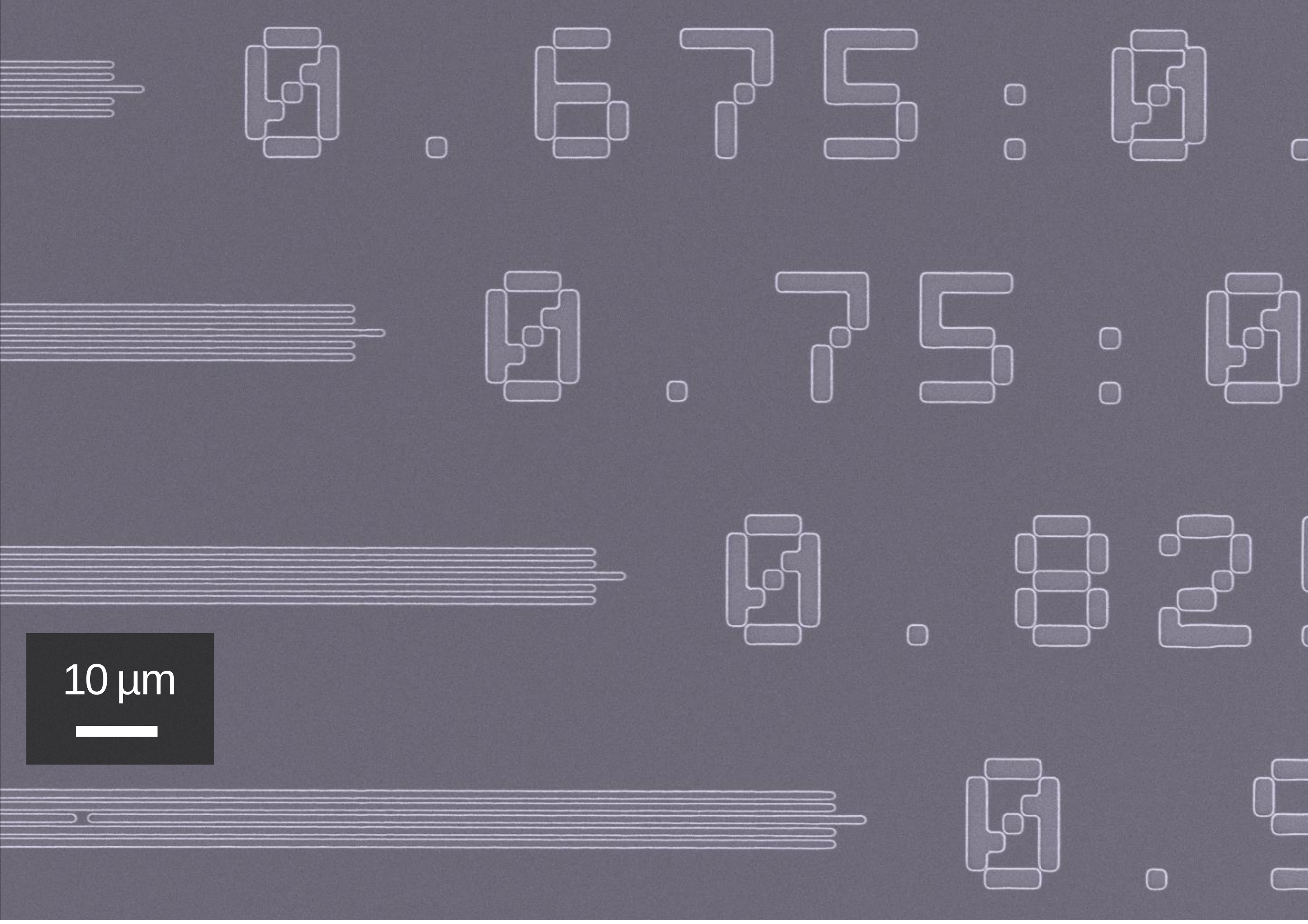

TECHNICAL NOTE

Photolithography exposure process with UV-LED

This document explains process details about photolithography exposure with the idonus UV-LED systems. The topics covered are: collimation angle of our telecentric illumination systems; optimum UV wavelength for a given photoresist; spectral response of UV sensors.

www.idonus.com
Document updated in September 2020

> The many advantages of UV-LED technology compared to mercury arc lamps for photolithography exposure are covered in our technical note entitled “UV-LED light engine for photolithography exposure”. We assume that you are convinced that UV-LED technology is the right choice.
>
> Now, you have several practical and operational questions: I have an established procedure for photolithography exposure with mercury arc lamp. How should I adapt my process to UV-LED exposure? Which wavelength should I choose for optimum exposure of a given photoresist? In fact, what distinguishes the idonus UV-LED exposure systems from their competitors? We address these questions hereafter. The supplemental data that you will find will help you to select the UV-LED exposure system that best suits your needs.

1. Introduction

This document explains several technical details about the idonus UV-LED exposure system (*UV-EXP* series) that are not covered in our technical note “UV-LED light engine for photolithography exposure”. To fully understand the supplemental explanations provided hereafter, please consult that document first.

In section 2, we explain the difference between our telecentric LED illumination system and a LED array (matrix) system. In sections 3 – 5, we explain how to select the appropriate LED wavelength to maximize the exposure energy for a given photoresist. The last section shows the spectral responses for a selection of UV sensors.

2. Telecentric versus LED array illumination

Most of the UV-LED exposure systems available on the market use an array of LEDs with individual miniature optical elements to illuminate a target surface. Such products are well-suited for non-critical exposure of mesoscale structures (> 100 µm feature size) or for some curing processes that can tolerate uneven illumination. However, such a design is unable to reach the high-performance level of a highly collimated telecentric optical design. Indeed, there is an overlap between each discrete LED illumination area and the transition overlap can never be perfectly smooth and flat, *i.e.* homogeneous. Our competitors can offer attractive prices, but their technical specifications must be read with extreme care: pay attention to the fact that the collimation angle obtained with such a design cannot technically achieve the quality of a telecentric system. The differences highlighted above between the two working principles are illustrated in Figure 1.

Collimation angle • For a LED array system, the collimation angle varies over the exposed surface, and is not clearly defined. Furthermore, a lot of energy spreads outside of the defined collimation angle. In the idonus *UV-EXP* telecentric systems, the collimation angle is the same everywhere and is clearly defined: 95% of the light is enclosed within the maximum collimation angle. For the same claimed collimation angle of less than +/- 2° (*i.e.*, $2\alpha < 4°$), comparing the two data plots in Figure 2, one can clearly see that the quality of the illumination is different.

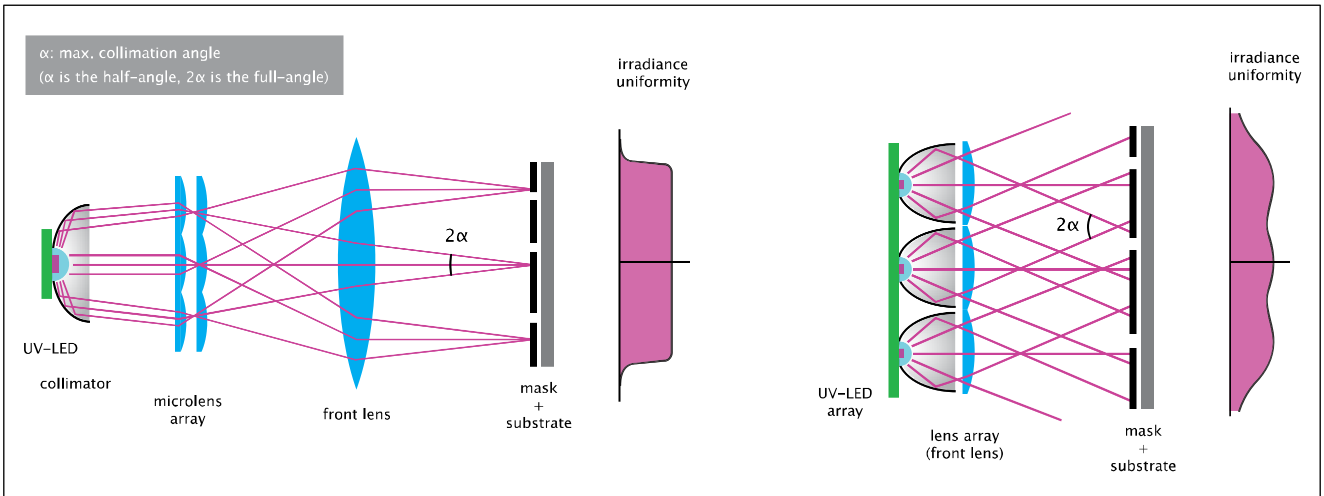

Figure 1: *Telecentric versus LED array illumination. Telecentric optics is the best solution if one needs to achieve small collimation angle and high uniformity of the illumination.*

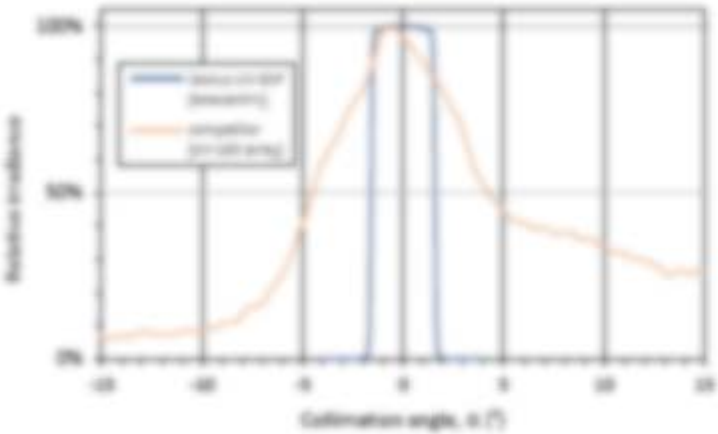

Figure 2: Comparison of collimation angles. The Idonus UV-EXP series of UV-LED exposure systems have a max. collimation angle of +/- 2° (2α = 4°). Competitor's product with similar claimed specifications has an actual max. collimation angle that is around +/- 4°.

3. LED optical power

The high-power UV-LEDs used by Idonus are designed for four distinct wavelengths that cover the near UV spectrum between 365 nm (i-line) and 405 nm (h-line). The total "optical power" (radiant power, Φ_e [W])² available for a given LED is dependent on the wavelength, as shown in the intensity spectra of Figure 3. The graph shows that the maximum power is achieved using the UV-LED which has the peak wavelength at 385 nm. Compared with that LED, the integrated power of the UV-LED modules offered by Idonus are:

- 100% @385 nm UV-LED
- 84% @ 395 nm
- 72% @365 nm
- 67% @405 nm

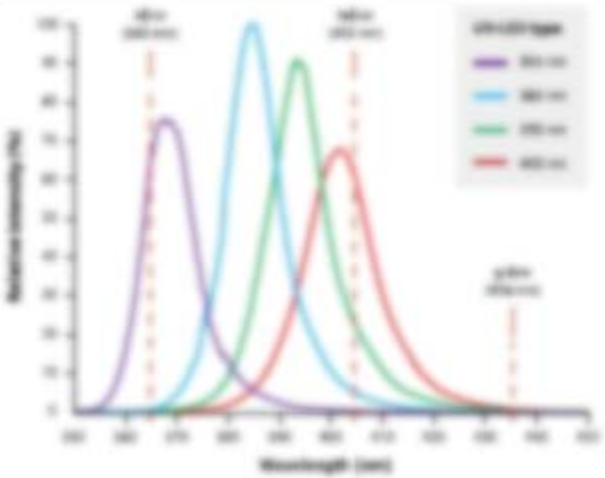

Figure 3: Spectral distributions of the UV-LEDs integrated into our UV-EXP products. The i-, h- and g-lines typical of Hg light are included for comparison purpose.

In Figure 3, for comparison purpose, we have also included the i-, h- and g-lines that are typical of mercury arc lamps. However, one should keep in mind that the purpose of UV-LED technology is not to mimic the spectral power distribution of Hg light. This is all the more unnecessary as the amplitude of these characteristic peaks can vary significantly from one Hg lamp reference to another.

4. Photoresist absorption

For photolithography applications, both the emission spectrum of the UV exposure system and the spectral sensitivity of the photoresist must be considered. Indeed, each photoresist

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[2] In accordance with the SI standard for radiometric quantities and units, the radiant flux – or radiant power – is noted with symbol Φ_e and is measured in watts [W].

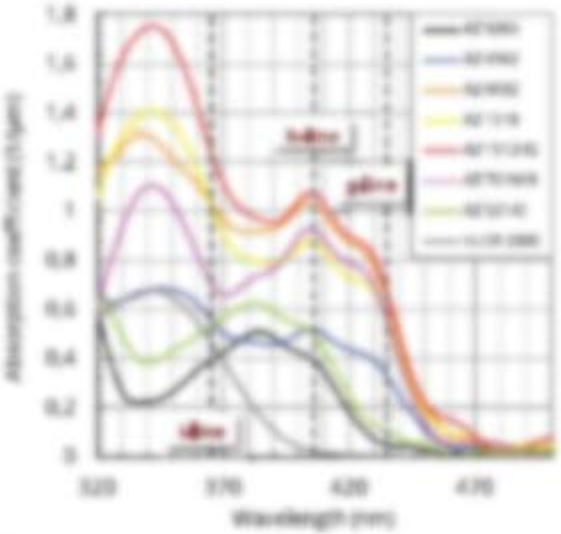


Figure 4: *Optical absorption characteristics of a selection of photoresists. Unexposed photoresists are sensitive to wavelengths ranging from approx. 480 nm (VIS) to near UV (300 – 400 nm). The absorption spectrum causes the typical reddish-brownish color of many photoresists.*

(source: microchemicals.com)

shows unique absorption characteristics. The absorption depends on the wavelength, as illustrated in Figure 4. Here, we take as an example the absorption coefficients for the AZ series of positive photoresists (technical specifications retrieved from MicroChemicals GmbH).

5. UV exposure

The exposure dose needed for photoresist curing (and thus the exposure time) mainly depends on the intensity profile of the UV source and on the absorption spectrum of the photoresist.

Example 1: AZ 1518 photoresist • In Figure 5, we show (i) the absorption curve of the AZ 1518 positive photoresist (black solid line, see also Figure 4); (ii) the relative spectral power density of our UV-LEDs (colored lines, see also Figure 3); and (iii) the response curves as calculated combining the photoresist absorption with each LED power spectrum (colored areas). Both the "385 nm UV-LED" and the "395 nm UV-LED" provide the maximum energy (100%). When compared to these optimum, we reach 84% of the energy with the "365 nm UV-LED", and 90% with the "405 nm UV-LED".

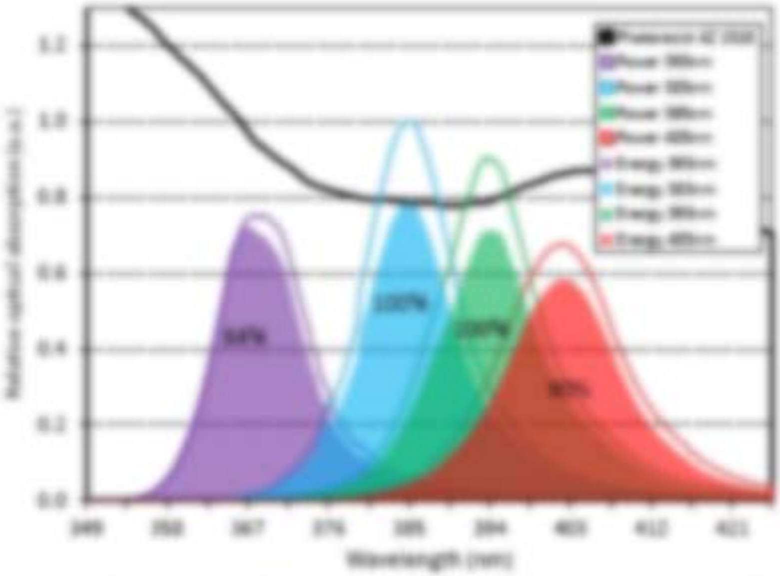


Figure 5: *Optical absorption characteristics of AZ 1518 positive photoresist vs. relative spectral power density of the idonus UV-LEDs*
(Sources: Refer to Figure 3 and Figure 4)

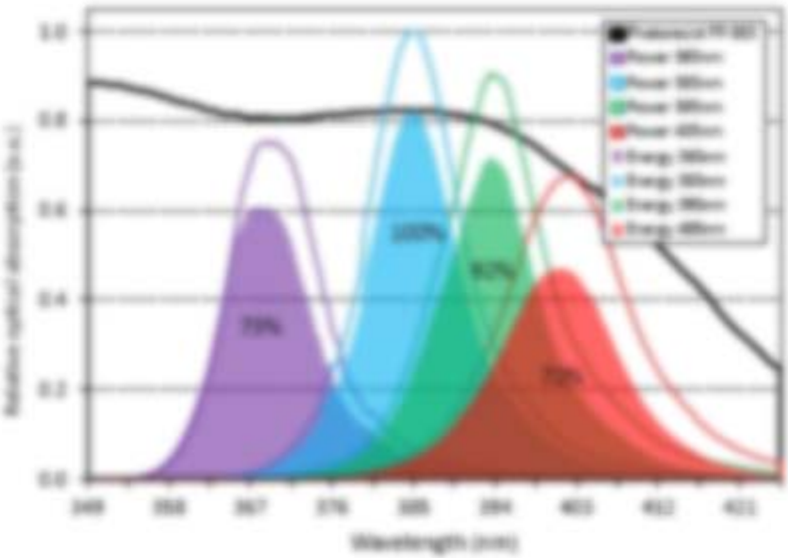


Figure 6: Optical absorption characteristics of FP-383 positive photoresist vs. relative spectral power density of the idonus UV-LEDs. (source: Characteristics of the FP-383 photoresist extracted from patent [illegible] (June 2002))

Example 2: FP-383 photoresist • In Figure 6, we show (i) the absorption curve of the FP-383 positive photoresist (black solid line), (ii) the relative spectral power density of our LEDs (colored lines, see also Figure 3), and (iii) the response curves as calculated combining the photoresist absorption with each LED power spectrum (colored areas). For this photoresist, the "385 nm UV-LED" provides the maximum energy. When compared to that reference, we reach 73% of the energy with the "365 nm UV-LED", 92% with the "395 nm UV-LED", and 72% with the "405 nm UV-LED".

8. UV sensors

UV sensors from different manufacturers have different spectral sensitivity. As a result, two different sensors can give a different result for the same exposure source.

In Figure 7, the sensitivity response as a function of the radiation wavelength is shown for a selection of UV sensors. The emission spectrum of Hg source, 365nm and 385nm LEDs are also shown for comparison purpose.

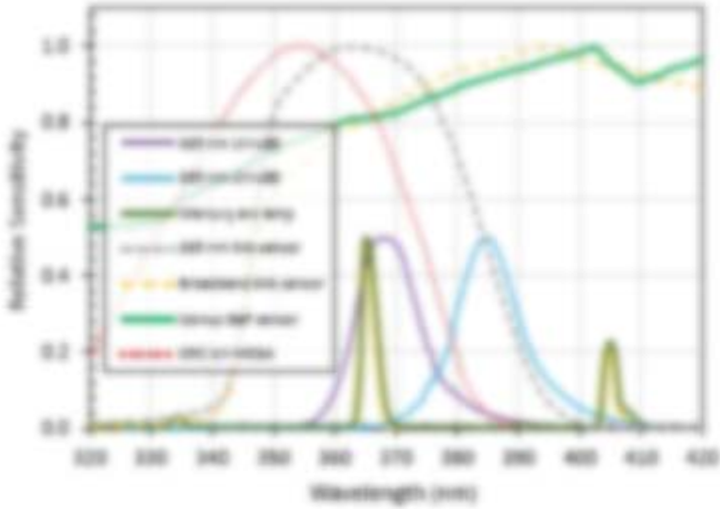


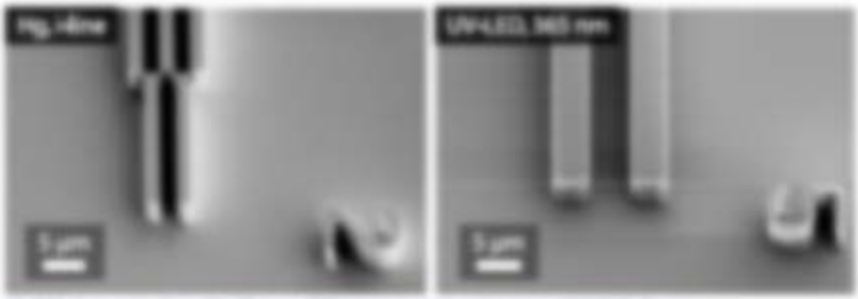
Figure 7: Sensitivity response of a selection of UV sensors. The UV sensor integrated in our UV-EXP products are based on Gallium Phosphide (GaP) substrates.

2. Photolithography results

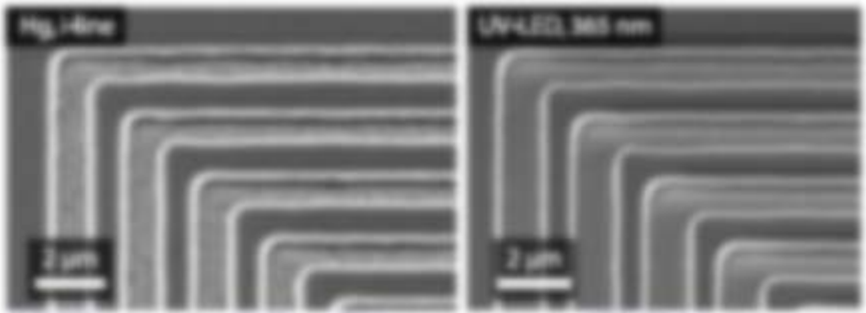
The most immediate way to evaluate UV-LED exposure is to compare our photolithography results with those obtained with traditional mercury-based photolithography equipment. For all the tests presented **hereafter**, UV-LED exposures were completed with the Idonus UV-EXP150P exposure system equipped either with a "365 nm" or with a "385 nm" high-power UV-LED. Exposures with mercury-arc **lamps** were completed on mask aligners equipped with i-line Hg mercury vapor lamps.

The results are presented in the form of Scanning Electron Microscope (SEM) micrographs that were taken by several academic partners during evaluation tests. They completed these tests on a selection of photoresists that they routinely use for microlithography:

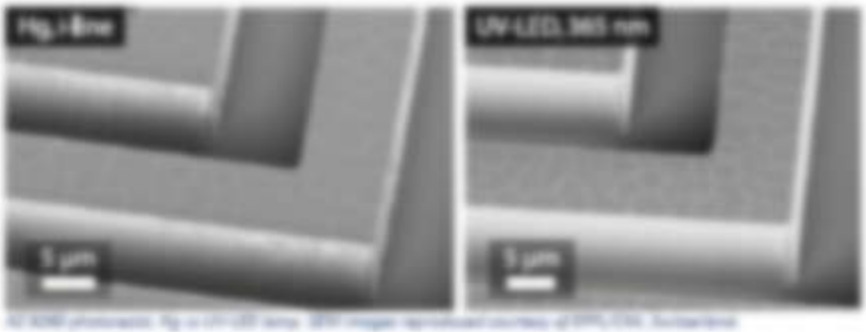
- **AZ 4533**, positive thick resist (g-, h- and i-line sensitive)
- **AZ ECI 3007**, broadband positive resist (g-, h- and i-line sensitive)
- **AZ 9260**, positive thick resist for high resolution (broadband and i-line)



AZ 4533 photoresist, Hg vs UV-LED lamp. SEM images reproduced courtesy of KIT-IMT, Germany.



AZ ECI 3007 photoresist, Hg vs UV-LED lamp. SEM images reproduced courtesy of EPFL/CMi, Switzerland.



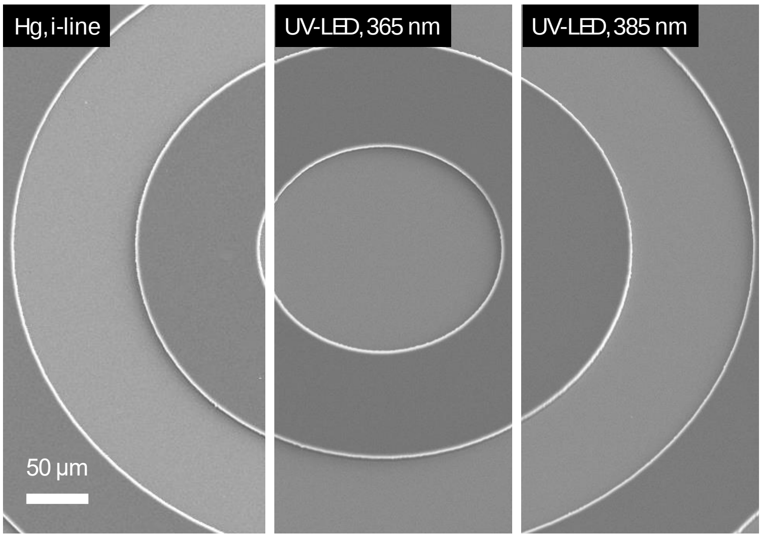
AZ 9260 photoresist, Hg vs UV-LED lamp. SEM images reproduced courtesy of EPFL/CMi, Switzerland.

Figure 8: SEM micrographs comparing photolithography exposure of different positive resists exposed to (left) conventional Hg vapor lamp vs. (right) our UV-LED-EXP equipment.

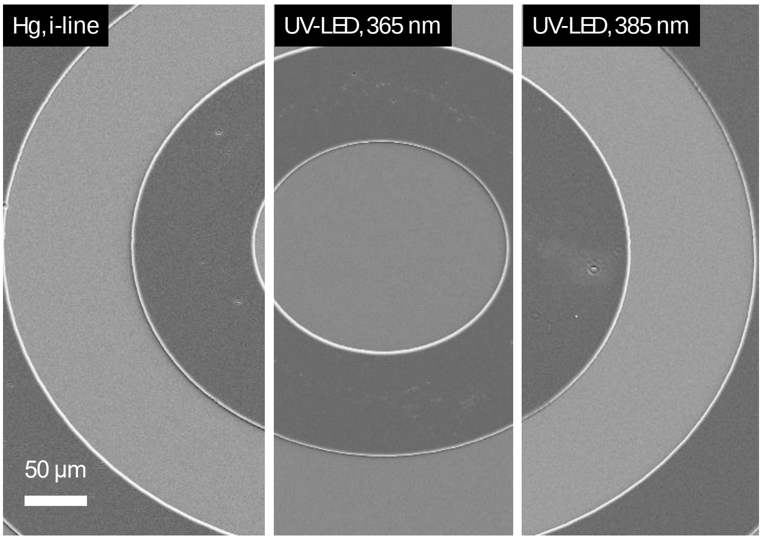
- **AZ nLOF 2070**, negative resist especially suited for lift-off lithography (i-line sensitive)
- **TI 35ESX**, image reversal resist (broadband, g-, h- and i-line sensitive)
- **SU-8 GM1075**, epoxy-based negative resist for thick layers > 100 um (i-line sensitive)

The information on sensitivities were taken from the manufacturers' datasheets. It can be noted that all these resists are i-line sensitive. It was therefore expected to obtain good results with the "365 nm" UV-LED. Furthermore, resists that are indicated to be either broadband or "g-, h and i-line" sensitive were expected to work properly with the "385 nm" UV-LED. Finally, considering the absorption characteristics of SU-8 resists, it was expected that the SU-8 would not give satisfying results with UV-LEDs emitting at 385 nm (or higher) peak wavelength.

The process parameters for each exposure are not detailed. In our view, this information is of minor significance because the optimum values are very specific and need to be adjusted to each application. The most interesting information – which has emerged from the various testimonies collected – is that the nominal dose needed for successful UV-LED photolithography was in most cases close to that recommended for Hg exposure. Thus, optimum exposure parameters could be easily obtained after only a couple of trials. Finally, according to testimonials from our partners, the results obtained with UV-LEDs were quite comparable to those obtained with the traditional mercury lamp. The following SEM pictures give a clear illustration of this.



AZ nLOF 2070 photoresist, Hg vs UV-LED lamp.



TI 35 ESX photoresist, Hg vs UV-LED lamp. Note that the resist may have been subjected to inappropriate atmospheric conditions (hygrometry).

Figure 9: *SEM micrographs comparing photolithography exposure of different negative resists exposed to (left) conventional Hg-vapor lamp vs. (center and right) our UV-LED-EXP equipment. SEM images reproduced courtesy of HE-Arc Ingénierie, La Chaux-de-Fonds, Switzerland.*

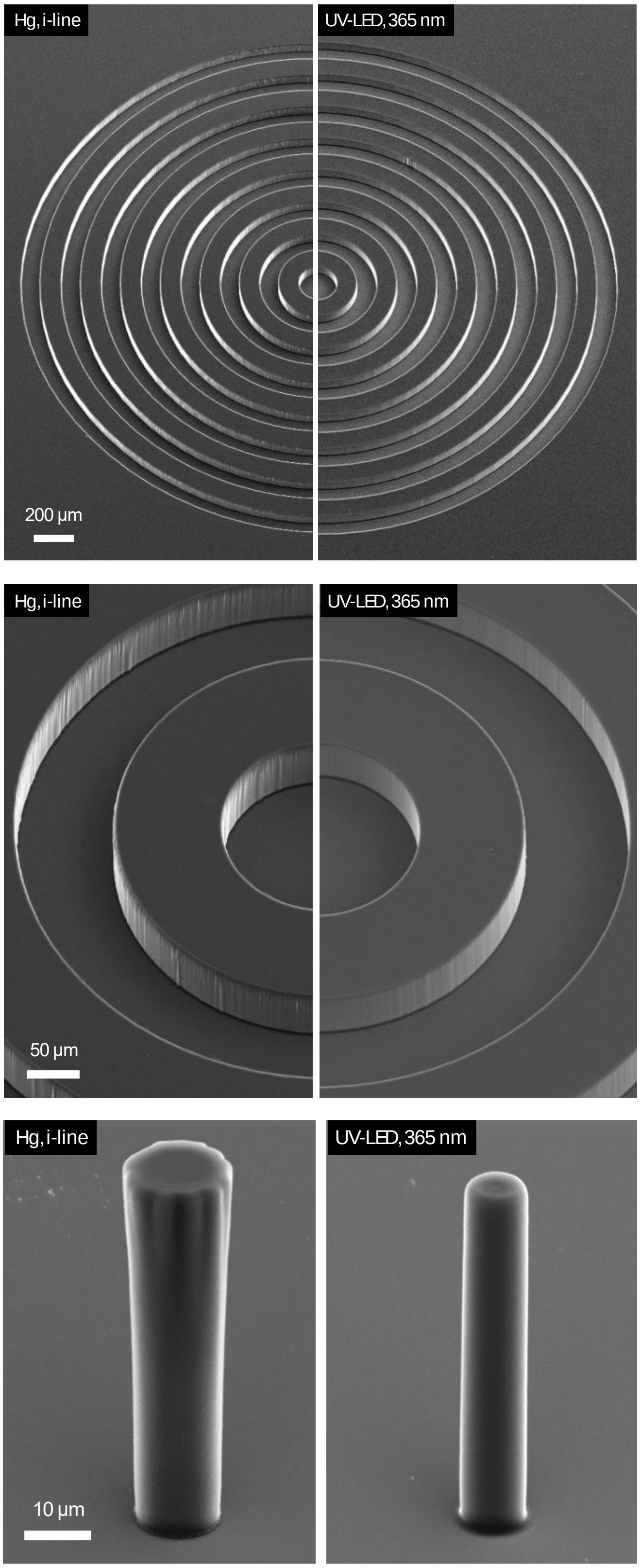


Figure 10: *SEM micrographs comparing photolithography exposure of SU-8 GM1075 negative resist exposed to conventional Hg-vapor lamp vs. our UV-LED-EXP equipment equipped with a "365 nm" UV-LED. SEM images reproduced courtesy of HE-Arc Ingénierie, La Chaux-de-Fonds, Switzerland.*

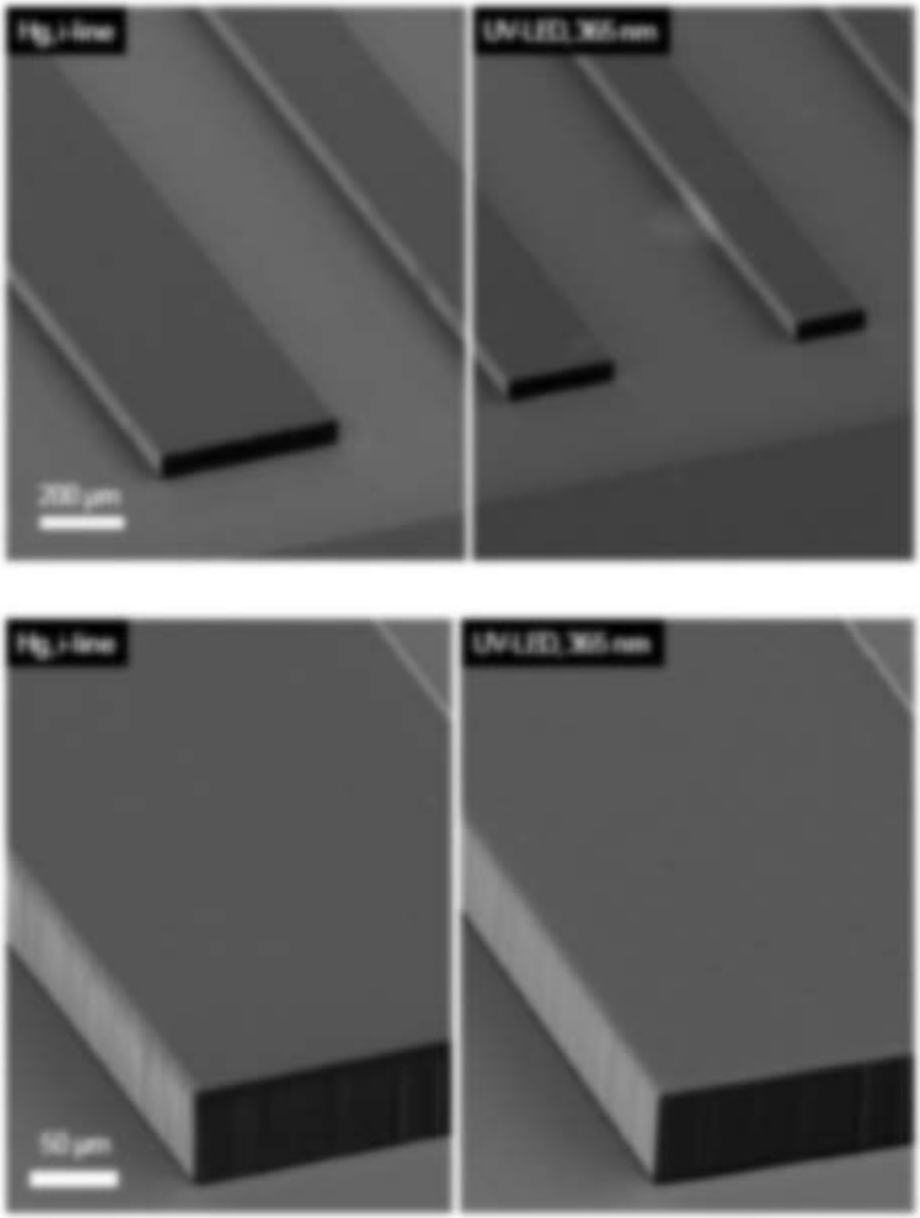
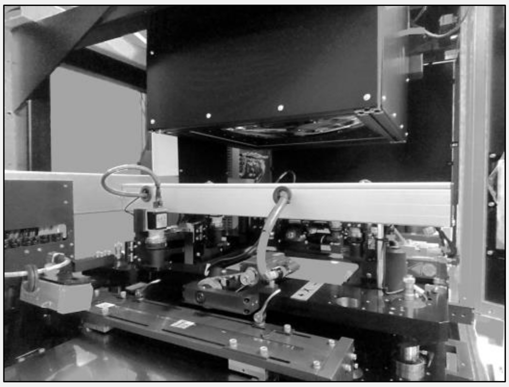


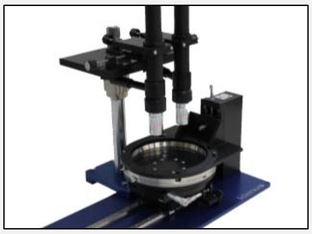
Figure 10 (continued)

Creative engineering and manufacturing • Our engineering team is accustomed to developing products according to client's needs. In-house machining and assembling facilities shorten the time from concept to finished products.

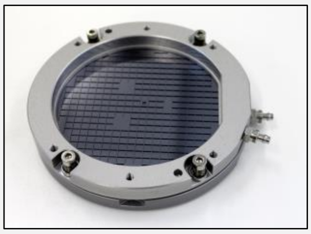


Customized UV-LED exposure system installed on a roll-to-roll machine

Visit our website to have an insight into our other products and activities. Contact us for further technical information and to obtain a quotation.



Double image microscope



A model of wafer chuck

About Idonus

Founded in 2004, Idonus is a Swiss company that develops and manufactures special equipment for the MEMS and watchmaking industries. Our product portfolio includes UV-LED exposure systems for photolithography, IR microscope for wafer inspection, vapor phase chemical etcher for silicon-based devices. Since 2016, we also provide ion implantation services and machines for the surface treatment of materials.

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