV spectrum.

Material and Methods

As a UV photodetector we used a GaP detector (Hammatsu, Japan) or a R 1826 vacuum diode (Hammatsu, Japan). Plessey's E-cell coulometer (Plessey, UK) was used in all constructions. The electronic reading device was constructed and the diffuser and filters were obtained from the Optical Laboratory (Technical University, Denmark). ADI filters (all dielectric interference filters) were manufactured as long-wave pass (LWP) or short-wave pass (SWP) filters with cut-off points at any given wavelength. The coating of filters consisted of a number of alternating layers of low refractive substance (quartz) and a high refractive substance (yttrium dioxide). The coating procedure was carried out as described elsewhere (2). Filters produced in this way were able to block radiation in a band of approximately 45 nm. To obtain a narrow band, several SWP and LWP filters were combined.

A 150 W xenon arc (Ziess, Germany) connected to a Jobin Yvon (France) single monochromator (H-20)

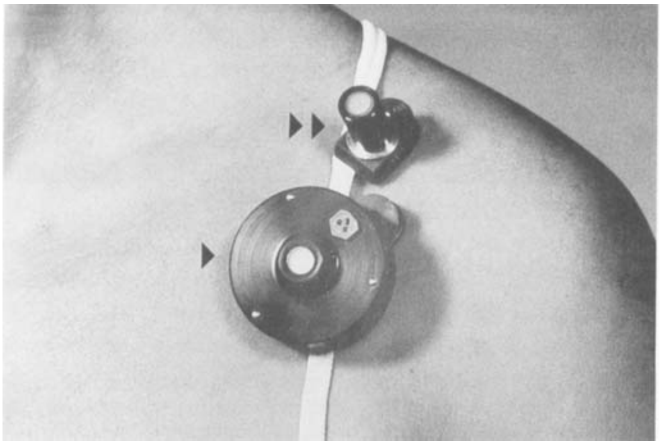

Fig. 1. The prototypes of the electronic dosimeter (marked with >) and crystal-based dosimeter (marked with >>) (1).

TABLE 1. Optical filters used in UVA, UVB, and UVC dosimeters

Dosimeter type	Filters

UVA	Optical glass B 270, 1 mm thick
	WBS 400, 8 mm thick
	LWP 320, interference
	SWP 400, interference
	SWP 420, interference

UVB	WBS 320, 6 mm thick
	SWP 315, interference
	SWP 370, interference
	LWP 250, interference
	LWP 280, interference

UVC	SWP 180, two, interference
	SWP 310, two, interference
	SWP 350, two, interference

LWP: long wave pass filter; SWP: short wave pass filter; WBS: wave band stop filter.

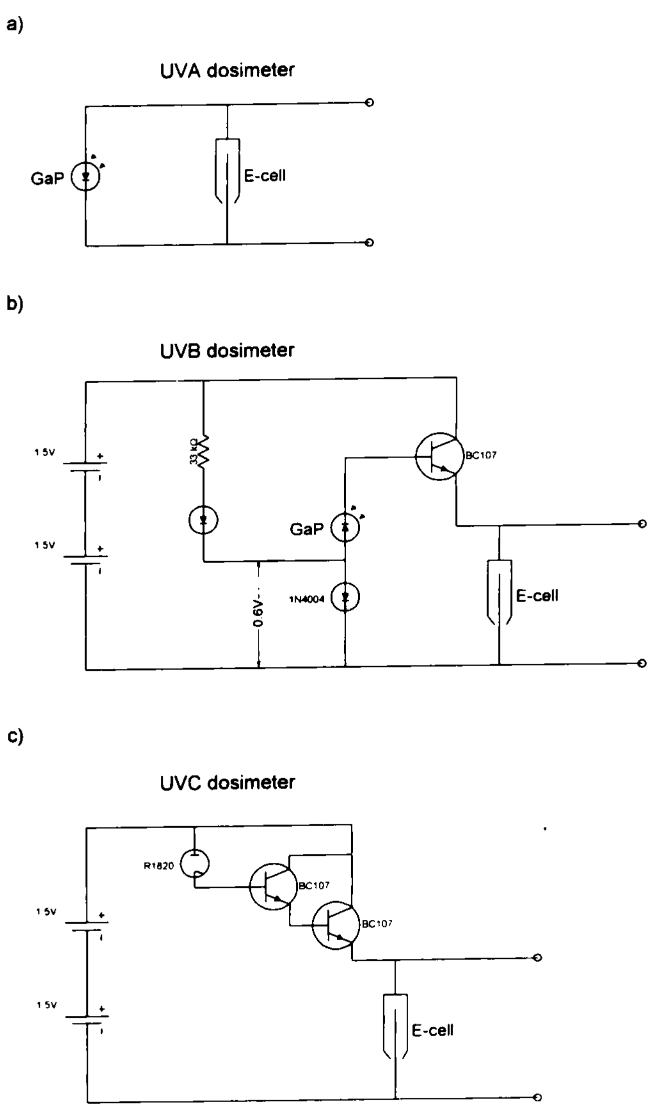

Fig. 2. The schematics of electronic circuits of (a) UVA, (b) UVB and (c) UVC dosimeters.

adjustable in 8-nm bands between 200 and 800 nm was used as an irradiation source.

Results

Construction of dosimeters

The prototype of the electronic dosimeter is shown in Fig. 1. By changing the filters in front of the photodetector and the selected electronic elements the instrument could be converted into an UVA, UVB or UVC selective dosimeter. The electronic schemes of UVA, UVB and UVC dosimeters are shown in Fig. 2. The filters used in particular dosimeters are de-

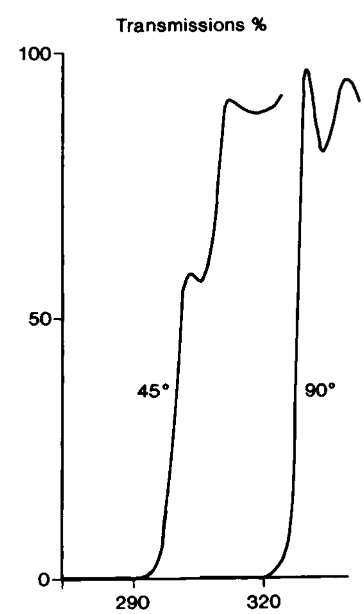

Fig. 3. Relation between the angle of UV rays and the cutoff of the interference filter. A ward from 90° to 45° results in a shift to shorter wavelengths in the transmitted spectrum.

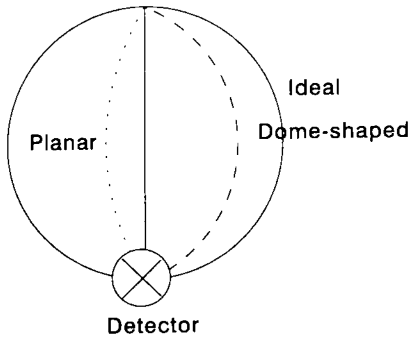

Fig. 4. Comparison of the response of planar and dome-shaped diffusers with the ideal cosine response.

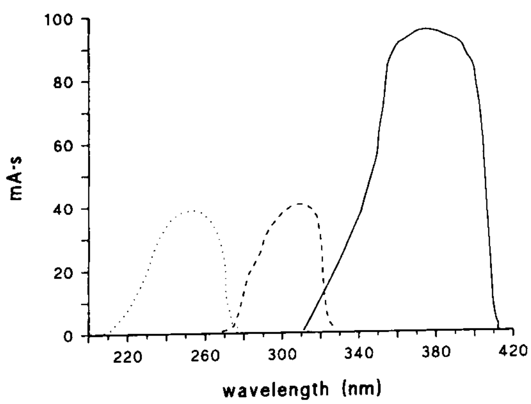

Fig. 5. Spectral sensitivity of the UVA (solid line), UVB (dashed line) and UVC (dotted line) electronic dosimeters.

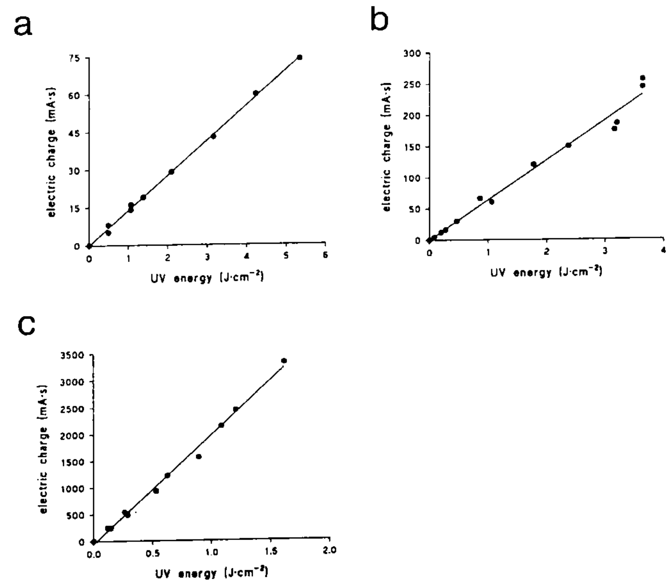

Fig. 6. Relationship between electric charge generated by UV light and the UV for (a) UVA, (b) UVB, and (c) UVC electronic dosimeters.

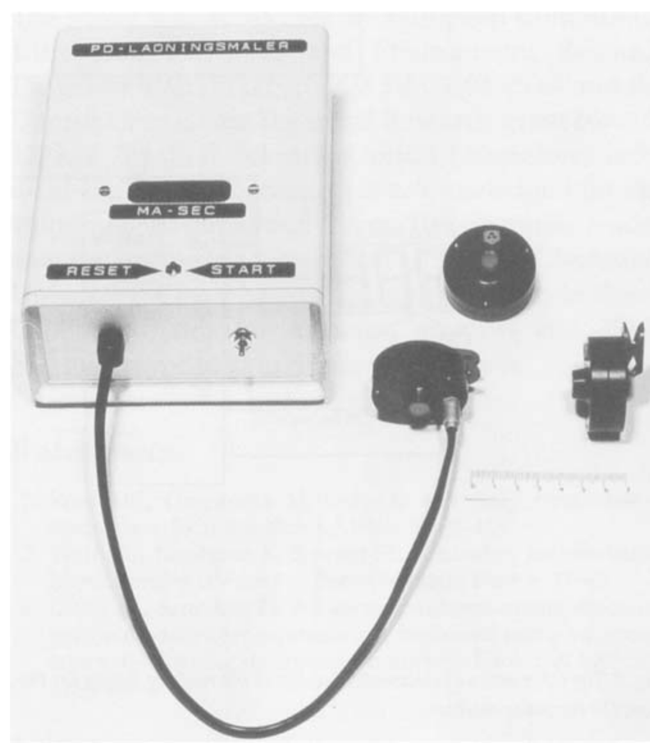

Fig. 7. The prototype of the reading instrument coupled to an electronic dosimeter.

scribed in Table 1. Since interference filters were used in the dosimeters it was necessary to control the angle of the passing light rays, as the cutoff for these filters varies depending on the angle of passing rays (Fig. 3). In front of the filter set, a planar diffuser was placed. The diffuser was used to ensure a standard angle at which the rays passed the filters. The response of the diffuser depended on its shape and the planar diffuser did not give a perfect cosinus response (Fig. 4).

The spectral sensitivity of our dosimeters is illustrated in Fig. 5. We obtained excellent sensitivity for UVA. The instrument was less sensitive to UV of shorter wavelengths, explaining the use of amplifiers in UVB and another detector and amplifier in the UVC model. All dosimeters demonstrated a satisfactory linear response to UV doses (Fig. 6).

Construction of the electronic reading device

Electric charge induced by UV on a photodetector was accumulated in the E-cell coulometer. The maximal capacity of the culometer was 2322 $J \cdot cm^{-2}$, 57 $J \cdot cm^{-2}$ and 1.8 $J \cdot cm^{-2}$ for UVA, UVB and UVC, respectively. The coulometer consisted of a silver cylindrical electrode (cathode) filled with an electrolyte fluid and containing a central golden wire anode. An electrical charge arriving at the coulometer from the photodetector triggered transport of silver

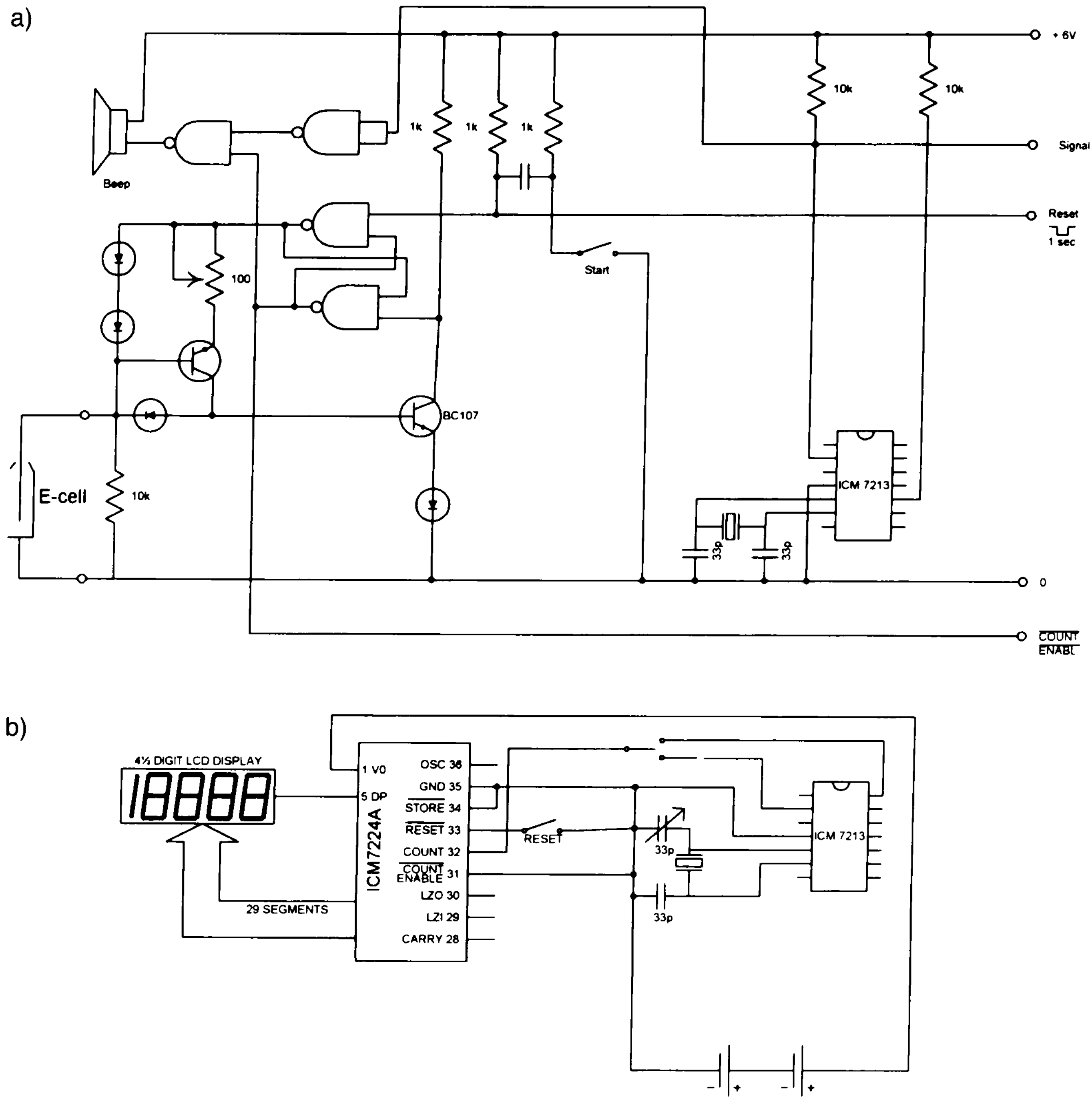

Fig. 8.The schematics of electronic circuits of the reading device for the dosimeters: (a) discharging circuit with a modified oscillator for pulse generation; (b) the pulse counter.

ions from the cathode to the anode. To measure the accumulated electric energy the coulometer was connected with a reading device (Fig. 7) which sent a standardized 1 mA current through the E-cell enabling the return transport of Ag^+ from anode to cathode. When all Ag^+ ions had been released from the anode the current suddenly changed and the reading stopped automatically. The reading device contained an electronic clock which measured the time (in seconds) required to discharge the coulometer with a 1 mA current. The energy accumulated in the coulometer was thus measured in mA · s units. The electronic diagram of the constructed reading device is shown in Fig. 8.

Discussion

In this paper we have described the construction of an electronic dosimeter enabling measurement of cumulative doses of UVA, UVB and UVC. In comparison with the CaF_2 crystal-based dosimeter, the electronic instrument is easier to operate and, more importantly, demonstrates a linear response to delivered UV energy over a wide range. Excellent sensitivity was obtained not only for the UVB and UVC range but also for the UVA range. Previously constructed electronic dosimeters had their peak sensitivity within the UVB wave band (3). A commercially available dosimeter is the Sunwatch (Saitek Ltd, Torrance, CA, USA). It is based on measurement of UV induced fluorescence of dye: para-terphenyl. The concentration of the dye is chosen so that its absorption matches the erythema action spectrum. Sunwatch is intended for public use. However, it is complicated to handle and requires experience and training.

The construction of a personal dosimeter with a linear response to UVA, UVB and UVC doses will enable personal monitoring of UV exposure. Changing of the filters converted the dosimeters into either UVA, UVB or UVC. We used both coloured glass filters and especially constructed interference filters which had a very steep cutoff and therefore were very suitable for separating UVA, UVB and UVC. Their disadvantage was the sensitivity to the influx angle (Fig. 3). The diffuser was used to ensure a reproducible penetration angle of UV rays through the filters. The cosine principle was employed, meaning that the intensity of rays coming from different angles is weighed by multiplication of light dose by the cosinus of the angle between the diffuser surface and a particular ray. As shown in Fig. 4 modulation by a dome-shaped diffuser was close to the ideal cosine response. However, the dome-shaped diffuser was not used in the prototype because of its large size.

Physical separation between the UV radiation measuring device and the dosimeter reading device enabled us to perform double-blind trials, where neither the patient nor the experimentor can read the UV dose during the experiment. However, for public use a built-in display system would be desirable. The disadvantage of the electronic dosimeter is its rather large size (Fig. 1) which at present makes it less appropriate for personal use, since the weight may make it tilt down when fixed to clothes. However, miniturization of the dosimeters is possible. It should also be possible to read the dose in relation to the time of exposure.

It has previously been shown that behaviour outdoors may be a more important factor in determining exposure of an individual rather than the level of ambient UV radiation (3). In this respect the dosimeter may be placed in the shoulder area, which will enable monitoring of the UV exposure of the face. It must be remembered, however, that exposure of other parts of the body will not be measured directly because of considerable UV protection provided by clothes. Evaluating personal UV exposure would enable a more precise quantification of exposure of the population and predict UV-dependent threats to the skin.

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