Advantages, Risks and Prospects of the Usage of UV-LED-Sources (365nm) for Fluorescence Stimulation in NDT

Marc BREIT
RIL-CHEMIE, 66271 Kleinblittersdorf, Germany, Phone: +49 6805-942574-0, Fax: +49 6805-942574-7, e-mail: marc.breit@ril-chemie.de, web: www.uv-led-lamp.com

Abstract:
UV-LED-sources become more and more common for fluorescence stimulation in NDT. This new technology gives us possibilities we never had before, but there are also technical challenges we have to take care of to enhance the probability of detection as well as the safety at work. Further it can alleviate the execution of non-destructive fluorescent crack- and leak-detection and opens really new potentials to respect all the different needs in all the different industries and regions fluorescent testing is present.

There are many factors of influence that have to be considered due to the real big differences in technology between classical UV-sources based on mercury-vapour, Xenon or metal-halide-bulbs and the LED-technology, especially UV-A-LED-technology. After more than 5 years of intensive research and practical experience in UV-LED-technology in NDT, this presentation will explain, show and clarify technically the following themes:

- differences between classical and UV-A-LED-sources
- technical challenges manufacturing UV-A-LEDs
- technical advantages and risks of the new technology
- how to find the perfect source for each special usage
- prospects for the future

Keywords: UV-LED, UV-sources, UV-light, fluorescent, magnetic-particle-testing (MT), penetrant-testing (PT), leak-detection, aerospace, NDT, visual testing

1. Introduction

The UV-LED-technology is relative new partition in the NDT-practice and the users really appreciate the pleasant work and the clear viewing conditions with high quality LED-based UV-sources. A LED is a semiconductor and the LED-technology will probably revolutionize the lighting- and radiation-emitting-sources in the area from ultraviolet- up to infrared-radiation like the electronics were revolutionized from diode tube to semiconductor diodes.

We are now, for the first time, able to use perfect UV-A-source in NDT that only emit the needed invisible UV-A-radiation without any unneeded, annoying or detrimental Output, LED technology allows flexible design of the sources related to the size, intensity and electrical security class needed, to enhance the POD (probability of detection), prevent certainly UV-A induced fade of indications and realize drastic higher level of safety at work.

Based on low transparency and missing standardization, parameterization and description many users and responsibles are insecure to use this awesome technics.

In a sensitive discipline as MT- and PT-Testing is it is mandatory to use only technical conform sources that ensure the high quality level of testing we are actually doing.

Most manufacturers obviously try only to substitute the classic bulbs through LEDs. They do not care about the important technical challenges and differences and do not utilize the possibilities this high technology requires and allows for our specific and very sensitive testing practice. Mostly the relevant parameters are not described in data-sheets and product descriptions.
Actually primes and MRO-providers in Aeronautics and Automotive Industry started initially to make specific qualifications of UV-LED-sources to protect their testing process and ensure the quality of testing using UV-LED-sources.

The presentation shows and clarifies the technical needs and description of secure, application specific UV-LED-sources to ensure better fluorescent testing processes than ever and will enable the user to find, evaluate and verify UV-LED-lamps regarding his specific application and usage and to realize the great possibilities this technique allows in practice.

1.1 Status quo
The fluorescent testing would not be what it is actually, if we didn’t have the classical UV-sources based on different kind of bulbs (mercury-vapour-, Xenon- or metal-halide-based) and its filters. The quality of testing and safety at work was enhanced slowly over the last 20 years and the technical possibilities and differences of prices were manageable.

Since High-Power-UV-A-LEDs (365nm) are available a very fast and big progress happened and many new and different UV-A-LED-sources came onto the market in scary different pricings, qualities and configurations. Further very dangerous sources with blue-light (450nm) to stimulate the fluorescence are also offered.

In this presentation we are only talking about the substitution of classical UV-Sources used in NDT since years, based on Mercury-vapour-, Xenon- or Metal-halid-bulbs through UV-A-LED-sources with a peak-wavelength of 365nm, plus/minus 5nm, that ensure NO disadvantage or change in fluorescence stimulation, but we have to respect all technical and practical requirements to ensure a secure testing WITHOUT disadvantages.

The spectral emission of high quality UV-LED-sources have a bit larger bandwidth than Mercury-Vapour lamps have and a much more smaller bandwidth than Xenon- and metal-halid-bulbs have. Due to this there is in fact no practical difference of the UV for the stimulation of the fluorescence by replacing the old technology through high quality UV-LED-sources!

1.1.1 Situation in practice
End users really appreciate the secure, lightweight, handy, not so hot, instant on/off switchable handlamps. Stationary lamps are also available. The users are mostly looking for a good value lamp that fits his applications, but they are more often than not unable to evaluate this lamps and he have to trust the marketing and sales department of his supplier in this interesting sales field. Some lamps have a visible light option.

Most manufacturer do not specify their lamps as it is needed technically. Many suppliers are not skilled, because they only sell the products and are not aware of the existential technical requirement of the sources and the requirements for the usage in NDT.

Many lamps generate better viewing results than the old technology but there can also be detrimental effects for the testing which the tester should NOT have to realise generally.

Due to the big change in technology and the many different possibilities we get using UV-LEDs there are arising many questions, misunderstandings and marketing tricks.

Now we realize observations and questions using UV-LED-sources we didn’t think about before and didn’t have to take care about during the usage of bulb-based lamps, because the whole testing systems are optimized for the usage with this kind of the lamp and nothing different was
available. If we want to use a different kind of source it is mandatory to clarify each detail, even if it seems, on the first view, small and irrelevant, to ensure to have always at least the same examination reliability and level of testing-quality that we had using the old technology.

All bulb based lamps have got the same disadvantages (e.g. hot housings, low efficiency, dangerous and detrimental unneeded outputs) and limitations in size, operation condition and safety at work.

1.1.2 Technical situation

At the bulb-based-sources there are only 2 important parts: the bulb and the filter and they were always technically the same independent whoever is the manufacturer of the lamp. There were not much difference possible in the design.

For UV-LED-sources there are much more important parts, many different ways to drive an LED and construct a lamp. Often the results only seem to be the same but many times they are NOT the same.

The qualification and characterization is poor and the user has to trust the supplier about the quality of the UV-LED-source to be a good product for NDT-usage. Many users and level-3-responsibles are insecure due to the big price differences and the missing standardization.

Due to the flexibility based on the new LED-technology, there are much more different kind of lamps available:
- Flashlights, handlamps, stationary lamps, waterproof lamps
- different wavelength
- unbelievable different intensities
- with and without filters
- different optics and optical systems
- different cooling systems an technologies
- different kind of electric and electronic drives
- with and without electronic controls for different parameters
- unknown UV-intensity-stability
- etc.

Most lamps have a high or too high intensity, even for penetrant testing, a counterproductive strong and sharp focussing and emit also a tender bluish output.

The minimal working distance is not defined and the homogeneity of the radiation can be quite different up to detrimental.

The illuminated area has hard radiation drop-off at the edge.

The large diversity and usage of the different UV-LED-lamp-types needs a much more detailed qualification to respect all relevant differences, requirements and usages.

Some systems are not designed for standard industrial use and do not respect the challenging technics that are necessary to build reliable and secure systems for NDT based on high-power UV-A-LEDs-components, e.g. there are lamps available that expect operation conditions from 5 to 35°C (41° to 95° F) which can not adhered every time in the industrial field.

1.1.3 Standardization

ASME Boiler and Pressure Vessel Code (BPVC) [1] expects ultraviolet light i.e. nominal 365nm, called black light.

ASTM E1417 M-11 [2] requires a wavelength of 365 to 370 nm and a measurement of the intensity prior to use. The standard recommends that the initial UV-light-intensity of battery powered black lights should be a minimum of 1.500μW/cm² in 15 in. (38.1 cm) to ensure that the strength of the battery will last through the examination to maintain a minimum of 1.000 μW/cm² at 15 in.
DGZIP EM6[3] used in MT- and PT-Testing, regards in its newest version UV-Emitting Diodes and oblige the lamp-manufacturers to test 3 samples of each design-type to determine the spreading in the spectrum.

ISO/FDIS 3059[4] will regard in the upcoming version the LED-technology through allowing UV-peak-wavelength of 365±5nm and that the test surface shall be irradiated evenly.

NDT special interest Group of ADS in UK[5] starts to discuss about relevant parameters of UV-LED-sources for aerospace NDT applications with the intention to provide a guidance document addressing the manufacturing of the lamps, the use of the sources in the workplaces and the associated training requirements to enable all these groups to select the right lamps and use them correctly.

1.1.4 Accreditation and Approvals
Actually does not exist any consistent national, international or industry-sector-specific accreditation that describes detailed and proper the requirements of suitable UV-LED-source.

For instance Daimler (Mercedes-Benz) in Germany did a large trial of all (approximately 6 to 8 different models) and created their own relevant parameters to classify and rate all available stationary UV-LED-lamps in 2011 and approved only 2 specific lamp types.

1.2 Challenges and risks of UV-LED-technology
The manufacturing of excellent UV-LED-sources for NDT is a real sophisticated challenge compared to LED-lamps for visible light, due to the relative low efficiency, very high-power and sensitive UV-LED-modules, raw working environment and the usage in an optical viewing application.

1.2.1 General challenges in manufacturing UV-LED-sources
Lamp manufactures have to regard the following, practical requirements:

- High quality, robust and lightweight lamps for hard industrial use
- Long life time
- High UV-intensity stability
- Good homogeneity of the radiation
- No visible interferences and reflections
- Solid and reliable system that runs properly independent from the common operation conditions we have in the industries (Temperature: 5 to 60° C (40 to 140° F), humidity rel. 10 to 80%)

1.2.2 Technical challenges for secure and reliable UV-LED-source in NDT
High-tech UV-LED-systems are on one side less sensitive against physical impacts but on the other side much more sensitive about the environmental influences like temperature and humidity. The high flexibility and the wide range of possibilities implicate also negative effects that are obliged to respect. Further standard electronics used for visible lighting can cause detrimental effects because we can NOT SEE what happens and came out of the UV-LED-lamp. Further heat is the most relevant and dangerous factor for the intensity and life-time of UV-LED-modules and has a strong influence on the output and also on the wavelength of the LED. As high as the steady state core-temperature is as short will be the life time of the LED. A high working temperature (under the limit), but nearby can cause 10 times faster aging and loss of intensity. Is it above the limit the LED can degrade up to 100 times faster or destroy the LED-chip.
To ensure a secure fluorescent testing based on the known standards with at least the viewing conditions we have with bulb-based-lamp it is mandatory to respect all the following items:

- proper electronic control, for constant and continuous LED operation WITHOUT pulsing on the obligatory high power level needed
- optimal heat management to guarantee high stability of the UV-intensity and Wavelength and a long life time
- proper and stable Peak-Wavelength and Wavelength-allocation
- Good distribution of radiation
- soft radiation drop at the border of the illuminated area
- Compensation of a failure of single LEDs
- Convenient system monitoring and safety shutdown

To have a better and less expensive testing than we ever had before it there is so more expect:

- Optimized filtration
- Flexible system design for optimal customized systems to fit all specific applications
- Easy to maintain and repairable systems
- Integrated, dimmable, high quality white light

1.2.3 practical risks of low quality UV-LED-sources in NDT

In Practice many bad and dangerous and detrimental things can happen to the testing and due to the invisible radiation we are working with, this problems can stay ‘invisible’ for the user or will be identified too late:

- Missing detectability caused on un-recognized UV-radiation gaps and missed fluorescent indications caused by strong focused LEDs and nonhomogeneous radiation distribution to get supposed high intensities in 15 inch (38cm) distance (where everybody is measuring) and in 5 to 10 in. distances (12 to 25cm) exist factually radiations between 200 and 12.000 µW/m², what is absolute unacceptable for NDT examinations.
- pulsed power-drive of the UV-LEDs to generate high power measurements, can be detrimental for the illuminating power of the fluorescent dyes and pigments in NDT-testing-systems and reduce the probability of detection (POD).
- unnoticed lost of up to 70% of intensity during usage, caused on manufacturing, design based, optical, heat and environmental issues. e.g. usage of cheap consumer- and home electronic-components. Unnoticed because based on the actual standardization and common practice the measurement of the intensity is mostly done about 10 to 15 minutes after switching on and the intensity can drop down until hours of usage continuously under hard industrial conditions and will not been seen! There is only the degradation realised through this time of measurement if it is not technical secured that the LED-source is really stable enough for NDT usage of this special and sensitive kind of LED modules.
- failure and low reliability of the source under hard industrial working conditions
- failure of one LED can cause on non homogenous lamps with a high minimal working distance spots with too low or no UV-radiation
- wrong ‘kind’ of UV-A-spectrum, intensity measurement errors, a high level of visible output, based on unsuitable also called UV-LEDs
- Low durability of the source
- low investment protection

1.3 advantages of using high quality LED-Technology based UV-sources

1.3.1 generally known advantages of LED-Technology comparing bulb-based lamps:
- Lower power consumption
- Long life-time
- High resistance against mechanical impacts and vibrations
- Compact devices, flexible design possible
- High versatility regarding the size of illuminated area and the power of illumination
- Low voltage systems possible
- Higher efficiency
- Environmental friendly

1.3.2 Advantages of UV-LED-Technology comparing bulb-based UV-lamps: UV-LED-Technology allows perfectly customized UV-irradiation-systems and practical advantages to enhance the quality and reliability of fluorescent crack detection in a way we never had before.

1.3.2.1 Advantage for NDT-applications
High-quality, properly configured and manufactured UV-LED-sources allow especially in NDT a wide range of new kind of sources for much better working and examination conditions:
- Maximum versatility regarding the size of the irradiated inspection area
- High variability of the intensity of radiation
- Homogenous distribution of the radiation (independent from the size)
- Perfect convenient UV-A-intensity for each different requirement and most secure and reliable testing, whatever the requirements are: wetting check/removing in penetrant testing (low intensity), size of parts at examination (normal intensity), especially in penetrant testing not too high, special conditions, e.g. fluorescent magnetic testing and low daylight conditions
- Steady intensity over a very long time
- Full intensity directly after switching on
- Real instant ON/OFF
- Additional, dimmable, high quality white-light that can be switched on in addition to UV or instead of the UV
- Soft white light, less 2fc (20 lx) possible
- Combination of fluorescent testing and visual testing in one place and/or in one step
- Really dark conditions without any visible light possible
- NO detrimental or dangerous Outputs, like old sources did
- NO reflections of bluish and violet light possible
- NO red or infrared irritations possible
- Ergonomic viewing conditions
- High reliability
- Higher examination reliability

1.3.2.2 Health & Safety and environmental and issues
Further there are big advantages through the drastic reduction of risks and hazards for the user’s health and the environment:
- NO UV-B and UV-C radiation possible, generates only UV-A
- NO unneeded UV-A-exposure
- NO infrared-radiation
- NO ozone generation
- NO explosion hazard
- NO or low fire hazard
- NO or low burn hazard
- SELV (safety extra-low voltage) lamps for all usages available
- Low power consumption
- RoHs conform lamps possible
- free of Mercury (Hg)
- free of Lead (Pb)

1.3.2.3 commercial aspects
UV-A-LED-sources require a higher investment than bulb-based sources. But regarding the total costs of ownership (TCO) all UV-LED-lamps are cheaper than bulb-based-lamps.

Especially the hand-lamps that substitute 100W mercury-vapour- or 35W Xenon-bulbs are amortized after some months or maximum two years, depending on the daily time of usage.

Further respecting the safety at work and quality of the viewing conditions allow a more secure and reliable testing, performance and motivation of the inspector, which is also a big commercial advantage, even if it is quite difficult to measure and numeralize.

Low quality lamps have lower purchase prices but can be detrimental for the examination and can not guarantee a secure return on investment.

1.4 Summary of the practical requirements
Due to the wide range of new possibilities and technical differences it is really important to define the needs and choose the right product for each different usage, check the choice in all important matters to ensure the maximum reliability and performance of the UV-LED-source to guarantee process-security, users satisfaction and return on investment.

2 Parameterization and Description of UV-LED-Sources
To ensure maximum reliability and investment protection as well as real improvement of the testing quality it is mandatory:
- to understand the meaning, relevance and importance of ALL parameters
- to check the following relevant parameters
- to ensure a well selection and qualification of the source for each specific usage

Due to the missing standardization of most of the following parameters they can be free described and interpreted. It is always recommended to ask the supplier of the lamp what the parameters describe if they do not correspond to a standard.

2.1 classical Parameters
2.1.1 UV-A-intensity:
Intensity of the UV-A-intensity that is used for stimulation of the fluorescence of the testing materials. Due to similarity of the UV-LED-output of high quality sources the measurement can be done with the same instruments used in the past, e.g. ISO3059 qualified UV-Meters.

2.1.2 illumination/testing area:
For bulb-based lamp, due to the design-limitations for the lamps they had a high intensity in the centre of the illuminated area, it was mostly described as the area with at least 50% of the maximum intensity.
Professional UV-LED-lamps should have, except the outer area where the intensity should degrade softly, a very uniform distribution of the radiation, for best examination. The 50% area is not are really convenient way to describe. A better way can be to describe the area where the intensity is higher than a specific value (e.g. 1.500 µW/cm²).
2.1.3 Life-time
To get an impression of the definition of the lifetime information it is very important to know what it means. Normally for light-sources the life-time $L_{70}$ and $L_{50}$ is used which is defined as the period until the lamp delivers at least 70% and 50% of the initial output. The LED manufacturers mostly use one of this value to describe the lifetime. In the past, the common used lifetime for UV-bulbs is $L_{(UV\ 1000)}$ or $L_{(UV\ 1500)}$, which means that the lamps should be used until the output decreased down to an intensity of 1.000 µW/cm² or 1.500µW/cm².

2.1.4 Peak wavelength
Relative maximum value of the spectral output in the UV-A-range of a UV-A-source.

2.1.5 Visible output (visible background light)
UV-LED-sources do not emit a classical white light fraction known from the bulb based lamps, where most of the emission is white light, that have to be filtered out for NDT-usage and have NO infrared radiation. They emit a very low but visible deep violet/bluish output in the range between 400 and 460nm, which is less 1.5-tenth of a per cent (1,5‰) of the LEDs UV-A output. It is impossible to measure this emission with standard Lux-Meters used for visible light measurements in NDT. This low output is not extremely detrimental but parasitical to the testing. Without a proper filtering it coats the testing area in a bluish fog.

2.2 Additional recommended parameters

2.2.1 Stability of UV-Intensity
UV-LED-Sources loose intensity while running only due to internal heating. This loose of intensity depends directly from the internal core-temperature of the LED-Chip, that mostly depends from the technical heat-management of the lamp-system. The stability of intensity shouldn’t be lower than 80% and allows a concrete conclusion to the aging and degradation of the LED and its life time $L_{70}/L_{50}$. In Fact a lamp with a stability of 95% will have 1,5 to 3 times higher lifetime than a lamp with only 80% UV-Intensity-Stability.

2.2.2 Minimum working distance and homogeneity
Based on the modular construction of UV-LED-sources the distribution of the UV-A-radiation can be detrimental non-uniform, up to radiation-wholes, where indications are invisible. It is very important to define a minimum working distance using UV-LED-sources where the irradiation is visible even on a planar, even fluorescent, surface area and to choose sources whose minimum working distance is less than it is usually is in practice. Source with high intensity in the center (as we have on bulb-based-UV-sources) can not cause inhomogeneities, but have a similar worse distribution of the radiation as bulb-based lamps have and are not recommendable because they do not use one of the biggest advantages of UV-LED-sources: the uniform distribution of the radiation. At most handlamps, due to the small distance between the LEDs it is not such sensitive theme than it is at stationary lamps.

2.2.3 Minimum start intensity
Lowest, acceptable intensity directly after switch on to guarantee enough irradiation during the work, even if the lamps heats up and outbid the stability of the UV-intensity described above.

2.2.4 Absolutely maximum intensity
Maximum intensity allowed.
2.2.5 full width at half maximum (FWHM) of 15 nm
Ensures the right UV-A-output and a reliable and secure quality of testing as well as measurements with the established measurement instruments.

2.3 context-sensitive and sometimes unclear parameter

Please take care what it really means and why they are used.

2.3.1 degradation
We have to distinguish two different kinds of degradation at UV-LED-sources:
Short time degradation: UV-LEDs can loose up to 25% of intensity due to the heating up to the maximum temperature and can be damaged from too high core-temperatures which is not detrimental but have to be respected at the definition of the minimum start intensity allowed for testing. (Keyword: stability of UV-Intensity)
Long time degradation: How fast will be how much of the initial output lost over the time of usage. (keyword: life time)

2.3.2 Time of usage vs. Life-time
Time of usage describes the time the lamp is running. UV-LED-lamps mostly run only if needed, bulb-based-lamps run in practice continuous during the complete shift, independent if needed or not. It is a small but very important difference also referring to the life time shown above. Mostly the time of usage is equivalent with the life time and time of usage for a UV-LED-source can be up to 100 times higher than the time of usage of bulb-base-lamp.

2.3.3 Measurement distance vs. working distance
What is the right value for the intensity measurement and what is his intention. E.g. it is detrimental to limit the intensity to 5.000µW/cm² (at 38 cm) if the working distance is 12cm to protect penetrant indication against degradation.

2.4 Extensive parameterization and description of UV-LED-sources for each special usage is necessary and mandatory to enable the user to verify all relevant factors

Based on UV-LED-Technology there are so much different possibilities to enhance, simplify and assist the fluorescent visibility in a way we never had before. But there are also much more technical risks that can cause a degradation of the testing quality. It is mandatory that the manufacturer and the users of these HIGH-TECH UV-sources, which are not anymore simple lamps, are obliged to observe, ensure and respect ALL technical, procedural relevant parameters and factors of influence. They have to check if the chosen lamp fits the needs for testing in a specific application and describe the systems capability in all relevant details how it can by done by the following parameters:
- UV-A-intensity in different distances
- Size and definition of illuminated area at specific distance
- Size of irradiated area with a deviation of less than 10% of the maximum
- Peak wavelength
- The outputs FWHM
- Visible output >400nm
- Stability of UV-Intensity
- Minimum working distance/distance without visible irregularities
- Minimum start intensity
- Sabsolutely maximum intensity
- Estimated /guaranteed time of usage
• Ambient conditions and output stability
• Maximum voltage of the handset (if available)
• Number of LEDs
• Possibilities of usage
• Additional security-, control- and monitoring-systems and -features

For maximum testing performance it is mandatory to measure the intensity regularly, to wear high-quality and clear UV-protection glasses, which have a proper cut-off at 400nm to ensure a clear and true view and have maximum safety at work and to check from time to time if all LED-modules are running properly.

3. Conclusion

UV-LED-Technology is the future for fluorescent stimulation in NDT and allows the clearest and realistic view in fluorescent NDT practice we ever had. but we have to take care to ensure that we are always better than we have been before with the old technology.

High Quality UV-LED-Sources enhance the quality, security and POD of the fluorescent MPI, FPI crack detection and and leak detection. UV-A-LED sources can be much more better in all practical disciplines than bulb-based-UV-sources ever have been in NDT.

Some professional and skilled manufacturer offer actually good products, which are better than all other UV-Sources we hade in the past.

The technology is matured and the big technology leap is done. Only the standardisation and some lamp-manufacturers have to do their homework to give the user the mandatory security needed in NDT.

There are and will be systems available for each different usage, e.g. for perfect and reliable illumination of penetrant washing stations and we actually have more different types of UV-LED-lamps than we had before.

A really big price reduction will not come, because the price of the LED-module, which was the cost driver in the past, decreased strongly in the last two years and its part in high-quality lamp systems is only a third up to the half. The prices of the modules will be stable only the output and efficiency will grow, like it is known from computer-semiconductors and processors.

Notes:
1. ASME Boiler and Pressure Vessel Code (BPVC) Section V, Nondestructive Testing
2. ASTM E1417-M-11: Standard practice for Liquid penetrant Testing
3. DGZIP EM6: National German Directive of the German NDT Society for the H&S classification of UV-source,
4. ISO/FDIS 3059: Non-destructive testing - Penetrant testing and magnetic particle testing
   - Viewing conditions
5. NDT special interest Group of ADS (AeroSpace/Defence/Security) in UK (www.adsgroup.org.uk)