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Instantaneous Surface Sanitization With Pulsed UV

Presented by

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Instantaneous Surface Sanitization with Pulsed UV

Abstract: The unique properties of pulsed ultraviolet (UV) light make it an ideal technology for both surface sanitization and photochemical processing in the development of hygienic paints and coatings. This paper will discuss the means by which pulsed light can sanitize and sterilize various infectious disease-contaminated surfaces by attacking bacteria, viruses, fungi, and protozoa on a molecular level, thus modifying the cell structure of their DNA. Pulsed UV is an environmentally benign technology, providing intense peak energy that easily penetrates thick and opaque substrates. The benefits of pulsed UV for curing adhesives and surface preparation for paints and coatings are also discussed.

Introduction to UV Light

There are two fundamental ways to generate light, namely pulsed and continuous. Each method provides significantly different energy levels, which in turn, determine their role in applications such as surface sanitization and treatment. For example, the “continuous” light of the sun, on the surface of the earth, has an energy level of about 100 milliwatts per square cm. In contrast, the peak power level of pulsed UV light can be as high as $1x\ 10^6$ watts, with pulse widths in the microsecond region. Thus pulsed UV light delivers 50,000 to 100,000 times the energy level of the sun in short, controlled pulses.

This unique quality of pulsed UV light was utilized by George Porter who won a Nobel Prize in 1967 for his work in fast reaction photochemistry and photobiology. The experiment involved passing continuous light through a solution and observing the spectrum of the light exiting the solution. The solution was then hit with an intense, microsecond duration pulse of UV light. The changes in the exiting light spectrum, during and after the on-time of the UV pulse, yielded information about the nature of the reaction and any transient free radicals over the range of microseconds. This knowledge opened the door to a new world of chemistry with universal, transformative effects.

About Pulsed UV

There are several sources of plasma-created UV radiation, the most common being the electric arc, the mercury lamp, and the most efficient of all…the pulsed xenon flashlamp.

A primary characteristic of the xenon flashlamp is its capability of generating wideband radiation (50 nm to 5 microns) with unequaled high efficiency, especially in the ultraviolet region from 280 nm (air cutoff) to 400 nm. This paper will focus on pulsed UV light and some of the key ways that it differs from continuous mercury light.

The pulsed UV process is environmentally benign since it does not create or use volatile organic compounds (VOC's) or create suspended airborne particulates. It is also capable of a providing a broad spectrum of light as illustrated in Figure 1.

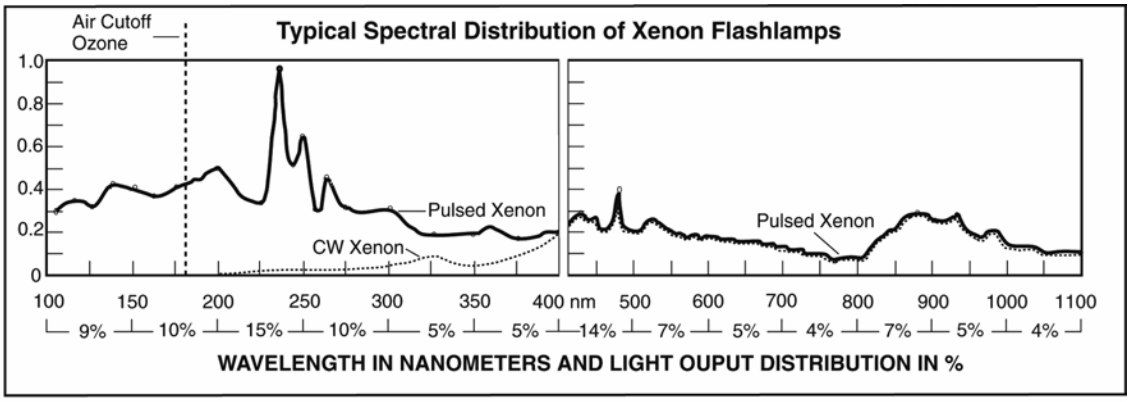


Figure 1: A typical spectrum of pulsed and continuous (CW) xenon flashlamps

Other key qualities of pulsed UV light include very high peak power, low substrate temperature buildup, instant on/off control, multishaped flashlamps, and worker safety.

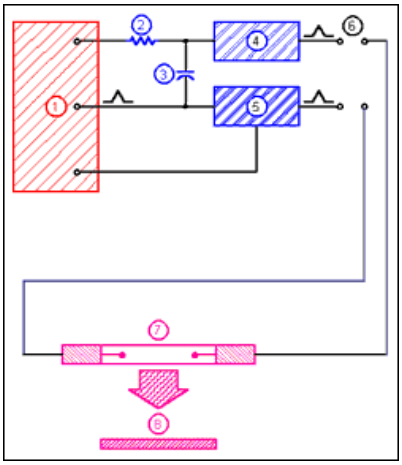


Figure 2: Block diagram of pulsed UV light system

The pulsed UV system works by converting high speed electronic pulses to high peak energy light pulses of short duration. It consists of three main units: the power supply, pulse configurator, and lamp. The lamp is the heart of the system. Depending on the specific application, data storage monitors and cooling equipment might be included. The power supply converts line voltage and current to high voltage and low current to charge the main energy storage capacitor. When the lamp is triggered, the stored energy discharges through the pulse

shaping network taking on preset pulse characteristics. The lamp converts the high voltage high peak current pulses to light at very high peak power. A diagram of these basic units is presented in Figure 2.

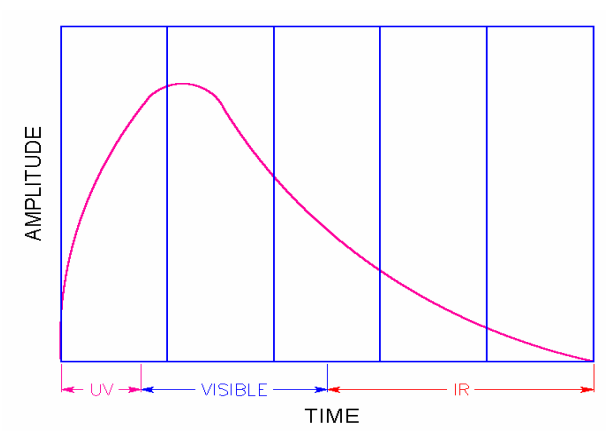


Figure 3: A single pulse of light with spectral components

A single pulse of light contains a dynamic spectrum and presents many opportunities for matching the light to the specific need of the application. For example, as illustrated in Figure 3, the spectrum of a single pulse is time dependent, starting with the deepest UV and ending with the longest wavelength IR.

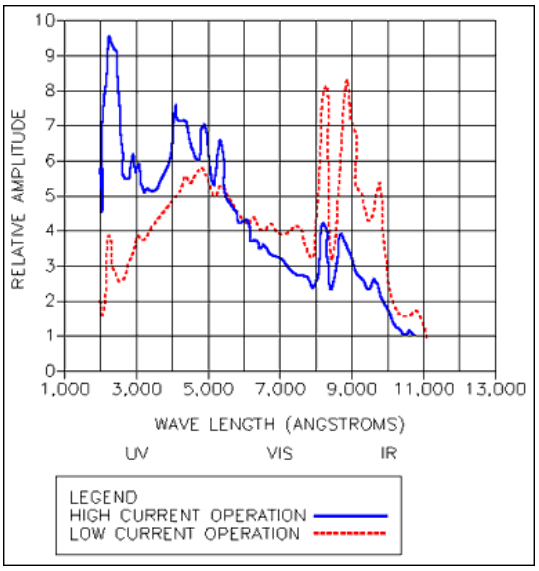


Figure 4: Spectral Dependence on flashlamp operating parameters

The pulsed UV is the only technology which allows the light spectrum to be changed without changing the lamp, as illustrated in Figure 4. Variations in current will result in predetermined changes in the flashlamp spectrum. This is extremely significant because it allows matching the flashlamp light to the chemistry requirements of the biological substrate. Additionally, changes in the heat delivered to smaller and thinner substrates can be controlled using this method. The need to make minor increases in the heat delivered is most common with formulations originally designed for continuous mercury lamps.

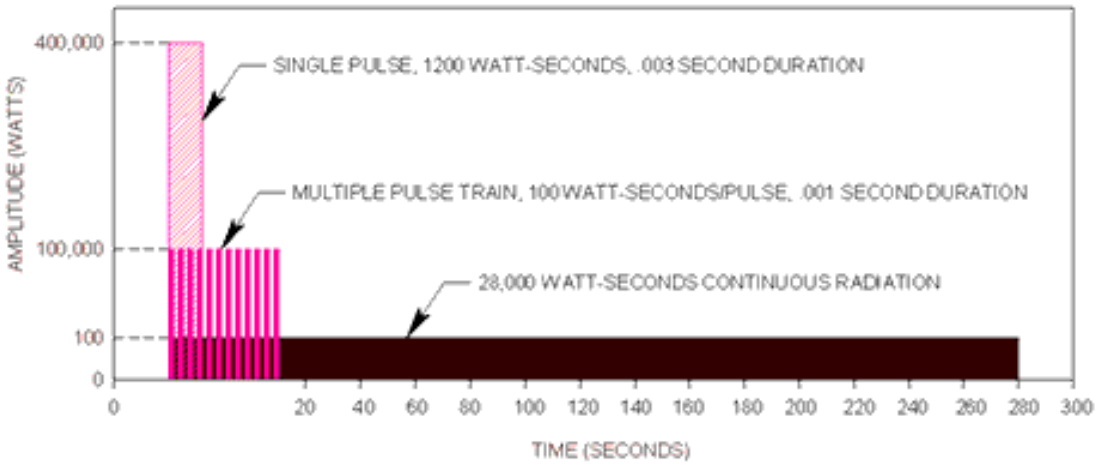


Figure 5: A comparison of pulsed vs. continuous light (pulsed light is illustrated in a single pulse and burst mode)

The light can be delivered in a single pulse, a burst of pulses, and a continuous array of pulses or in random sequences to meet specific process requirements. Generally, the lower pulse frequencies deliver pulses with higher energy per pulse, as shown in Figure 5.

Consequences of Pulsed UV Exposure

Pulsed UV provides one of the most effective methods of photophysical and photochemical reactions of light absorption by molecules, producing novel chemical pathways such as short lived chemical species, charge-transfer reactions and energy transfer phenomena in chemical biological systems.

The efficacy of the pulsed light-photochemical process is attributed to the unique effects of the high peak power and broadband spectral output, as well as methods to regulate both the pulse duration and frequency of the output of the flashlamp.

Microorganisms encompass a wide variety of unique structures. Due to variations in the absorbing molecules, reactions that occur between absorbing molecules at excited states and adjacent molecules depend on the specificity of the system

under investigation. The elucidations of the actual sequence of events involved in the observed results attributed to the application of pulsed light effects are complex.

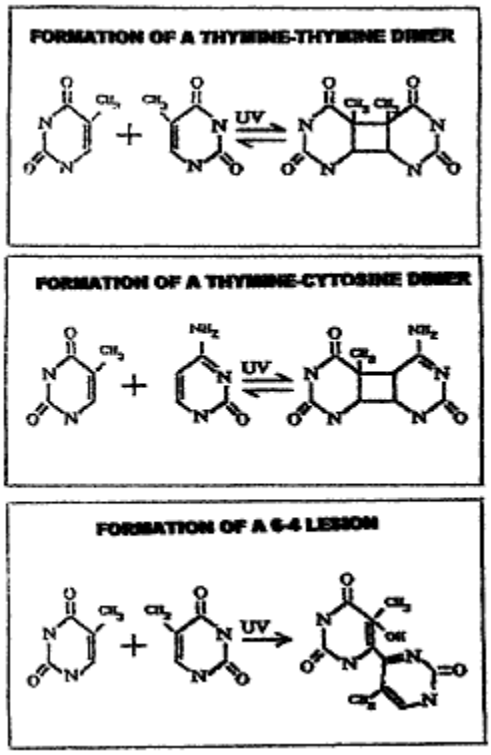


Figure 6: Formation of Dimers and 6-4 Lesions after UV Exposure

Biological effects produced by the photochemical and photophysical changes in the UV exposure of deoxyribonucleic acid (DNA), ribonucleic acid (RNA) and proteins have been investigated by both continuous and pulsed light sources. The primary process in sterilization of microorganisms is by changes in the genetic material. Inactivation occurs by several mechanisms including chemical modification and cleavage of the DNA. Large doses of UV may kill a cell outright by creating too much damage in its DNA.

Ultraviolet photons of different energies have various effects on DNA. One severe consequence of exposure at specific wavelengths by macromolecules is the dissipation of the absorbed energy via photochemical reactions and damage of the genetic information. DNA damage caused by UV exposure includes the formation of pyrimidine dimers and (6-4) photoproducts. Without sufficient repair mechanisms, these damages result in mutations, impairment of replication and gene transcription, and finally in the death of the organism. Other types of base damage may also occur, but they are not as biologically important as the most prevalent dimers or 6-4 lesions.

Cells of all types have evolved mechanisms for repairing DNA damage. Photo reactivation uses visible light as an energy source to “undimerize” pyrimidine dimers. If the change (mutation or recombination) alters an important gene, the cell may die even though the dimers were repaired.

Conventional continuous UV exposure primarily affects DNA by mechanisms that are reversible under certain conditions. Pulsed UV radiation, however, with the ability to adjust the required light intensity, pulse duration and number of pulses leads to ultimate genetic destruction of various microorganisms.

Surface Sanitization

In recent laboratory tests performed by Abraham L. Sonenshein, PhD, Department of Molecular Biology and Microbiology, Tufts University School of Medicine (USA), the high peak energies of pulsed UV light proved to be effective in the destruction of anthrax surrogate spores.

Test Procedure: Bacterial endospores of the type produced by *Bacillus* and *Clostridium* species are known to be highly resistant to various forms of radiation and other physical and chemical agents. The high peak power of pulsed ultraviolet light was suspected to overcome such resistance and to kill spores efficiently. To test this hypothesis, samples of *Bacillus subtilis* spores were irradiated and the loss of viability was measured as function of UV dose and position with respect to the axis of the UV flashlamp. With spore suspensions at 1×10^9 (sample A1), 1×10^8 (sample B1) and 1×10^7 (sample C1) spores per ml, it was possible to completely eliminate viability with three pulses of UV light, in less than one second, as shown in Figure 7.

Test conclusion: Pulsed UV light is an effective device for reducing the viability of Bacillus subtilis spores in suspension. Killing is rapid (under 1 second) and reduces viability by a significant factor – 100,000-fold with three pulses for the most concentrated sample (A1). It is reasonable to assume that the method described here would give similar results in applications requiring surface sanitization.

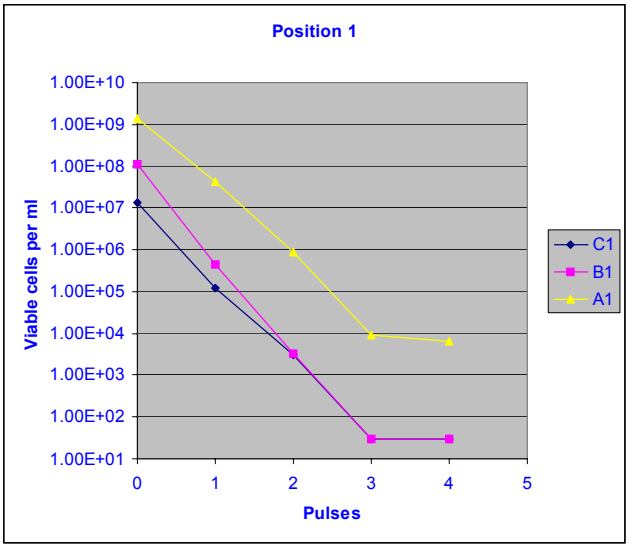
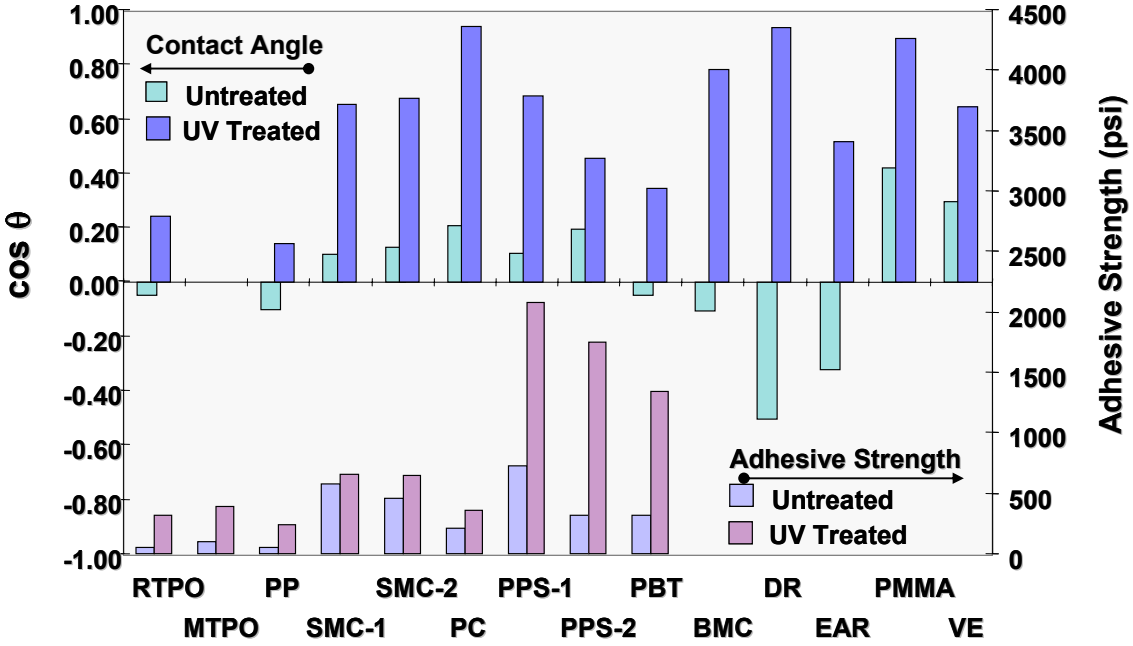


Figure 7: Viability of *bacillus subtillus* spore samples A1, B1 and C1 when located on the flashlamp axis and at the mid point of the flashlamp (Figure provided by Abraham L. Sonenshein, PhD)

Non-Contact Surface Treatment

Pulsed UV can be used as a non-contact polymer and metal surface treatment, as reported by Prof. Lawrence T. Drzal, Composite Materials & Structures Center, Dept. of Chemical Engineering and Materials Science, Michigan State University (USA).

Paint and adhesive performance depends on the quality (cleanliness and surface energy) of the substrate (adherent) surface. Disadvantages of existing surface pretreatment methods like plasma, flame, corona, and solvent washing are labor intensive, time consuming, damage to the adherent surface, and emission of volatile organic compounds. Many polymers used as matrices for polymer composites are being investigated. Figure 8 obtained at MSU within the past year with a wide range of thermoset and thermoplastic polymers illustrates the significant improvements in surface energy that can be obtained and that have resulted in better wetting of plastic surfaces by adhesives and coatings, and substantial increase in adhesion of UV treated surfaces as measured by a tensile butt test to an epoxy matrix. Polymers investigated have included thermoplastic as well as thermoset matrices. Although this group of polymeric matrices represents some of the materials commonly used in industry (TPO, Polypropylene, Polyester, Polycarbonate, Poly Phenylene Sulfide, Poly methylmethacrylate and vinyl ester), the breadth of applicability of this pulsed UV treated method indicates that it has a high potential of being very useful with other materials as well.



- Thermoplastic polyolefin (TPO)
  - Reactor Grade (RTPO)
  - Mechanical grade (MTPO)
- Sheet molding compound (SMC)
  - Regular (SMC1)
  - Toughened (SMC2)
- Polyphenylene Sulphide (PPS)
  - White (PPS1)
  - Black (PPS2)
- Polypropylene (PP)
- Polybutylene terephthalate (PBT)
- Bulk Molding Compound (BMC)
- Diene rubber (DR)
- Ethylene Acrylic Rubber (EAR)
- Polymethyl methacrylate (PMMA)
- Vinyl Ester (VE)
- Polycarbonate (PC)
- Bexloy (Ionomer) Composite

Figure 8: Samples treated with pulsed UV (Figure provided by Prof. Lawrence T. Drzal)

A model including the important parameters of this UV surface treatment and comparison of methods are shown in Figures 9 and 10 respectively. The flexibility of pulse light delivery to the substrate (i.e., pulse recurrence frequency, pulse duration, and spectrum) brings “tuning” possibilities to various substrates. Pulsed UV meets the need for a continuous, environmentally benign, fast, cost effective and non-contact surface preparation process.

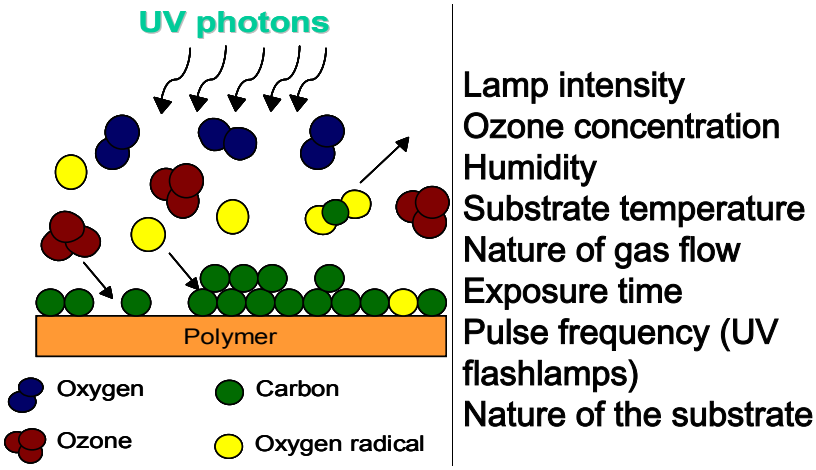


Figure 9: Parameters for surface treatment process model. (Figure provided by Prof Lawrence T. Drzal)

	Conventional Surface Treatments (Flame, Corona, Plasma, Chemical)	UV Surface Treatment
Current Status	Flame, Corona and Chemical Wash are mainstream surface treatment technologies. Plasma - limited acceptance.	Developing technology - Equipment manufacturing base exists.
Environmental Impact	Chemical – VOC emission, waste disposal. Corona – High levels of ozone produced. Flame – Greenhouse gases, organic fuels.	Very low levels of ozone produced in contained environment.
Ability to Treat Complex Geometries	Flame, Corona and Plasma Treatments have severe limitations in treating complex geometries.	Line-of-sight treatment. Potential to treat complex geometries is excellent.
Treatment Time	Corona, Flame – Very fast treatment times Chemical, Plasma – Moderate treatment times	Fast treatment times (Time scales inversely with lamp power)
Hazards	Chemical – human exposure, waste disposal Corona – very efficient Ozone production	UV protection for humans
Cost	Corona, Flame, Chemical – Inexpensive Plasma – Expensive	Inexpensive
Suitability in Manufacturing Environment	Corona, Flame – Web treatment applications. Removal of process gases required. Chemical – Adverse environmental impact, hazardous. Plasma – Unsuitable for large scales.	Excellent suitability for all applications – flat, complex geometries, large scale. Minimal hazards – UV protection, Removal of low levels of ozone required.

Figure 10: Comparison of conventional surface treatment and pulsed UV. (Figure provided by Prof. Lawrence T. Drzal)

Implantable Medical Device Production

Pulsed UV light technology is easily integrated into an automated manufacturing environment, such as medical device production. One such application requires the complete curing of a lubricious coating on a medical device guide wire involving several curing steps as shown in Figure 11. In another application, capsules containing insulin move at high speed through the manufacturing process. The forward tip of the capsule is cured and the pulsed UV light is immediately stopped to prevent UV exposure to the insulin contained in the main body of the capsule. In both applications, the pulsed UV light results in no unwanted irradiation exposure during the production steps, unlike that which exists with continuous-wave mercury radiation exposure.

Figure 11: A pulsed UV lamp application for curing lubricous coating on medical-device guide wires is integrated into an automated production environment at Guidant Corporation.

Conclusion

The unique properties of pulsed UV light, namely an environmentally benign, non-contact process, high peak power, deep penetration, low substrate temperature, ability to handle complex 3D geometries, and instant on/off control, make it an ideal technology for sanitization and the treatment of polymer and metal surfaces. Applications include hygienic coatings for flat surfaces and medical devices.

References

1. Capobianco, Robert A. Chief Scientist, Xenon Corporation, *UV Curing Equipment for Assembly Applications*, Xenon Application Note AN-103, May 2002
2. L. P. Haack, A. M. Straccia, J. W. Holubka, A. Bhurke, M. Xie, L. T. Drzal, *Chemistry Of Surface Modification With UV/Ozone For Improved Intercoat Adhesion In Multilayered Coating Systems*. Surf. Intrf. Anal., 29, No. 12, pages 829-836, (2000).
3. Lawrence T. Drzal, R. Schalek, P. Askeland, M. Rich, A. Bhurke And P. Tummala, *Ultraviolet Light Surface Treatment Of Polymers, Composite And Metals As An Environmentally Benign Surface Preparation*, International Sampe Technical Conference, Seattle, WA, November 4-8, 2001
4. Panico, L.R. *UV Curing Equipment for Assembly Applications*, RadTech 2002, April, 2002
5. Panico, L.R. *Pulsed Light Sterilization of Drug and Drug Products*, Louis R. Panico, June 2001
6. Panico, L.R. *Pulsed UV Curing for Medical Devices*, Medical Device & Diagnostic Industry, October 1999
7. Panico, L.R. *Pulsed UV Curing Provides User-friendly Solutions to Tough Problems*, Adhesive Age, January 1997
8. Ruggerio, Paul, *Pulsed UV Curing of Photoresist*, Analog Devices, Solid State Technology, 1983
9. Blank, E., *Flash Xenon UV Curing – An Alternative System*, J. Radiation Curing, October 1980
10. Panico, L.R., *Simulating the Sun with Pulsed Light*, 6th Space Simulation Conference, May 1972
11. Marshald, I.S., et al., *New Flashtubes*, Uspekly Naoteshnoy, Photographic 6:48:1959