Introduction to UV/EB Equipment Selection

Stephen C. Lapin, Ph.D.
Applications Specialist
PCT Engineered Systems

RADTECH
THE ASSOCIATION FOR UV&EB TECHNOLOGY

UV/EB Technology Comparison

- UV and EB are complementary, not competing technologies
- UV and EB have some similarities and fundamental differences
- Selection of UV or EB should be based on the best fit for the process and application
- Best fit considerations may include:
  - Enabling of end-use
  - Process integration
  - Capital cost
  - Operating costs
  - End-use properties
  - Substrate considerations

Energy

UV

- Energy in the form of photons
- Wavelength determines energy; typically 250 to 450 nm
- Energy unit conversion; 350 nm photon = 3.5 eV
- Total applied energy typically 0.1 to 0.5 J/cm2

EB

- Energy in the form of accelerated electrons
- Accelerating voltage determines energy; typically 80 to 180 kV
- Typical electron energy at substrate; 70,000 eV
- Total applied energy typically 20 to 40 kGy
  - 1 kGy = 1 J/gram
  - For 50 gram/meter^2 layer = 0.1 to 0.2 J/cm^2

Energy

UV

- Energy not sufficient to directly initiate polymerization (non-ionizing)
- Photoinitiator must be used

EB

- Will ionize any organic material
- No photoinitiator needed

Penetration

UV

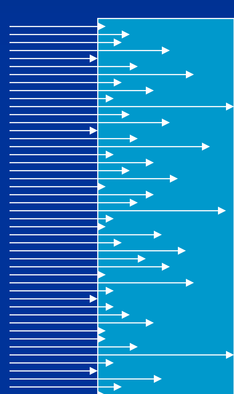
- Penetration depends on the optical density of the material
- Penetration is controlled by the peak irradiance (power and focus) of the UV source
- Good penetration into clear materials
- Limited penetration into pigmented, filled, and opaque materials
  - Effective curing of thin ink films
  - Effective curing of thick coatings with low pigment loading
  - Lamination of clear materials

EB

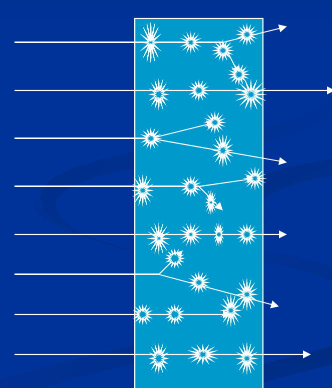
- Penetration depends on the mass density of the material
- Penetration is controlled by acceleration potential (voltage) of the beam
- Easily penetrates into clear, pigmented, filled, and opaque materials
  - Can cure thick and/or heavily pigmented or filled inks and coatings
  - Enables lamination of opaque materials

Penetration/Energy Deposition

UV Photons



EB Electrons



Inerting

UV

- Free-radical curing inhibited by atmospheric oxygen
- Curing in air can be accomplished for many systems due to high surface irradiance
- Air curing important for sheet-fed printing and 3D applications
- Inerting can greatly accelerate cure and/or reduce photoinitiator requirements

EB

- Free-radical curing inhibited by atmospheric oxygen
- Inks and coating require an inert atmosphere to cure
- Effective inerting limited to web and flat substrate applications
- Laminations can be cured without inerting since laminate layer excludes oxygen

Effect on Substrates

UV

- Non-ionizing energy has limited effect on thermal and mechanical properties of substrates
- Separate UV primer layer may be used for grafting/enhanced adhesion

EB

- May cross-link or degrade polymer substrates
- Effect may be beneficial
  - Cross-linking of film to modify mechanical properties
  - Simultaneous curing and grafting for enhanced adhesion
  - Simultaneous curing and sterilization of food or medical packaging
- Low energy allows surface curing while minimizing the effect on substrates

Equipment Safety

UV

- UV light can cause skin and eye damage upon exposure
- High temperature mercury lamps could result in skin burns upon contact
- UV sources are completely self shielded

EB

- Limited penetration of electrons
- Secondary x-rays are primary hazard
- Not radioactive. No radiation can be present unless high voltage is on
- Low energy EB units are completely self-shielded
- Interlocked to cut power if shielding is removed
- Continuous monitoring will shut-down unit if x-rays are present

Capital Cost

UV

- Relatively low cost for few number of relatively narrow lamps
- High-speed (>1000 ft/min) will typically require 4 to 6 lamps in series
- Wide web (>50 inch) multi-lamp systems begin to approach EB costs

EB

- Original higher energy (>150 kV) units cost >$ 1 MM
- Newer lower energy equipment has reduced cost 50% or more
- Single EB unit will cure >50 inch-wide web at >1000 ft/min

Operating Costs

UV (mercury lamps)

- About half of the energy input is converted to UV light
- Remaining energy is lost as heat
- Additional energy required for lamp cooling (air blowers most common)

EB

- More efficient conversion of electrical power to curing energy
- Additional energy requirements for vacuum pumps, water cooling
- Additional cost of Nitrogen

Depending on the application, operating costs for

UV and EB curing could be similar

Heat Control

UV (mercury lamps)

- Significant heat output from lamps
- Heat control measures needed for many applications/substrates
  - Dichroic reflectors
  - Hot mirrors
  - Water cooled lamps
  - Chill drums

EB

- Cooler process compared to UV
- Many substrates can be run without special cooling
- EB units available with or without integral chill drums

Consistency/Maintenance

UV (mercury arc)

- Output can decrease as lamps age
- Decrease not uniform across spectral output and across the width of the lamp
- Typical preventative maintenance interval 1000 to 3000 hours
- Maintenance interval will depend on process cleanliness and lamp temperature control
- Typical maintenance items are bulbs and reflectors
- Multiple lamp systems allow process to continue at slower speed in case of single lamp failure

EB

- Output is very consistent over time (on or off)
- Cross-web uniformity is constant over time
- Typical preventative maintenance interval is 4000 to 8000 hours
- Maintenance interval will depend on process cleanliness and window/foil temperature control
- Typical preventative maintenance items are window foil and filaments
- Process must be stopped for window foil or filament change

Measurement

UV

- Measurement is critical for maintaining a constant process
- Wide range of radiometers are available
  - Probes (inserted, fixed)
  - Radiometer attached to substrates
  - UV sensitive films attached to substrates
- Need to understand limits of each type of radiometer

EB

- Measurement is critical for maintaining a constant process
- EB sensitive film dosimeters most common
- Dosimeters traceable to NIST standards

Equipment Size

UV

- Relatively small
- Easily integrated into a wide range of processes
- Printing: full interstation installation (lamp after each print deck)
- 3D: multi-lamp or robotic lamp positioning allows exposure of complex geometry
- Compact LED arrays very attractive for integration

EB

- Original industrial equipment is quite large
- Newer low energy equipment is much smaller; however, space required is still large compared to UV
- High speed web curing achieved with a single EB unit
- Sealed tube modular units (Comet) may facilitate 3D and multi-emitter installations

UV Equipment

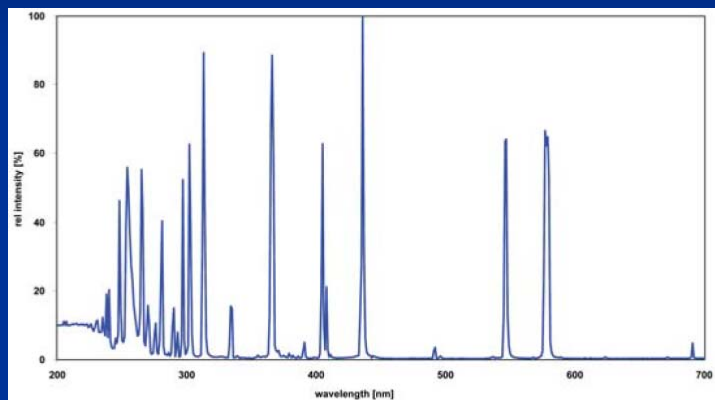
- Medium pressure mercury electric arc powered lamps
- Medium pressure mercury microwave powered lamps
- Pulsed xenon lamps
- Solid state LED arrays

Mercury Arc Lamp Components

Medium Pressure Mercury Arc Lamps

- Strengths
  - High throughput
  - Wide widths available (>60")
  - Broad spectral output
  - Doped bulbs available to shift spectral output
- Weaknesses
  - High heat output
  - Long warm-up time (shutters)
  - Non-uniform aging

Medium Pressure Mercury Arc Lamp Spectral Output



Medium Pressure Mercury Arc Lamps Applications:

- Printing
  - Web and sheet-fed
  - End of press and full interstation
  - Narrow and wide widths
- Web converting
- Wood finishing
- Pipe & tube
- Field applied coating and curing
- Many, many more industrial applications

In-line Flexo Printing with Interstation UV Curing

Microwave Powered Mercury Lamp Components

Microwave Powered Mercury Lamps

- Strengths
  - High throughput
  - Long lamp life/consistent output
  - Fast warm-up (no shutters)
  - Broad spectral output
  - Doped bulbs available to shift spectral output
- Weaknesses
  - Each lamp 10" max width – use multiple lamps end-to-end for wider widths
  - High heat output

Microwave Powered Mercury Lamps Applications:

- Optical fiber coatings
- Pipe and tube finishing
- 3D part assembly/finishing
- Web converting
  - Release coatings
  - Hard coats
- Many, many more industrial applications

Pulsed Xenon Lamp System

Pulsed Xenon Lamp Systems

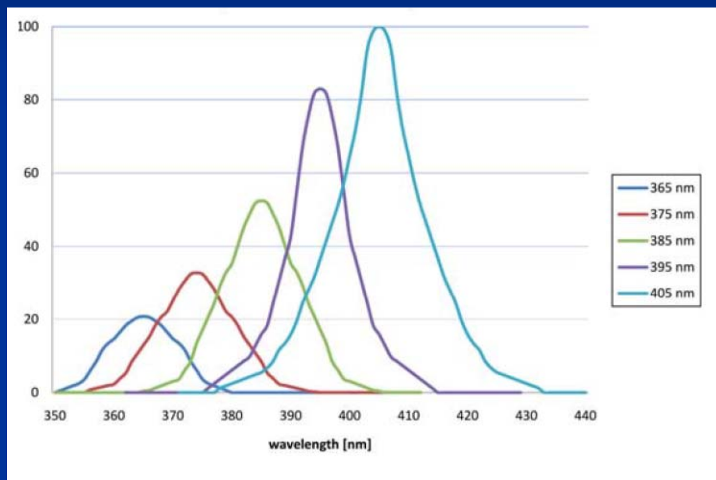
- Strengths
  - Very low heat
  - Special shapes – to match material being irradiated
  - High pulse irradiance – deep penetration
  - Broad spectral output
- Weaknesses
  - Low continuous output
- Applications - index (stop and go) processes
  - CD lacquering
  - DVD bonding

UV LED Array

UV LED Arrays

- Strengths
  - Very long life
  - Instant on
  - Compact/modular/scalable – allows system integration
  - Low substrate heating – heat generated and removed from back of LEDs
- Weaknesses
  - Narrow spectral output (bands centered at 365, 385, or 405 nm)
  - Lower throughput (improving – now up to 16 w/cm^2)
  - Low peak irradiance (unfocused)
  - Close proximity to substrate

UV LED Arrays
Spectral Output Options



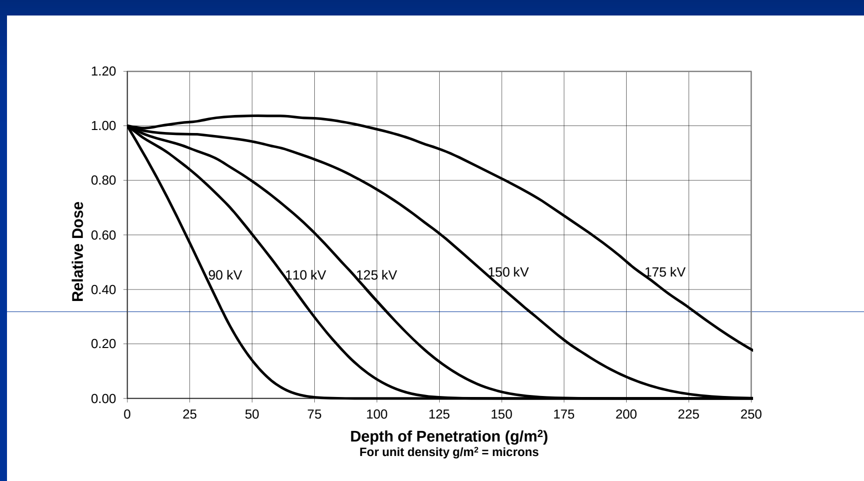
UV LED Arrays
Applications:

- Digital printing - ink jet
- Assembly - adhesive spot curing
- Narrow web flexo printing (emerging application)

EB Equipment

- High energy scanning type
  (300 – 10,000 kV)
- Industrial self-shielded multi-filament type
  (150 – 300 kV)
- Low energy self-shielded multi-filament type
  (80 – 150 kV)
- Low energy sealed tube modular type
  (80 – 180 kV)

EB Energy Deposition



High Energy Scanning EB
300 to 10,000 kV (10 MeV)

Dynamatron (0.5 to 5.0 MeV)

Rhodotron (2 to 10 MeV)

High Energy Scanning EB
300 to 10,000 kV (10 MeV)

- Limited usage in curing applications
- Strengths
  - Penetrates very thick materials
- Weaknesses
  - High capital costs
  - Large size
  - Extensive shielding requirements
- Applications
  - Crosslinking of wire and cable
  - Crosslinking of tires
  - Bulk sterilization of food and medical equipment

Industrial Self-Shielded Multi-Filament EB Equipment
(150 to 300 kV)

Industrial Self-Shielded Multi-Filament EB Equipment
(150 to 300 kV)

- Strengths
  - Very high throughput
  - Wide widths (>100")
  - Penetration of thick films (> 18 mils)
- Weaknesses
  - High capital cost
  - Large size
  - Potential substrate damage
- Applications
  - Film Crosslinking
  - Pressure sensitive adhesive crosslinking
  - Manufacturing of casting papers
  - Manufacturing of decorative laminates

Low Energy Self-Shielded Multi-Filament EB Unit
(80 to 125 kV)

Low Energy Self-Shielded Multi-Filament EB Unit
(80 to 125 kV)

- Strengths
  - Very high throughput
  - Wide widths (>72”)
  - Controlled penetration
  - Lower capital cost compared to industrial EB unit
  - Low operating cost
- Weaknesses
  - Not suited for interstation curing on printing presses
  - Flat sheet materials require custom machine design
  - Not well suited for 3D applications

Low Energy Self-Shielded Multi-Filament EB Unit Applications:

- Printing and packaging
  - Web offset ink curing
  - Flexo ink curing (limited installations)
  - Clear coatings over conventional inks
  - Package laminations
- Web converting
  - Embossing
  - Transfer coating
  - Release coatings
- Metal coil coatings (emerging application)
- Controlled depth crosslinking
  - Shrink films
  - Pressure sensitive adhesives

Low Energy EB Curing In-Line with Web Off-Set Printing

Sealed Tube Modular EB Equipment
(emitter, cable, power supply)

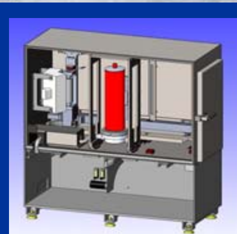
Sealed Tube Modular EB Equipment

- Strengths
  - Lower cost
  - No vacuum pumps (permanent vacuum)
  - Compact modular design (enables integration)
  - Quick service by emitter exchange
- Weaknesses
  - Width maximum 16” per emitter
  - Lower throughput
  - No on-site service of emitters

Sealed Tube Modular EB Equipment Applications:

- Surface sterilization of packaging
- Narrow web printing, converting, crosslinking (emerging applications)
- Curing finishes on 3D parts (emerging application)
- Lab units

EB Equipment Incorporating Sealed Tube EB Emitters



Summary

UV Strengths

- Web, sheet, or 3D applications
- Cure surface coatings in air
- Compact size facilitates process integration
- Relatively low capital cost

EB Strengths

- High throughput web applications
- Cure through thick pigmented, filled and opaque materials
- No photoinitiator
- Consistent output

Thank You

PRESENTED BY:
Steve Lapin
Applications Specialist
PCT Engineered Systems, LLC
SCLapin@TeamPCT.com