A Comparison of ArF and KrF Laser Performance At 2kHz For Microlithography

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ABSTRACT

Exposure tools for 193nm lithography are expected to use Argon-Fluoride lasers at repetition rates of at least 2kHz. We are showing that, by revisiting several key technologies, the performance and reliability of ArF lasers at 2 kHz are trending towards a level comparable to KrF lasers.

Keywords: ArF laser, KrF laser, 193nm microlithography, 248nm microlithography, Exposure Sensor Feedback.

1. INTRODUCTION

Argon Fluoride lasers are the light source of choice for the next-generation lithography at 193 nm. In 1999, 1 kHz ArF lasers have started to be used for process development by several end-users. However, those systems are not at the level of performance expected for 193 nm volume production which is expected to requires 20 W average power with better than +/-0.5% dose stability and bandwidth less than 1 pm for the 95% integral. A 2 kHz/5 mJ ArF system represents an intermediate step towards the first volume production ArF sources and allows the validation of the technology improvement that will be needed in the near future.

2. MAIN 2kHz ARGON-FLUORIDE PERFORMANCE

2.1 Spectral performance

Using Cymer's proven line-narrowing technology, the typical bandwidth performance is better than 0.5 pm bandwidth for FWHM and 1.3 pm bandwidth for 95% of the energy at 2 kHz. Figure 1 shows a spectrum obtained on a system using modules (chamber and optics) that have accumulated over 2 Billion shots: the FWHM is equal to 0.39 pm and 95% of the energy is contained within 1.05 pm.

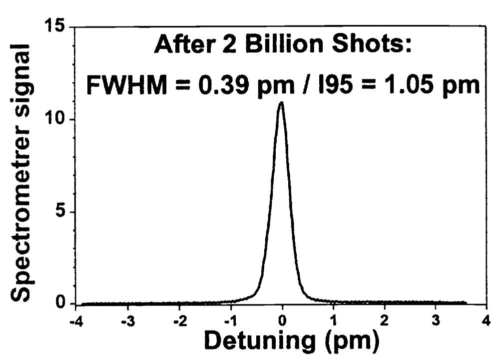

Fig.1: Typical 2kHz ArF spectrum.

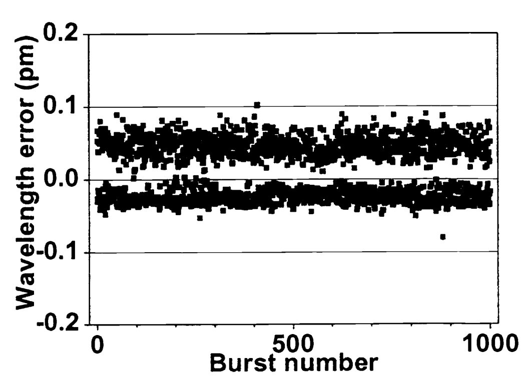

Fig.2: Wavelength stability

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The 95% integral is believed to be the key parameter influencing contrast loss of the aerial image and thus, high-resolution metrology tools are necessary. The spectrum presented has been obtained using a high-resolution 2-pass grating spectrometer developed at Cymer[1]. Another key spectral parameter is the wavelength stability. Figure 2 shows the variation of the central wavelength calculated over a sliding window containing 50 pulses. For each burst of 500 pulses, the highest deviation in both directions is recorded. Typical performance is better than +/- 0.1 pm.

2.2 Dose Stability

The second important parameter is dose stability. Integrated over a sliding window of 50 pulses, the dose stability is consistently better than +/- 0.45%. Figure 3 shows the stability obtained over 1000 bursts at 2 kHz which, for this data set, is better +/- 0.3%.

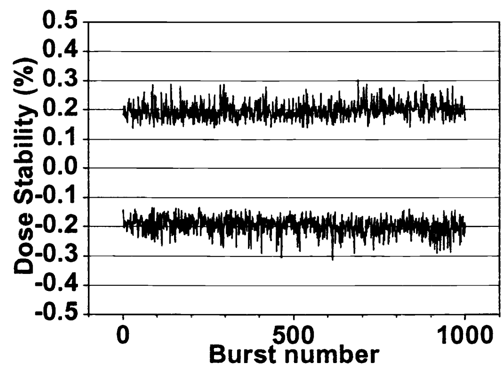

Fig. 3: Dose stability over a sliding window of 50 pulses, measured for 1000 bursts of 500 pulses

3. KEY TECHNOLOGY IMPROVEMENTS

3.1 SSPPM

In order to transfer the electrical energy more efficiently to the gas, an improved Pulsed Power Module has been developed. Figure 4 compares its performance with our previous Pulsed Power technology. The dynamic range of the laser output energy is improved by 50% enabling a higher energy extraction from the laser chamber. Laser output energy stability is also improved by 20%.

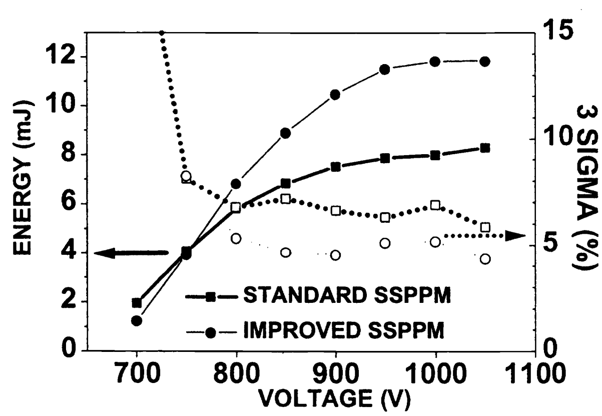

Fig. 4: Effect of an improved Solid State Pulsed Power Module on laser efficiency & stability

3.2 Discharge chamber

By revisiting key chamber technologies, a more stable and more efficient discharge chamber has been developed. Among the improvement are a more stable discharge and more efficient pre-ionization. Fig 5 shows the relative impact of both on dose stability.

An important output of the developments in Chamber and Pulsed Power technology is a four times improvement of the chamber lifetime with respect with previous 1 kHz technology. Figure 6 shows the increase of the operating voltage at 5 mJ over life for several chambers in ongoing life test. Based on this sample, we expect a chamber life better than 4 Billion shots. For the chamber that reached 4.5 Bshots (down triangles), the Line Narrowing Module has been exchanged at 2 Bshots creating the step in voltage.

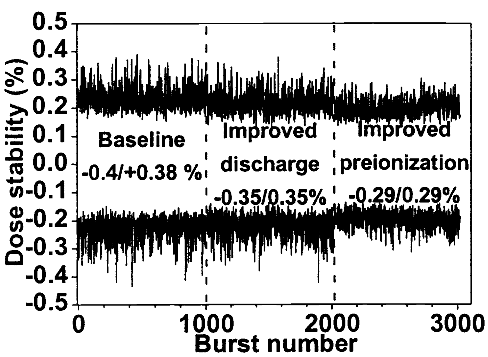

Fig.5: Improvement of dose stability with progress in chamber technology

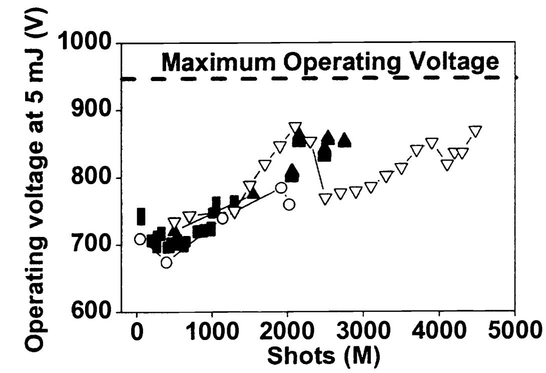

Fig.6: Result of current life testing of 4 chambers

3.3 Dose Control

Controlling the dose stability at the output of the laser does not ensure optimum dose control on the wafer since that does not take into account effects that occur in the beam delivery system or the illuminator of the scanner. The Exposure Sensor Feedback (ESF™) technology utilizes proven Cymer Energy Control (CEC™) algorithm, but with the energy sensor placed in the scanner illuminator rather than the laser. In this way, the laser compensates for both internal energy variation and transients or drifts between the laser and the exposure sensor.

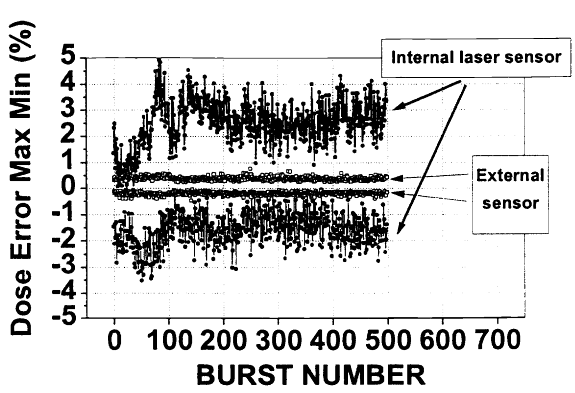

Fig. 7: ESF testing results for 2 kHz ArF

Figure 7 shows results obtained at 2 kHz where a sensor was placed on an optical table away from the laser. The use of this technique is especially critical at 193 nm where thermal effect in the scanner optics can be the source of important absorption transients.

3.4 Optical cavity: pursuit of narrow spectral bandwidth

The industry requirement for spectral performance will depend on the amount of Calcium-Fluoride the lens manufacturers will be able to use in their design, but it is believed that the 95% integral bandwidth will need to be of the order of 1 pm or less. In order to meet this expected requirement, new concepts for line-narrowing are being developed in order to reduce bandwidth 95% integral down to 1 pm or below.

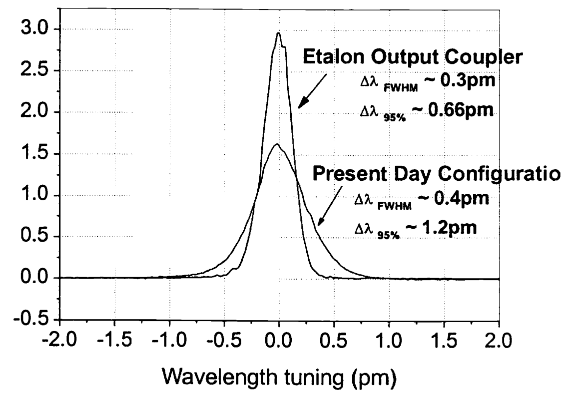

Fig.8: Spectrum measured with a standard optical cavity and the Etalon Output Coupler

Testing of the Etalon Output Coupler[2] scheme at 2 kHz ArF has demonstrated the capability of this technique to meet the future requirements: figure 8 presents a spectrum with measured bandwidth of 0.35 pm FWHM and 0.8 pm 95%.

3.5 Optical coatings, optics lifetime

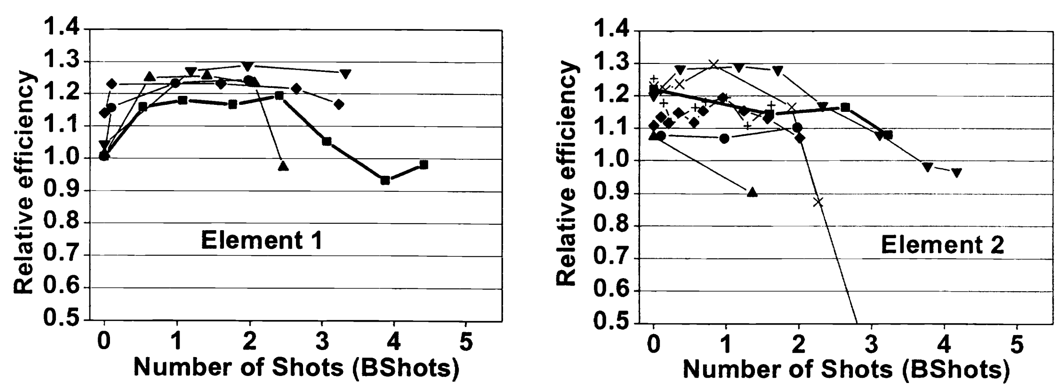

Fig. 9: Lifetime of the main optical elements in the Line Narrowing Module

Degradation of optics and especially coatings has been a concern at 193 nm. Figure 9 summarizes results of ongoing optics life testing on two of the main optical elements in the Line Narrowing Module. When evaluating optics lifetime, it is critical to run multiple tests in parallel in order to get a statistically valid estimate of the component lifetime. A significant spread in the results is noticed and is believed to be due to variations in environment control and manufacturing processes. Improvements in both directions are expected to lead to lifetime of more than 4 Billion shots.

4. LIFETIME & PERFORMANCE: A COMPARISON WITH KrF

4.1 Performance

As 193 nm introduction in production lines approaches it is interesting to compare performance and lifetime of the volume production 2 kHz KrF tools and the ArF 2 kHz system.
Since spectral requirements are a lot different due to different lens designs and materials, the only relevant parameter when comparing ArF and KrF is dose stability. If we allow for similar manufacturing margin the respective dose stability is +/- 0.5% over 32 pulses for 2 kHz KrF systems and +/- 0.45% over 50 pulses for 2 kHz ArF. If active dose control is applied, the dose stability is proportional to 1/n, n being the number of pulses in the analysis sliding window. Consequently, we recalculate both values over 50 pulses, the KrF dose stability then equals to +/- 0.32% which is 1.4 times better than ArF dose stability.

4.2 Lifetime

Concerning the performance related to cost of ownership, the following graph shows the evolution of the ratio (KrF/ArF) for module lifetime over time. For chamber lifetime, ArF is now down to 2 times KrF lifetime. As for optics, there is still a 4 times factor between KrF and ArF.

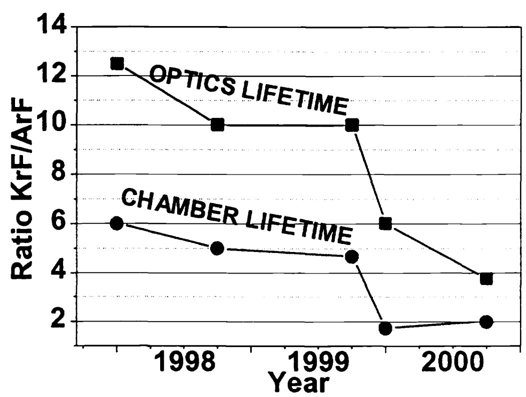

Fig.10: Ratio KrF/ArF for lifetime from 1998 to 2000

CONCLUSION

The fast pace of improvement of Argon-Fluoride laser technology now allows a sensible comparison with the established KrF technology. By improving all core modules, the performance and lifetime of ArF are now approaching those of equivalent KrF modules at 2 kHz. Also, techniques like Etalon OC and ESF address the specific issues ArF lithography brings, namely the need of highly line narrowed spectrum and compensation for transmission transients of scanner optics at 193 nm.

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