Glossary of Terms*

Terminology Used for Ultraviolet (UV) Curing Process Design and Measurement

This glossary of terms has been assembled in order to provide users, formulators, suppliers, and researchers with terms that are used in the design and measurement of UV curing systems. It was prompted by the scattered and sometimes incorrect terms used in industrial UV curing technologies. It is intended to provide common and technical meanings as used in and appropriate for *UV process design, measurement, and specification.* General scientific terms are included only where they relate to UV measurements. The object is to be "user-friendly," with descriptions and comments on meaning and usage, and minimum use of mathematical and strict definitions, but technically correct. Occasionally, where two or more terms are used similarly, notes will indicate the preferred term.

For historical and other reasons, terms applicable to UV curing may vary slightly in their usage from other sciences. This glossary is intended to "close the gap" in technical language, and is recommended for authors, suppliers, and designers in UV curing technologies.

absorbance. An index of the light absorbed by a medium compared to the light transmitted through it. Numerically, it is the logarithm of the ratio of incident spectral irradiance to the transmitted spectral irradiance. It is unitless number. Absorbance implies monochromatic radiation, although it is sometimes used as an *average* applied over a specified wavelength range.

absorptivity (absorption coefficient). Absorbance per unit thickness of a medium.

additive lamps. Medium pressure mercury vapor UV lamps (arc or microwave) that have had small amounts of metal halide(s) added to the mer-

* Published with permission of RadTech International North America.

cury within the bulb. These materials will emit their characteristic wavelengths in addition to the mercury emissions. (This term is preferred over **doped lamps**).

bandwidth. The range of wavelengths between two identified limits, expressed in the same units as wavelength (nm).

cosine response. Description of the spatial response to incident energy where response is proportional to the cosine of the incident angle. A radiometer with a diffuser or a photo-responsive coating will exhibit nearly cosine response.

dichroic. Exhibiting significantly different reflection or transmission in two different wavelength ranges. Dichroic reflectors which have reduced reflectance to long wavelengths (IR) are also called "cold mirrors."

diffuse. A characteristic of a surface that reflects or scatters light equally in all directions (often confused with *spread reflectance*).

doped lamps. Term applied to UV lamps having metal halide additives to the mercury to alter the emission spectrum of the lamp. (Historically, this term has been used by UV arc lamp manufacturers. It is a slightly imprecise usage, as the added chemical does not alter the properties of the other). (The preferred term is **additive lamps**).

dose. A common, but loosely used, term for **energy density**, or radiant flux density, at a surface. (It is a precisely defined term in EB curing: 1 Gray (Gy) = 1 J/kg, a measure of absorbed energy per unit mass). In other technologies, the term usually applies to energy absorbed *within* the medium of interest, but in UV curing, is equated only to **irradiant energy density** *arriving at the surface* of the medium of interest. (The preferred shortened term is **energy density**, expressed in J/cm^2 or mJ/cm^2).

dynamic exposure. Exposure to a varying irradiance, such as when a lamp passes over a surface, or a surface passes under a lamp, or lamps. In that case, energy density is the time-integral of the irradiance profile.

dynamic range. The span between the *minimum* irradiance and the *maximum* irradiance to which a radiometer will accurately respond. Expressed as a ratio, or in measured units (e.g., $watts/cm^2$).

effective energy density. Radiant energy, *within a specified wavelength range,* arriving at a surface per unit area, usually expressed in joules per square centimeter or millijoules per square centimeter (J/cm^2 or mJ/cm^2). Is expressed in a specified wavelength range (without wavelength specification, it is essentially meaningless). Commonly accepted abbreviations are W_λ or E_λ.

effective irradiance. Radiant power, *within a specified wavelength range,* arriving at a surface per unit area. It is expressed in watts or milliwatts per square centimeter (W/cm^2 or mW/cm^2) in a specified wavelength range (without wavelength specification, it is essentially meaningless). For brevity, when the wavelength range is *clearly* understood, the term is

shortened to **irradiance**. Commonly accepted abbreviations are E_λ or I_λ. Compare **spectral irradiance**.

emission spectra. Radiation from an atom or atoms in an excited state, usually displayed as radiant power vs wavelength. Emission spectra are unique to each atom or molecule. The spectra may be observed as narrow line emission (as in atomic emission spectra), or as quasi-continuous emission (as in molecular emission spectra). A mercury plasma emits both line spectra and continuum simultaneously.

energy density. Radiant energy arriving at a surface per unit area, usually expressed in joules or millijoules per square centimeter (J/cm^2 or mJ/cm^2). It is the time-integral of irradiance. (Terms applied in other technologies include "radiant exposure," "light dose," and "total effective dosage"). Compare **fluence**, **dose**.

fluence. The time-integral of fluence rate (J/m^2 or J/cm^2). For a parallel and perpendicularly incident beam, not scattered or reflected, **energy density** and **fluence** become identical.

fluence rate. The radiant power of all wavelengths passing from all directions through an infinitesimally small sphere of cross-sectional area dA, divided by dA. For a parallel and perpendicularly incident beam, not scattered or reflected, **irradiance** and **fluence rate** become identical. (W/cm^2 or mW/cm^2).

flux (radiant flux). The flow of photons, in einstein/second; one einstein = one mole of photons.

intensity. A generic term, with a variety of meanings; undefined, but commonly used to mean **irradiance**. Generally misapplied in UV curing. Its *precise* optical meaning is flux/steradian (W/sr), applied to *emission* of light; not useful in UV curing. (The preferred terms are **irradiance** or **effective irradiance**).

irradiance. Radiant power arriving at a surface from all forward angles, per unit area. It is expressed in watts per square centimeter or milliwatts per square centimeter (W/cm^2 or mW/cm^2). Compare **effective irradiance, spectral irradiance,** and **fluence rate**.

irradiance profile. The irradiance pattern of a lamp; or, in the case of dynamic exposure, the varying irradiance at a point on a surface that passes through the field of illumination of a lamp or lamps; irradiance versus time.

joule (millijoule). A unit of work or energy (a newton-meter). The time-integral of power. Abbreviated ***J*** or ***mJ***. (Although derived from a proper name, the term is *not* capitalized, while its abbreviation *is* capitalized).

line emission. Narrow lines of emission from an atom in an excited state. These are the "spikes" observed in spectrometry. Low-pressure sources exhibit finely distinguished line emission; higher pressure sources exhibit more continuous spectra.

monochromatic. Light radiated from a source that is concentrated in only a very narrow wavelength range (**bandwidth**). This may be accomplished either by filters or by narrow-band emission.

monochromator. An instrument that separates incoming radiant energy into its component wavelengths for measurement. Two methods are used for dispersing the radiation: diffraction grating or prism. The typical resolution may be 1 nanometer or less.

nanometer. Unit of length. Abbreviated nm. Equals 10^{-9} meter, = 10^{-3} micron, = 10 Å (ångstrom). Commonly used unit to define wavelength of light, particularly in the UV and visible ranges of the electromagnetic spectrum. An older equivalent term, millimicron, is rarely used today.

optical density. The logarithm of the reciprocal of reflectance or transmittance. A dimensionless number. In printing and color, it is the log of the ratio of visible light absorbed by an "absolute white" to the light absorbed by the measured ink.

peak irradiance. The intense peak of focused power directly under a lamp. The maximum point of the **irradiance profile.** Measured in irradiance units (W/cm^2).

photometer. An instrument for measuring visible light, usually filtered or corrected to match the human eye response.

power (radiant) (see **radiant power).** The rate of radiant energy or total radiant power (W) emitted in *all* directions by a source.

power (UV lamp). Tubular UV lamps are commonly described by their operating power in "watts per inch" or "watts per centimeter." This is derived simply from the electrical power input divided by the effective length of the bulb. (It does not have a direct meaning to the output efficiency of a lamp system, to the spectral conversion efficiency, to the curing performance, or to the UV irradiance delivered to a work surface).

polychromatic, or **polychromic.** Consisting of many wavelengths.

quantum yield. A measure of the photon efficiency of a photochemical reaction. The ratio of the number of chemical events per unit time to the number of photons absorbed per unit time. It is a unitless measure.

radiachromic. Exhibiting a change of color or optical density with exposure to light. A character of films whose color or density change can be correlated to exposure to UV energy.

radiance. Generally refers to the radiant *output* of a source. It is radiant flux per unit area per steradian ($W/cm^2/sr$). In UV curing, it is used generically rather than as a precise optical term.

radiant power. Rate of energy transfer, expressed in watts or joules/second (W = J/sec).

radiant intensity. Power per unit of solid angle from a source, expressed in watts/steradian (W/sr).

radiant energy. Energy transfer, expressed in joules or watt-seconds (J = W×sec).

radiometer. A device that senses irradiance incident on its sensor element. Its construction may incorporate either a thermal detector or a photonic detector. The instantaneous signal output will usually have a linear proportionality to radiant flux, and will depend on incident wavelength(s). The resulting characteristic response to irradiance versus wavelength is called responsivity.

responsivity (spectral sensitivity). The response or sensitivity of any system in terms of incident wavelength. In radiometry, it is the output of a device versus wavelength.

spectral output. The radiant output of a lamp versus wavelength. It is displayed in a variety of ways, but commonly a graph or chart of output watts plotted against wavelength. The appearance of the plot will vary dramatically, depending on the wavelength resolution used. A technique of normalizing is to integrate energy over 10-nanometer bands, to reduce the difficulty of quantifying the effects of line emission spectra.

spectral absorbance (absorbance spectrum). Absorbance described as a function of wavelength.

spectral irradiance. Irradiance at a given wavelength per unit area per unit wavelength interval. Expressed in $W/cm^2/nm$. Usually measured with a spectroradiometer. Compare **effective irradiance.**

spectroradiometer. An instrument that combines the functions of a radiometer and a monochromator to measure irradiance in finely divided wavelength bands.

static exposure. Exposure to a constant irradiance for a controlled period of time. Contrast with **dynamic exposure**.

UV. Ultraviolet. Radiant energy in the 100–450 nm range. 100–200 nm is generally called *vacuum UV (VUV)*, because it does not transmit in air. There is no precisely defined boundary between UV and visible light, and may be considered about 400–450 nm.

UVA, UVB, UVC. Designations of UV wavelength ranges, originally for distinction of physiological effects of UV, and establishment of safe exposure limits. The generally accepted ranges are:

VUV: 100–200 nm
UVC: 200–280 nm
UVB: 280–315 nm
UVA: 315–400 nm

UVA is commonly referred to as *long UV wavelengths*; while **UVC** is considered *short UV wavelengths*. **VUV** stands for "vacuum UV." Measurement of specific ranges may be defined by the responsivity of a radiometer. It should be made clear, when referring to these ranges, *exactly* what wavelengths they represent. Specific manufacturers of radiometers will use uniquely specified ranges.

watt (milliwatt). The absolute meter-kilogram-second unit of power equal to the work done at the rate of one joule per second or to the power produced

by a current of one ampere across a potential difference of one volt : 1/746 horsepower. Abbreviated W or mW. In optics, a measure of radiant or irradiant power. (Even though the term is derived from a proper name, it is *not* capitalized, while the abbreviation *is* capitalized).

wavelength. A fundamental descriptor of electromagnetic energy, including light. It is the distance between corresponding points of a propagated wave. It is the velocity of light divided by equivalent frequency of oscillation associated with a photon. UV wavelengths are currently measured in nanometers (10^{-9} meter). An older term, Ångstroms (Å= 10^{-10} meter) is rarely used today. The typical symbol for wavelength is λ(lambda).