UV 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 or UV 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.

actinometer

A chemical system or physical device that determines the number of photons in a beam integrally or per unit time. For example, solutions of iron (III) oxalate can be used as a chemical actinometer, while bolometers, thermopiles, and photodiodes are devices whose electrical response can be correlated with the number of photons detected.

actinometry

Determination of the number of photons in a beam per unit time, or integrated over time.

additive lamps

Medium pressure mercury vapor UV lamps (arc or microwave) that have had small amounts of metal halide(s) added to the mercury 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***). In radiometry, it is important that the basis of the limits (i.e., % response of the instrument used) be specified or known. Band (wavelength range) *must* be communicated with radiometric data.

cold mirror

A type of dichroic reflector that has low reflectance to IR compared to its reflectance of shorter wavelengths, visible or UV. Also see **dichroic**.

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 that have reduced reflectance to long wavelengths (IR) are called "cold mirrors," while reflectors having enhanced reflectance to long wavelengths are called "hot mirrors."

diffuse

A characteristic of a surface that reflects or scatters light or UV 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 an imprecise usage, as the added chemical does not alter the properties of another.) [The preferred term is **additive lamps**.]

dose

Energy *absorbed* per unit mass. A precisely defined term in EB curing and ionizing radiation technologies: 1 gray (**Gy**) = 1 **J/kg** = 0.1 **Mrad**. In UV curing, the term is often used instead of the preferred terms for energy measured at a surface. Preferred UV terms are **energy, effective energy density** or **exposure** (for energy delivered to a surface per unit area, *not* energy absorbed).

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 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 $W\lambda$ or $E\lambda$. [An alternate term is **exposure**.]

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/cm²** or m**W/cm²**) 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 $E\lambda$ or $I\lambda$. Compare **spectral irradiance**.

einstein

One mole of photons. Sometimes equated to the *energy* of one mole of photons—although this use is discouraged.

electromagnetic spectrum

An extremely wide range of radiation that travels at the speed of light, and characterized by wavelength. Extends from radio waves (~10^4 meters), through visible and UV (~10^{-4} meters), to gamma rays (~10^{-14} meters).

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/cm²** or **mJ/cm²**). It is the time-integral of irradiance. Same as **exposure**. For a parallel and perpendicularly incident beam, not scattered or reflected, **energy density** and **fluence** become identical. Compare fluence. [Not equivalent to **dose**.]

exposure

Effective radiant energy density at a surface; the time-integral of irradiance within a specified bandwidth, expressed in **J/cm²** or **mJ/cm²**. The time-integral of fluence rate, in **J/m²** or **J/cm²**. Also **radiant exposure**. In solar UV exposure applications, larger units may be used—**J/m²** or even **MJ/m²**. Compare **fluence**. [Not equivalent to **dose**.] The definition varies in radiation chemistry and in clinical chemistry.

fluence

The total radiant energy of all wavelengths passing from all directions through an infinitesimally small sphere of cross-sectional area dA, divided by dA. Units are typically **J/cm²** or **mJ/cm²**.

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. Units are typically **W/cm²** or **mW/cm²**.

flux (radiant flux)

The flow of photons, in einstein/second; one einstein = one mole of photons.

hot mirror

A dichroic reflector having a higher reflectance to IR than to visible or UV. See **dichroic**.

intensity

A generic term, with a variety of meanings; undefined, but sometimes 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. [Compare **irradiance** or **peak 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/cm²** or **mW/cm²**). Compare **effective irradiance, spectral irradiance** and **fluence rate**.

irradiance profile

The irradiance pattern 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 vs. 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 joule is not capitalized, while its abbreviation is capitalized.)

light

Radiant energy in the ***visible*** range of the electromagnetic spectrum.

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 generally exhibit more continuous spectra.

monochromatic

Light or UV 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 one 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/cm²**.

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, nor 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. Note that it is based on the *absorbed* and not the *incident* photon flow.

radiachromic

Exhibiting a change of color or optical density with exposure to light or UV. 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 in a generic sense 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**).

radiant exposure

See exposure.

radiochromic

Preferred term is **radiachromic**.

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 vs. wavelength is called *responsivity*.

responsivity (spectral sensitivity)

The response or sensitivity of any system in terms of incident wavelength. In radiometry, it is the relative output of a device vs. wavelength. In photochemistry, it may also be applied to the spectral response of photoinitiators.

spectral output

The radiant output of a lamp vs. 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 spectral power over 10-nanometer bands, (**W/10nm**), 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/cm²/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 nm to 450 nm range. 100 nm to 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, VUV

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** should not to be confused with the very long UV range called **UVV** (400-450 nm).

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, the term watt 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). ◗

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