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Filter-radiometer-based realization of candela and establishment of photometric scale at UME

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Abstract

The luminous intensity unit of candela was realized based on filter-radiometer, which is traceable to detector-based primary standard electrical substitution cryogenic radiometer (ESCR). In that realization the traditional Osram Wi41/G-type incandescent lamp and filter-radiometer consisting of an aperture, a $V(\lambda)$ filter and a silicon photodiode based trap detector were used as light source and detection element, respectively. Measurement techniques of effective aperture area, spectral transmittance of $V(\lambda)$ filter and absolute responsivity of trap detector are also presented.

Keywords: Responsivity; Optical power; Filter-radiometer; Trap detector; Luminous intensity; Candela

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1. Introduction

Optical radiometry covers measurements in the wide range of the electromagnetic spectrum. However, human eye is only sensitive to visible portion of this radiation range, which includes the wavelength range between 380 and 780 nm. In order to photometrically measure visible effects in the mentioned spectral range a unit, described as the candela, is defined. Candela is one of the seven units of SI unit system (Systéme International), which is adopted by CGPM (Conférence Générale

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des Poids et Mesures) in 1954 and formed base for all photometric quantities [1]. Up to 1948, candela was derived from some form of primary standard sources like standard candles (in 1860), oil lamps (in 1880), gas lamps (in 1898) and carbon-filament lamps (in 1909) [2]. In 1948, standard realization of candela was performed based on blackbodies and defined by CGPM in terms of the luminance of a blackbody radiator at the freezing-point temperature of molten platinum (2042 K). However, there are some problems associated with difficulties of realization like instability in the reproducibility of luminance at the freezing temperature of platinum which brings a variation of brightness more than ~2.1% and non-uniform emission of the cavity [3,4]. In order to compare luminous intensity scales of national laboratories an intercomparison was organized in 1969 by the CCPR (Comité Consultatif de Photométrie et Radiométrie) and disagreement was also found on color temperature measurements of light sources [5]. The main factor in disagreement was the color temperature of modern tungsten filament light sources (2856 K), which was far from color temperature of freezing point of platinum. Also use of broadband rather than monochromatic radiation and extrapolation of the spectral distribution of blackbody radiator to higher color temperatures was the major uncertainty in the calculation of maximum spectral luminous efficacy of radiation (K_m) and realization of luminous intensity unit [4,6].

In 1977, CIPM (Comité International des Poids et Mesures) evaluated differences among calculations of K_m value on worldwide and adopted a value of $683\,\mathrm{lm\,W^{-1}}$ as a constant for photometric and radiometric connections. Later, in 1979, CGPM defined candela by relating it to the radiometric unit (watt) [7]. The new definition states that "the candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 w/sr". The relevant frequency of 540×10^{12} Hz corresponds to the wavelength of 555 nm at which human eye has maximum sensitivity. This definition does not state that the candela must be realized at a wavelength of 555 nm, it defines how K_m factor is equal to 683 lm/W. In order to determine candela in the visible range the full sensitivity curve of human eye was tabulated in 1924 by Commission Internationale de I'Eclairage (CIE) and named as $V(\lambda)$ photopic spectral efficiency function [8], which have been playing an important role in photometry since 1924.

With the new definition, candela has been realized using detector-based standards instead of source-based standards. For this purpose, electrical substitution cryogenic radiometer and silicon-based detectors have been used as primary and transfer standards respectively. Silicon photodiodes are most preferable detection elements because of the good stability, very fast response time and predictable responsivity. Moreover in 1979, Geist and Zalewski showed that internal quantum efficiency (IQE) for certain types of Si diodes are very close to unity over the wavelength region of 500–950 nm [9]. In the past, single photodiode-based detectors were used to realize luminous intensity unit. However due to the high reflectivity of photodiodes (~35%) interreflections between photodiode and $V(\lambda)$ filter reduces the accuracy of the measurements [1,10]. With the design of trap detectors, this problem and, therefore, the uncertainties in the photometric and radiometric realizations were minimized [11].