

Ultraviolet Sources

Related terms:

White Dwarf, Lithography, Electrons, Luminescence, Photoelectrons, Photons, Droplet, Irradiation, X Ray

Introduction to Coatings Technology

Reinhold Schwalm, in UV Coatings, 2007

1.3 UV TECHNOLOGY AND APPLICATIONS

UV curing has now been established as an alternative curing mechanism to thermal hardening, contrary to the past, where it was only considered for the curing on temperature sensitive substrates, like wood, paper and plastics. This alternative curing technology uses the energy of photons of radiation sources in the short wavelength region of the <u>electromagnetic spectrum</u> in order to form reactive species, which trigger a fast chain growth curing reaction.

Out of the electromagnetic spectrum (shown in Figure 1.5 is the range from the near-infrared (NIR), over visible and ultraviolet (UV) to <u>electron beams</u> and X-ray) the UV region, further classified into UV-A, UV-B, and UV-C radiation, is mainly used for this technology.



FIG. 1.5. Electromagnetic energy spectrum.

The energy content of a photon is defined by the equation

$E = hv = hc/\lambda$,

where ν is the frequency and λ is the wavelength (nm). This equation tells us, that the shorter the wavelength, the higher the energy of a photon. UV light in the wavelength region of 300–400 nm should already be able to cleave C-C bonds. The high energy photons of e-beam and X-ray are sufficient to cleave C-C or C-H bonds, thus, they do not need a special photoinitiator for forming the desired radical species as initiators for <u>polymerization</u>. In the case of UV exposure, however, photoinitiators are commonly used, since the direct <u>cleavage</u> processes are not efficient enough. The photoinitiators are excited and after a cascade of reactions form the desired reactive species. In the case of using longer wavelength exposures, more complicated energy transfer reactions are needed.

From the spectrum of usable radiation energy sources, UV technology is by far the most common one. From the higher energy radiation sources, e-beam technology has been widely explored for <u>coatings technologies</u>. It is still the most economical

technology for industrial applications with very high volumes. However, the high safety requirements related to the use of e-beam technology and the high investment costs hamper the widespread use of this technology. At the RadTech Conference 2005 in Barcelona, considerable interest has been expressed in the session dealing with e-beam technology for "printing, varnishing and laminating for the packaging industry".¹⁰ The reasons for this alertness are new developments of compact and less expensive EB equipment and new formulation advances in flexographic printing inks, coatings and adhesives. Especially in the packaging printing for food contact applications the use of EB technology has advantages over UV coatings since no photoinitiator is needed, which can migrate, if the coating is inadequately cured.



FIG. 1.6. Energies as a function of wavelenght in comparison to bond energies.

As can be seen from the few application examples shown in Figure 1.7, UV curable coatings are traditionally used on temperature sensitive substrates, like wood, paper and plastics, for example, clear coats for parquet, furniture, vinyl flooring, on plastic substrates (crash helmet, boards), compact discs, headlight lenses or overprint varnishes (posters, high gloss packaging). However, since coatings are used almost everywhere, the UV coatings market is expanding to new applications, where traditionally thermal curing systems have been the workhorses. Applications like UV curable coatings on metals (automotive, coil coating) and exterior uses on windows, on glass, bikes, on appliances, like refrigerators, washing machines, and most prominently on cars are good examples. A multiplicity of coating applications is often less noticed, such as adhesives and <u>protective coatings</u> for DVD and CD's, protective coating on glass fiber wires, inside and outside of beverage cans, on automotive parts, like headlight mirrors and in multiple functions on electronic parts. This list can easily be extended even further.



FIG. 1.7. UV coatings - from traditional to new applications.

Up to now, UV curable systems are mainly used in clear coat applications, thus posing high demands on the performance of this layer; at the surface of the coating it is exposed to attack by mechanical or chemical stresses, like scratches, household chemicals (detergents, red wine, coffee, mustard), by air polluents (acids, water, bird excrements) as well as stone chipping or many other impacts. The formulations used for radiation curable coatings depend therefore on the specific performance requirements and on the application technique. The traditional formulations of UV curable coatings are still 100% liquids (or also commonly referred to 100% solids, despite used in liquid form, in order to point out that they contain no solvents or other volatiles). However, in the meantime, due to the consideration of UV curing as an alternative to thermal hardening, the use of small amounts of solvents in order to reduce the viscosity, the formulation of UV curable water-based systems and the development of UV powder have been pursued.

The market penetration of UV coatings is up to now still regarded as a niche technology. This is due to several factors, one decisive reason is based on the curing technology itself, which is still stamped as a two-dimensional curing process, in which only planar substrates are feasible. Up to now there are only few applications involving three-dimensional objects.

As shown schematically in the diagram of Figure 1.8, the application processing is mainly based on industrial applications on two-dimensional substrates. The substrate is first coated, exemplarily shown is a casting line, and then passed under lamp units, where it is exposed to intense radiation. Within a fraction of a second, the liquid low molecular mass is thereby transferred via a photo-induced <u>radical</u> <u>polymerization</u> to a solid crosslinked network. After the end of the line, the fully cured and dry substrate can be stacked and further processed immediately.



FIG. 1.8. Scheme of the UV curing process and UV induced cross-linking.

Typical compositions of UV curable coatings (Table 1.5) contain in the range of 25% to 90% oligomeric resins, which are responsible for the film formation and the basic coating properties. Reactive diluents are <u>low molecular weight</u> compounds, which are incorporated into the <u>polymer network</u>, and used instead of solvents (in conventional lacquers) in order to adjust the viscosity to the requirements of the application process. Typical application viscosities range from 3000–5000 MPa s (Pascal × second) for roller application to 100– 200 mPa s for spray applications. In UV curable lacquers, about 1–8% photoinitiators, as well as several other additives (from 1% up to 50%), like leveling agents, <u>stabilizers</u>, UV absorbers, radical scavengers, pigments and so on, are used to tailor the formulation to the application process and coating property requirements.

TABLE 1.5. General composition and function of an UV lacquer

Component	Share (%)	Function
Oligomeric resin	25–90	Film formation Basic properties
Reactive diluents	15–60	Viscosity adjustment X-link density
Photoinitiator	1-8	Initiation
Additives	1–50	Surfactants, pigments, fillers, stabilizers, etc.

This general composition of UV curable coatings applies to radically polymerizable coatings as well as to cationically curable systems and EB curable coating, which, however, do not need photoinitiators.

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URL: https://www.sciencedirect.com/science/article/pii/B9780444529794500019

Light Sources

Graeme G. Lister, John F. Waymouth, in <u>Encyclopedia of Physical Science and</u> <u>Technology (Third Edition)</u>, 2003

IX.C Dielectric Barrier Discharge lamps

<u>Dielectric barrier discharges</u> are finding increasing applications as UV sources. Recently, OSRAM introduced a new lamp (PLANON) based on this principle which, through pulsed excitation, has achieved an efficiency of 60% conversion from electrical power to VUV xenon <u>excimer</u> radiation. The lamp is filled with 100 torr xenon and is extremely thin (~10 mm) with large surface area (~800 cm²).

The <u>dielectric</u> barrier discharge is a <u>nonthermal plasma</u> in which the <u>EEDF</u> is very far from <u>LTE</u>. A dielectric coating covers at least one <u>electrode</u> to limit the electron current. The discharge is filled with high-current density (100–1000 A cm⁻²) micro-discharges of radii ~0.1 mm. The duty cycle of the voltage pulse must be adjusted to minimize electron density (and hence the high-energy tail of the EEDF) while maximizing the production of metastable Xe* atoms. The <u>metastable atoms</u> then combine with ground-state Xe in a three-body interaction to produce the Xe*₂ excimer which has a broad band emission centered at 172 nm.

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URL: https://www.sciencedirect.com/science/article/pii/B0122274105003781

LASERS | Excimer Lasers

J.J. Ewing, in Encyclopedia of Modern Optics, 2005

Background: Why Excimer Lasers?

Excimer lasers have become the most widely used source of moderate power pulsed ultraviolet sources in laser applications. The range of manufacturing applications is also large. Production of computer chips, using excimer lasers as the illumination source for lithography, has by far the largest commercial manufacturing impact. In the medical arena, excimer lasers are used extensively in what is becoming one of the world's most common surgical procedures, the reshaping of the lens to correct vision problems. Taken together, the annual production rate for these lasers is a relatively modest number compared to the production of semiconductor lasers. Current markets are in the range of \$0.4 billion per year (Figure 1). More importantly, the unique wavelength, power, and pulse energy properties of the excimer laser enable a systems and medical procedure market, based on the excimer laser, to exceed \$3 billion per year. The current average sales price for these lasers is in the range of \$250 000 per unit, driven primarily by the production costs and reliability requirements of the lasers for lithography for chip manufacture. Relative to semiconductor diode lasers, excimer lasers have always been, and will continue to be, more expensive per unit device by a factor of order 10⁴. UV power and pulse energy, however, are considerably higher.

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Excimer laser sales revenue



Figure 1. The sales of excimer lasers have always been measured in small numbers relative to other, less-expensive lasers. For many years since their commercial release in 1976 the sales were to R&D workers in chemistry, physics and ultimately biology and medicine. The market for these specialty but most useful R&D lasers was set to fit within a typical researcher's annual capital budget, i.e., less than \$100K. As applications and procedures were developed and certified or approved, sales and average unit sales price increased considerably. Reliance on cyclical markets like semiconductor fabrication led to significant variations in production rates and annual revenues as can be seen.

The fundamental properties of these lasers enable the photochemical and photophysical processes used in manufacturing and medicine. Short pulses of UV light can photo-ablate materials, being of use in medicine and <u>micromachining</u>. <u>Short wavelengths</u> enable photochemical processes. The ability to provide a narrow <u>linewidth</u> using appropriate resonators enables precise optical processes, such as lithography. We trace out some of the core underlying properties of these lasers that lead to the core utility. We also discuss the technological problems and solutions that have evolved to make these lasers so useful.

The data in Figure 1 provide a current answer to the question of 'why excimer lasers?' At the dawn of the excimer era, the answer to this question was quite different. In the early 1970s, there were no powerful short wavelength lasers, although <u>IR lasers</u> were being scaled up to significant power levels. However, visible or <u>UV lasers</u> could in principle provide better propagation and focus to a very small spot size at large distances. <u>Solid state lasers</u> of the time offered very limited <u>pulse repetition frequency</u> and low efficiency. Diode pumping of solid state lasers, and <u>diode arrays</u> to excite such lasers, was a far removed development effort. As such, short-wavelength lasers were researched over a wide range of potential media and <u>lasing wavelengths</u>. The excimer concept was one of those candidates.

We provide, in Figure 2, a 'positioning' map showing the range of laser parameters that can be obtained with commercial or developmental excimer lasers. The map has coordinates of pulse energy and pulse rate, with diagonal lines expressing average power. We show where both development goals and current markets lay in a map. Current applications are shown by the boxes in the lower right-hand corner. Excimer lasers have been built with clear apertures in the range of a fraction of 0.1 to 10^4 cm², with single pulse energies covering a range of 10^7 . Lasers with large apertures require <u>electron beam</u> excitation. Discharge lasers correspond to the more modest pulse energy used for current applications. In general, for energies lower than ~5 J, the <u>excitation method</u> of choice is a self-sustained discharge, clearly providing growth potential for future uses, if required.



Figure 2. The typical energy and pulse rate for certain applications and technologies using excimer lasers. For energy under a few J, a discharge laser is used. The earliest excimer discharge lasers were derivatives of CO_2 TEA (transversely excited atmospheric pressure) and produced pulse energy in the range of 100 mJ per pulse. Pulse rates of order 30 Hz were all that the early pulsed power technology could provide. Early research focused on generating high energy. Current markets are at modest UV pulse energy and high pulse rates for lithography and low pulse rates for medical applications.

The applications envisaged in the early R&D days were in much higher energy uses, such as in laser weapons, laser fusion, and <u>laser isotope separation</u>. The perceived need for lasers for isotope separation, laser-induced chemistry, and bluegreen laser-based communications from satellites, drove research in high pulse rate technology and reliability extension for discharge lasers. This research resulted in prototypes, with typical performance ranges as noted on the positioning map that well exceed current market requirements. However, the technology and underlying media physics developed in these early years made possible advances needed to serve the ultimate real market applications.

The very important application of <u>UV lithography</u> requires high pulse rates and high reliability. These two features differentiate the excimer laser used for lithography from the one used in the <u>research laboratory</u>. High pulse rates, over 2000 Hz in current practice, and the cost of stopping a computer chip production line for servicing, drive the reliability requirements toward 10¹⁰ shots per service interval. In contrast, the typical laboratory experiments are more often in the range of 100 Hz and, unlike a lithography production line, do not run 24 hours a day, 7 days a week. The other large market currently is in laser correction of <u>myopia</u> and other imperfections in the human eye. For this use the lasers are more akin to the commercial R&D style laser in terms of pulse rate and single pulse energy. Not that many shots are needed to ablate tissue to make the needed correction, and shot life is a straightforward requirement. However, the integration of these lasers into a certified and accepted medical procedure and an overall medical instrument drove the growth of this market.

The excimer concept, and the core technology used to excite these lasers, is applicable over a broad range of UV wavelengths, with utility at specific wavelength ranges from 351 nm in the near UV to 157 nm in the vacuum UV (VUV). There were many potential excimer candidates in the early R&D phase (Table 1). Some of these candidates can be highly efficient, >50% relative to deposited energy, at converting electrical power into UV or visible emission, and have found a parallel utility as sources for lamps, though with differing power <u>deposition rates</u> and configurations. The key point in the table is that these lasers are powerful and useful sources at very short wavelengths. For lithography, the wavelength of interest has consistently shifted to shorter and shorter wavelengths as the printed

feature size decreased. Though numerous candidates were pursued, as shown in Table 1, the most useful lasers are those using <u>rare gas halide</u> molecules. These lasers are augmented by <u>dye laser</u> and Raman shifting to provide a wealth of useful wavelengths in the visible and UV.

Table 1. Key excimer wavelengths

Excimer emitter	λ (nm)	Comment
Ar ₂	126	Very short emission wavelength, deep in the Vacuum UV; inefficient as laser due to absorption, see Xe ₂ .
Kr ₂	146	Broad band emitter and early excimer laser with low laser efficiency. Very efficient converter of electric power into Vacuum UV light.
F ₂	157	Molecule itself is not an excimer, but uses lower level dissociation; candidate for next generation lithography.
Xe ₂	172	The first demonstrated excimer laser. Very efficient formation and emission but excited state absorption limits laser efficiency. Highly efficient as a lamp.
ArF	193	Workhorse for corneal surgery and lithography.
KrCl	222	Too weak compared to KrF and not as short a wavelength as ArF.
KrF	248	Best intrinsic laser efficiency; numerous early applications but found major market in lithography. Significant use in other materials processing.
Xel	254	Never a laser, but high formation efficiency and excellent for a lamp. Historically the first rare gas halide excimer whose emission was studied at high pressure.
XeBr	282	First rare gas halide to be shown as a laser; inefficient laser due to excited state absorption, but excellent fluorescent emitter; a choice for lamps.
Br ₂	292	Another halogen molecule with excimer like transitions that has lased but had no practical use.
XeCl	308	Optimum medium for laser discharge excitation.
Hg ₂	335	Hg vapor is very efficiently excited in discharges and forms excimers at high pressure. Subject of much early research, but as in the case of the rare gas excimers such as Xe_2 suffer from excited state absorption. Despite the high formation efficiency, this excimer was never made to lase.
I ₂	342	lodine UV molecular emission and lasing was first of the pure halogen excimer-like lasers demonstrated. This species served as kinetic prototype for the F_2 'honorary' excimer that has important use as a practical VUV source.
XeF	351, 353	This excimer laser transition terminates on a weakly bound lower level that dissociates rapidly, especially when heated. The focus for early defense-related laser development; as this wavelength propagates best of this class in the atmosphere.
XeF	480	This very broadband emission of XeF terminates on a different lower level than the UV band. Not as easily excited in a practical system, so has not had significant usage.

Excimer emitter	λ (nm)	Comment
HgBr	502	A very efficient green laser that has many of the same kinetic features of the rare gas halide excimer lasers. But the need for moderately high temperature for the needed vapor pressure made this laser less than attractive for UV operation.
XeO	540	This is an excimer-like molecular transition on the side of the auroral lines of the O atom. The optical cross-section is quite low and as a result the laser never matured in practice.

All excimer lasers utilize molecular dissociation to remove the lower laser level population. This lower level dissociation is typically from an unbound or very weakly bound ground-state molecule. However, <u>halogen</u> molecules also provide laser action on excimer-like transitions, that terminate on a molecular excited state that dissociates quickly. The vacuum UV transition in F_2 is the most practical method for making very short wavelength laser light at significant power. Historically, the rare gas dimer molecules, such as Xe₂, were the first to show excimer laser action, although self absorption, low gain, and poor optics in the VUV limited their utility. Other excimer-like species, such as metal <u>halides</u>, metal rare gas <u>continua</u> on the edge of metal atom <u>resonance lines</u>, and rare gas oxides were also studied. The key <u>differentiators</u> of rare gas halides from other excimer-like candidates are strong binding in the excited state, lack of self absorption, and relatively high optical cross-section for the laser transition.

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URL: https://www.sciencedirect.com/science/article/pii/B0123693950008460

Ozone Measurements and Trends (Troposphere)

Johannes Staehelin, in <u>Encyclopedia of Physical Science and Technology (Third</u> <u>Edition</u>), 2003

IV.B.1 Open Path UV-Absorption Spectrophotometry (Including DOAS)

In the open path absorption method ozone in ambient air is measured by its absorption in the UV. A UV-source with known intensities at different wavelengths provides the source of the UV-light and a receiver allows one to measure the decrease of the light at the respective wavelengths when the <u>light beam</u> passes through the air. The distance between the light source and the receiver varies between a few hundred meters to several kilometers. Measurements have to be performed at different wavelengths in order to attribute the absorption to ozone since other substances including aerosol particles also absorb UV-light in the atmosphere. This method was used for reliable surface ozone measurements since 1918. At Arosa (Switzerland) ozone near the surface was measured in the 1930s by using measurements at 8 to 18 wavelengths which extended from 248 to 303 nm. However, such measurements could only be made during the nights and the determination of the ozone concentration was rather time consuming.

The ozone spectrum exhibits distinct <u>fine structures</u> with several maxima and minima in the UV (260 to 350 nm) and in the visible which can be used to measure ozone by differential optical absorption spectroscopy (DOAS). The light source is a Xenon high-pressure lamp which <u>emits light</u> from 200 to 700 nm. A fast <u>rotating</u> <u>disk</u> allows one to measure the received light by a <u>photomultiplier</u> with very high resolution in time and wavelength. The high time resolution is required to eliminate the influence of changes in the trace gas concentrations caused by turbulence, whereas the high optical resolution (less than half of 1 nm) allows one to identify and to quantify the concentrations of the trace gases. Ozone measurements are performed, e.g., in the wavelength region around 335 or 425 nm and the high wavelength resolution allows one to separate the absorption of ozone from other compounds in ambient air which include SO₂, NO, and NO₂.

The averaged ozone concentration over the light pass is calculated based on its absorption spectrum.

<u>DOAS</u> instruments are commercially available. In the absence of large spatial gradients the results of DOAS measurements (averages over the light path) yield equivalent results to the *in-situ* UV-method.

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URL: https://www.sciencedirect.com/science/article/pii/B0122274105000375

Radiation Sources and Detectors

H. Mizoguchi, J. Fujimoto, in Comprehensive Biomedical Physics, 2014

8.08.5 Future Development Plan

The roadmap for the Gigaphoton LPP-EUV light source is shown in **Figure 27**. After ETS development, we have been developing the first HVM EUV source (250 W clean power). It will be released in 2012. After GL200E, we will develop a 350 W system, known as GL200E +, with upgrades from the GL200E configuration. In the following years, we will develop a 500 W system, named GL400E, for higher throughput of scanners. Our plan is heavily dependent on advances in lithography tool technology (Wagner et al., 2010).



EUV model		ETS	GL200E	GL200E+	GL400E
Drive laser power	kW	10	23	33	40
Conversion efficiency	%	3.0	5.0	5.0	6.0
C1 mirror collector angle	sr	5.5	5.5	5.5	5.5
efficiency*	%	74	74	74	74
C1 mirror reflectivity	%	(50)	57	57	57
Optical transmission	%	95	95	95	95
SPF (IR, DUV)	%	N/A**	62	62	62
Total EUV power (after SP)	W	100	250	350	500

Figure 27. Roadmap of Gigaphoton's LPP-EUV light source.

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URL: https://www.sciencedirect.com/science/article/pii/B9780444536327006080

The ultraviolet and fluorescence study of paintings and manuscripts.

Franz Mairinger, in Radiation in Art and Archeometry, 2000

4 FILTERS

In reflected ultraviolet and fluorescence photography two different types of filtration are applied.

 Filters with a high percentage <u>transmittance</u> of long wave ultraviolet and no visible light transmittance. This type is known as *exciter filter*. They are used either in front of UV sources to remove the visible components, when recording the

visible fluorescence or for (reflected) UV photography in front of the camera lenses to block out the visible light. In this case the filter must be optically polished.

 Filters which transmit visible fluorescence and remove any residual reflected or scattered UV radiation, which would also affect the <u>photographic emulsions</u>. They are called (UV-) barrier filters.

Occasionally other filters, such as colour compensating or conversion filters, are used in combination with barrier filters. They are especially helpful when colour films are exposed or in case of black-and-white films to enhance contrast between colours of similar or equal brightness.

4.1 Exciter Filters

The most common exciter filter, used with the radiation source, are made of Woods' glass, whose exact composition varies. It is a special barium-sodiumsilicate glass, which is tinted with about 9 % nickel oxide, their transmittance is limited to long wave UV region. This is not a disadvantage in UV photography since the transmittance of camera lenses is also limited to this region. There are no gelatine filter suitable for this type of filtration.

For some fluorescence applications (e. g. minerals) medium wave and short wave <u>ultraviolet radiation</u> is necessary for excitation, than tinted quartz filters must be used. Some UV sources include exciter filters, attached to the lamp house or incorporated in the (tinted) glass envelope (Philips HPW or TL types). There are several manufacturers for this type of filters. Data of some of these species are given in Table 1.

Table 1. UV Exciter Filters

Manufacturer	Designation	Transmission range (nm)	Remarks
Kodak	18 A (2 mm)	310-400	Transmits Infrared
Corning Glass #5840	CS 7–60 (2 mm)	310-400	
Corning Glas 9863	CS 7–54 (5mm)	250 – 380	
Schott	UG 1 (2mm)	310-400	Transmits infrared
Schott	UG 5	240–480	Transmits infrared

As can be seen in Figure 4, most of the filters have also a high transmittance in the infrared region. This fact is of importance only, if infrared sensitive films are used.



Figure 4. Transmittance of Schott UG 1 exciter filter (2mm)

4.2 Barrier filter

The exciter filter transmits the radiation, which excites fluorescence, but not all of this radiation is used up in this process. There will be an appreciable amount, which is reflected, transmitted or scattered by the object. Since the brightness of fluorescence is usually very low, this residual radiation will cause more exposure than the fluorescence, this would degrade fluorescence recording. So in front of the camera lens a filter must be used, which acts by absorption as a barrier to the UV radiation.

So a barrier filter must absorb all radiation transmitted by the exciter filter and transmits only the wavelengths of the generated fluorescent light. If the exciter filter passes UV and some of the short visual blue (up to 420 nm), then the barrier filter must absorb in this region also.

The *selection* of a suitable *barrier filter* depends not only on the spectral distribution of the exciting radiation, but also upon the wavelengths of the fluorescent light. This is only a problem, when the object exhibits a blue fluorescence, which is the same or near to the wavelength of blue light transmitted by the exciter filter. In this case either the exciter filter must be substituted by a filter, which has no blue transmittance or when the wavelength of the fluorescence light is longer than the transmitted blue, than a barrier filter of the interference type (long pass filter) can be used.

If no fluorescence in the blue region occurs or the blue fluorescence should be suppressed, the selection of filters is very simple, any of the (cheap) yellow gelatine filter which absorb UV can be used (e. g. Wratten gelatine filters Nos. 9, 12, 15). These filters transmit freely green, yellow, orange and red. If the fluorescence occurs in the infrared region, the Wratten filter No. 87 is an effective barrier filter. For this purpose an infrared sensitive film must be used.

An other difficulty may arise from the fact, that some of these filters show a bright fluorescence, they seem to glow when irradiated with UV. This would lead to a severe degradation of the fluorescence record. To avoid that, a filter which absorbs only UV (e. g. Wratten 2A or 2B) is placed in front of yellow filter.

It should also be kept in mind, that the dyes used for gelatine UV filters are not very stable, so the filters should be replaced from time to time.

In Table 2 the data of some barrier filters with different absorption edges are summarised.

Table 2. Data of UV Barrier Filters

Manufacturer	Designation	Transmission starts at nm	Remarks
Kodak	Wratten 2B	395	Pale Yellow
Kodak	Wratten 2A	410	Pale Yellow
Kodak	Wratten 2E	420	Pale Yellow

Manufacturer	Designation	Transmission starts at nm	Remarks
Kodak	Wratten 9	480	Yellow
Kodak	Wratten 12	510	Deep Yellow
Schott	GG 420	420	Pale Yellow (Glass)
Schott	GG 495	495	Yellow
Schott	LP 400	400	Interference filter
Schott	LP 430	430	

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RESONANT GAS MEDIA FOR OPTICAL PHASE CONJUGATION

M. DUCLOY, ... D. BLOCH, in Laser Spectroscopy, 1989

IV. EXTENSION TO THE UV RANGE

Extending nonlinear optics from the IR and visible domain to the ultraviolet (UV) range is a task of importance justified by various interests. It lowers the diffraction limit, which can be important for image processing. Shorter wavelengths also considerably increase the efficiency of photochemical processes or photoablation in material processing. In laser induced fusion, shorter optical wavelengths are also of considerable importance, and the intense, but aberrated laser pulses can be in principle optically restored thanks to OPC. However, extension to the UV range is often made difficult by the lack of convenient UV sources, and by <u>absorption bands</u> of dense nonlinear materials. In the deep UV range, it is well-known that only gas media, which are transparent but in the vicinity of an atomic absorption line, can be used for frequency up-conversion to the VUV region.

In a recent work [14] we have operated the first c.w. phase conjugator in the UV region. FWM emission has been observed from Mg vapor irradiated with a laser tuned to the ${}^{1}S_{0} - {}^{1}P_{1}$ resonance line (λ =285 nm). The UV source is an intracavity frequency-doubled single-mode actively stabilized tunable dye laser delivering up to 8 mW. The Mg resonance line was chosen because Mg vapor requires moderate heating $[T = 280^{\circ}C \text{ for } 5.10^{10} \text{ atoms/cm}^3]$ and because of the absence of hyperfine optical pumping. Up to now, the PC reflectivity has remained low ($R_{PC} \le 10^{-6}$) essentially because it is hard to saturate a broad resonance line (Γ =85 MHZ) with a 8 mW source. Indeed, the estimated saturation parameter does not exceed 5.10^{-3} . Along the same principles for optimization as developped for <u>Cs</u> vapor, higher Mg density and a re-designed and shorter cell would be necessary, and stronger beam focusing could help to reach a better efficiency. However, even for comparable intensities, the expected efficiency on Mg remains lower than on Na (and a fortiori, than on Cs) as shown by the γ/λ^3 efficiency factor. This illustrates the specific difficulty of nonlinear processes in the UV originating from the λ^{-3} dependence of stimulated emission processes.

Although the efficiency remains weak, this first demonstration is very encouraging because the main limit is due to the low power of the source, and because the wavelength is already in the absorption band of most nonlinear crystals. In the pulsed regime (frequency-doubled pulsed <u>dye lasers</u> or new solid state sources [15]), remarkable reflectivities should be expected. An exciting development, which seems attainable in the near future, would be to perform OPC in the VUV region [16]. Rare gases or H whose <u>resonance lines</u> are reachable with tunable coherent sources (Xe: 147 nm; Kr: 124 nm; H: 121,5nm) would be good candidates for such demonstrations.

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III-Nitride Semiconductor Optoelectronics

M.H. Crawford, in Semiconductors and Semimetals, 2017

1 Introduction

AlGaN alloys have emerged as the most promising compound semiconductors for DUV optoelectronics given band gaps that can be tuned over an impressively wide range of the UV spectrum (~ 363–200 nm). With desirable properties including low size, weight, and operating power, AlGaN-based UV devices have the potential to replace traditional UV sources such as Hg lamps in applications ranging from water purification to fluorescence-based bioagent sensing. However, many AlGaN materials properties are far from ideal. In Fig. 1, we present a generic design for AlGaN-based UV emitters and highlight some of the materials challenges to achieving high-performance <u>light-emitting diodes</u> (LEDs) and laser diodes (LDs). This review focuses on two challenges that are largely responsible for the poor performance of AlGaN UV emitters relative to InGaN visible light emitters: doping and substrate challenges. For each of these material challenges, we present the state of the art and exploratory concepts for overcoming these challenges and enabling higher performance UV devices.





The focus on doping and substrate challenges necessarily omits other topics of interest. In particular, point defects in AlGaN alloys and related impact on radiative efficiency (Chichibu et al., 2011), bandstructure limitations to light extraction (Nam et al., 2004; Wierer et al., 2014), and optical gain (Chow and Kneissl, 2005) are found in the provided references. In addition, an excellent recent review on III-Nitride ultraviolet emitters (Kneissl and Rass, 2016) is recommended.

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Optical Fiber Techniques for Medical Applications

Abraham Katzir, in <u>Encyclopedia of Physical Science and Technology (Third</u> <u>Edition</u>), 2003

VII.F Cancer Diagnoses and Photochemotherapy

It has been known since the 1940s that certain compounds, called <u>porphyrins</u>, are preferentially concentrated in malignant tumors, with respect to healthy tissue. Porphyrin fluoresces under UV excitation, and therefore by illuminating tissue, one may distinguish malignant tumors from benign tissue. In the 1960s, a compound called <u>hematoporphyrin</u> derivative (HPD) was found to have even better <u>properties</u> than porphyrin. HPD and other compounds are now used for cancer diagnosis and therapy. This method is based on three interesting properties of these compounds:

- 1. *Selective retention:* In practice, HPD may be injected into a patient, and after a few days this dye concentrates only in cancer tissue.
- 2. Diagnosis: If a tissue area is now illuminated with a suitable UV source, malignant tissue will emit a characteristic red light. The fluorescence of HPD is mostly in the red part of the spectrum, with two prominent emission peaks at 630 and 690 nm. This fluorescence can be excited by UV or by blue light, but excitation at around 400 nm gives rise to the highest fluorescence. The fluorescence efficiency (emitted red power divided by excitation UV power) is fairly low, and therefore lasers are required for excitation. A krypton laser emitting about 0.25 W at 413 nm is suitable for this application. In order to see this red emission one has to attach to an imaging system an optical filter that transmits at 630 nm and blocks the exciting light at 413 nm.
- 3. <u>Photodynamic therapy</u>: It was found that the use of HPD with lasers could serve not only for diagnosis of cancer but also for <u>therapeutic purposes</u>. If rather than illuminating a tumor with <u>UV light</u>, one uses red light ($\lambda = 630$ nm) of sufficient energy, the results are strikingly different. Red light penetrates deeply into the tissue. HPD absorbs this red light, a series of <u>photochemical reactions</u> occur, and the end result is the release of some photoproduct (probably singlet oxygen), which kills the host malignant tissue. The method itself is called photodynamic therapy (PDT). This is actually photochemotherapy, because it involves the administration of a drug and the use of optical radiation for triggering the process that cures the disease. Roughly 10–50 mW/cm² of red light is needed for this photochemotherapy.

The diagnostic method mentioned in (1) can be readily adapted in endoscopy. A special <u>endoscope</u> could incorporate a quartz fiber for UV illumination and a red transmitting filter in front of the imaging fiberscope. With such an endoscope, tumors inside the body could be irradiated by krypton laser light (or even by a Xe lamp with a UV transmitting filter), and using the red image formed, one could locate malignant tumors. This may be used for early detection of lung cancer, when the malignant tumors are too small to be detected by chest X-ray or by <u>computed tomography</u>.

Photodynamic therapy, mentioned in (2), is also adaptable for use in conjunction with fiberoptic systems. A high-intensity red light can be transmitted through a quartz fiber, and delivered directly inside the tumor. This light may then selectively destroy cancer cells. In the past, a Nd:YAG laser pumped or Ar laser pumped dye laser, emitting at $\lambda = 630$ nm, was used for this purpose. There has also been progress with the development of miniature semiconductor lasers, which emit continuously several watts at 630 nm.

The endoscopic diagnosis and treatment of cancer has been reported in the esophagus, lungs, larynx, prostate, and cervix. Other photosensitive drugs are being tested, including benzoporphyrin derivative and <u>phthalocyanines</u>.

Laser endoscopic photochemotherapy has been proposed for noncancer applications, such as the treatment of age-related degenerate macula. Another example is photodynamic laser angioplasty, which would be used to treat coronary artery disease. Other examples are the treatment of <u>rheumatoid arthritis</u>, in orthopedics, and the treatment of the endometrium, in <u>gynecology</u>. Different photosensitive drugs, such as <u>aminolevulinic acid</u> (ALA) and <u>lutetium texaphyrin</u>, have been also tried for these applications.

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Drinking Water Quality and Treatment

Dan Askenaizer, in <u>Encyclopedia of Physical Science and Technology (Third</u> Edition), 2003

VII.D Ultraviolet (UV) Irradiation Technology

<u>UV light</u> is electromagnetic energy that is located in the <u>electromagnetic spectrum</u> at wavelengths between those of X-rays and visible light. UV light that is effective is destroying microbial entities in located in the 200- to 310- nm range of the <u>energy</u>

<u>spectrum</u>. Most typical applications of UV at <u>water treatment</u> plants apply UV light in the <u>wavelength range</u> of 250 to 270 nm. Most lamps emit UV irradiation by passing an electrical arc between filaments in a pressurized gas or vapor (typically mercury vapor). Ultraviolet dosage is commonly measured as milliWatt-second per <u>square centimeter</u> (mW-s/cm²) or milliJoule per square centimeter (mJ/cm²).

Typically a UV process is designed such that water flows in a narrow region around a series of UV lamps. <u>Microorganisms</u> in water are inactivated through exposure to the UV light. In general, a molecule in the ground state absorbs electromagnetic energy from the UV source and the bonds in the molecule are transformed to an excited state, and chemical and physical processes become thermodynamically possible. The process works on the principle that UV energy disrupts the DNA of the <u>microorganisms</u> and prevents it from reproducing.

There are four types of UV technologies of interest to the water industry. They include (1) low-pressure, low-intensity UV technology; (2) low-pressure, medium-intensity UV technology; (3) medium-pressure, high-intensity UV technology; and (4) pulsed-UV technology. Unlike using <u>disinfectants</u> such as ozone, chlorine, or <u>chlorine dioxide</u>, UV irradiation does not provide oxidation for color, taste, and <u>odor control</u> because UV light is not a <u>strong oxidant</u>.

A <u>UV treatment</u> process is comprised of a series of UV lamps enclosed inside a quartz sleeve. The UV light passes through the quartz sleeve and into the water. Due to the high energy emitted by the UV lamps, the temperature of the quartz sleeve can rise substantially causing the precipitation of various scales on the surface of the sleeve, thus blocking the passage of the UV light into the water and dramatically reducing the efficiency of the process. The scales are commonly caused by the precipitation of calcium, iron, or <u>magnesium salts</u>. Preventing the buildup of this scale is a major operational challenge for the use of UV. One of the current problems facing the use of UV irradiation is determining the actual UV dose the water receives, because measuring a residual is not possible.

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