Performance of Very High Repetition Rate ArF Lasers

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ABSTRACT

We report the performance of a very high repetition rate ArF laser optimized for next generation, high NA, high throughput scanner. The laser's repetition rate exceeds 4kHz, at 5mJ, and at bandwidths of less than 1.2 pm (at 95% integral). We discuss the complexity of high power operation, and make some estimates about the robustness of this technology. In particular, we discuss the risks of scaling to this high repetition rate, and prospects of exceeding 4kHz to near 6kHz with 95% bandwidths of less than 1pm.

Keywords: ArF laser, scanner, NA, linewidth

1. INTRODUCTION

The most recent acceleration of the SIA road map has moved the 0.13 micron design node for MPU device fabrication into Y2001. Because of process ecomomy 193nm will be the preferred exposure wavelength at this dimension. While 193nm wafer process development is underway, less than two years remain for lithography tool manufacturers to complete their equipment design that meets throughput demands at acceptable COO conditions for mass volume chip production. 193nm ArF-excimer lasers are expected to operate at extremely high repetition rates to enable wafer throughput of more than 120 wafers per hour

2. THE REQUIREMENTS

2.1 More Power and higher spectral purity

Demands for high wafer throughput and better source economy by chip manufacturers are driving both, the scanner and laser technology to boost its performance to much higher levels in shortest possible time. Image resolution and contrast control of high NA scanner optics require high laser output of ultra-narrow spectral distribution. The following graph (FIG 1) show the history of the spectral power (power / laser spectrum (FWHM)) required by the industry over the last 10 years. The spectral power triple in average every three years, therefore the ArF light source riches his maturity with a power beyond 2kHZ. Cymer, is dedicated to meet the semiconductor industry requirement with a new 4kHz, 20 W highly line-narrowed ArF laser design, that will match speed and lens resolution of advanced 300mm scanners technology early 2001.

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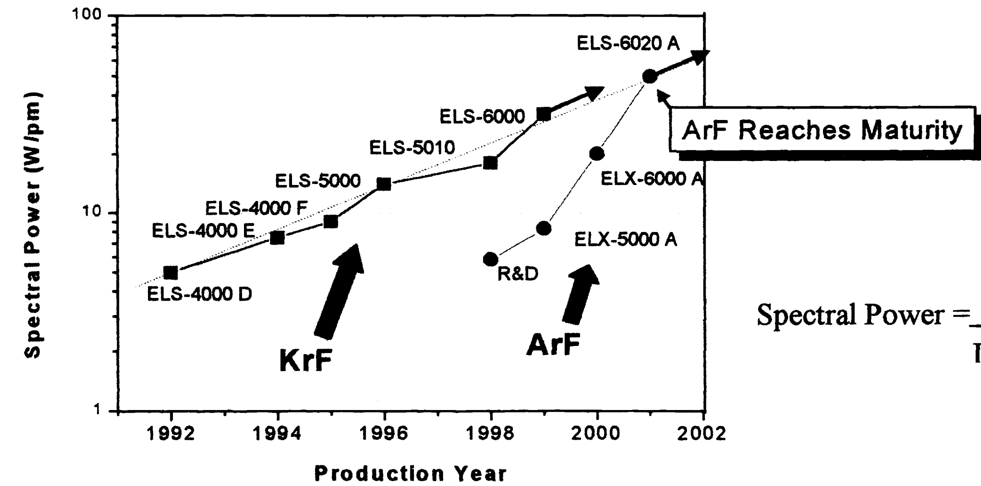


$$\text{Spectral Power} = \frac{\text{Laser Power}}{\text{Laser Linewidth (FWHM)}}$$

Figure 1: Historical trend of the Spectral Power.

2.2 The Targets

The table below compares the current performance status achieved on Cymer's 2kHz platform with the 4kHz target specifications aimed to support >0.7 NA lens contrast and 300mm/sec scan speed. Target specs for core modules lifetime as chamber and line-narrowing optics (LNM) which to a large degree determine the system CoOp are shown as well. Meeting this spec results in a 400% CoOp reduction compared to 1kHz ArF lasers installed today.

	4kHz Target	Current 2kHz
Repetition rate	4kHz	2kHz
Pulse Energy	5mJ	5mJ
Maximum power	20 W	10 W
Spectral requirement		
- Wavelength	193 nm	193 nm
- Spectral shape	1.1 pm	1.3 pm
Dose Stability	+/- 0.2 % 20 ms window	+/- 0.4 % 20 ms window
Lifetime All Modules Chamber/LNP/ Stabilization Module	> 5Bpulses	5Bpulses

3. ACHIEVEMENTS

Despite the remarkable performance that Cymer's 2kHz ArF technology has demonstrated so far, power scaling to 20Watts (4kHz) at 193nm is still a challenge, that will drive the fundamental design of the laser core laser technology as the chamber (gas flow, and heat removal), as the line-narrowing resonator (ultra-narrow bandwidth solution, and improved thermal management of LNM optics), and as the Pulse-Power Module (retain stable charging capacity at twice the repetition rate and thermal management) to implement new, innovative concepts.

3.1 Energy

The focus of Cymer's engineering efforts is to realize robust technical solutions with enough margin for at least 5 billion laser pulses. Figure 2 give a snapshot of the evolution of two of the critical laser parameters at constant voltage over a large range of repetition rate; the energy and the pulse to pulse stability (3sigma).

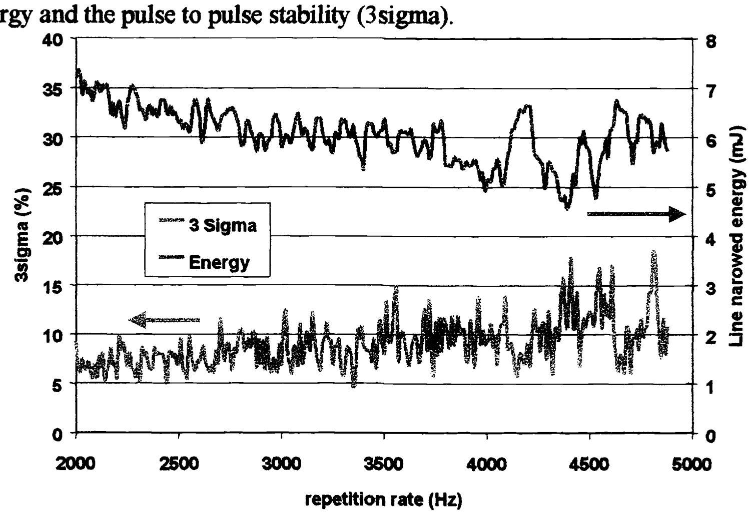


Figure 2: Energy and Energy stability (3sigma) at constant voltage versus repetition rate (5Hz step)

Therefore the technology implemented on Cymer's 4kHz ArF development lasers allows to achieve at 4kHz a dose stability measure over 20 ms comparable to the performance at 2kHz (cf. Fig.3)

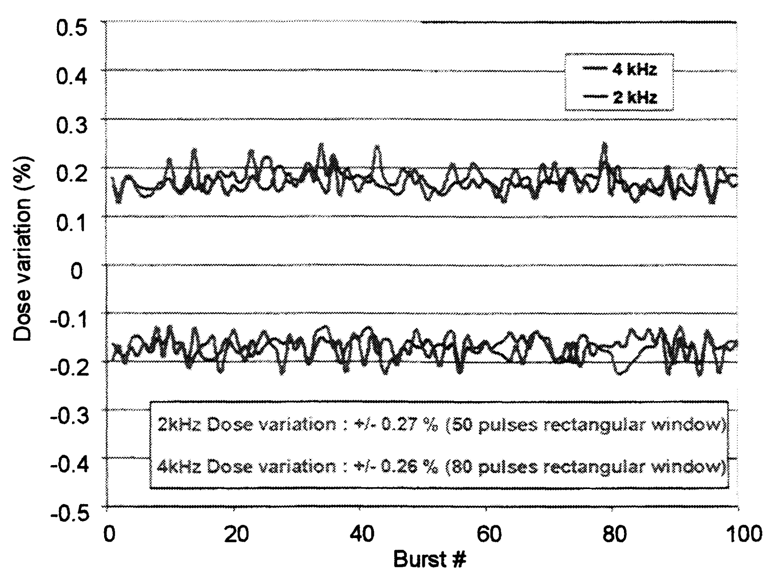


Figure 3: dose variation 4kHz operation vs 2kHz operation 500 pulses / 1s off Energy target 5mJ

3.2 Spectral purity

3.2.1 Standard optical cavity

The emphasis on the I95, which represents the bandwidth associated with 95% of the pulse energy, rather than the standard FWHM (full width half maximum) spec is also pushing the involved laser metrology to extend their limits. Fast PDA-based double pass etalon (DPES) and grating spectrometer (DPGS), able to capture each pulse have been developed at Cymer to improve the measurement accuracy and verify the true spectral performance of this new laser generation.

Figure 4 show a typical spectrum with no deconvolution applied, 95% of the integral is within 1pm and no degradation is observed between 2kHz and 4kHz.

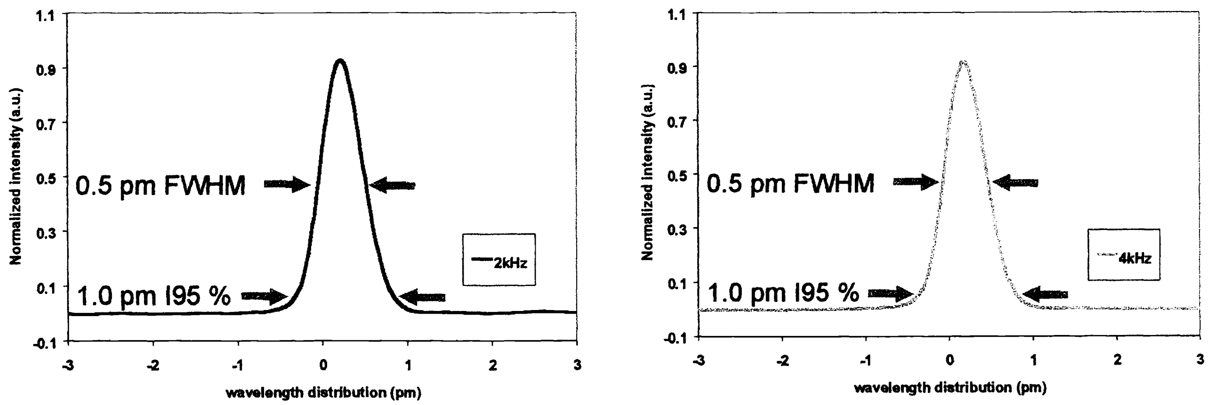


Figure 4: 193 nm convolved spectra @ 2kHz and 4kHz

3.2.2 Advanced optical cavity

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

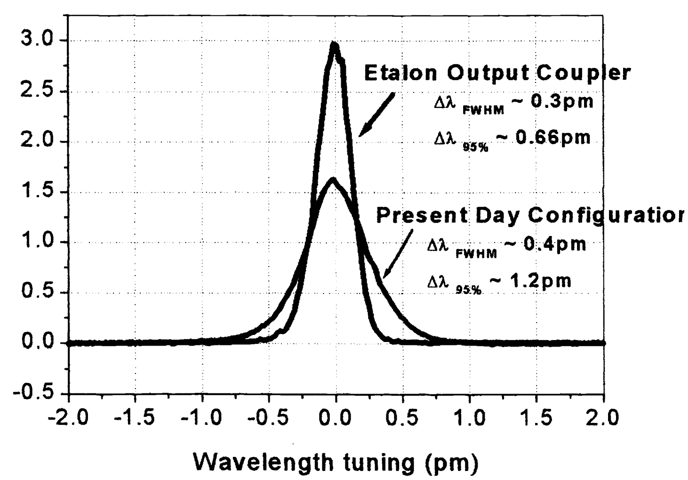
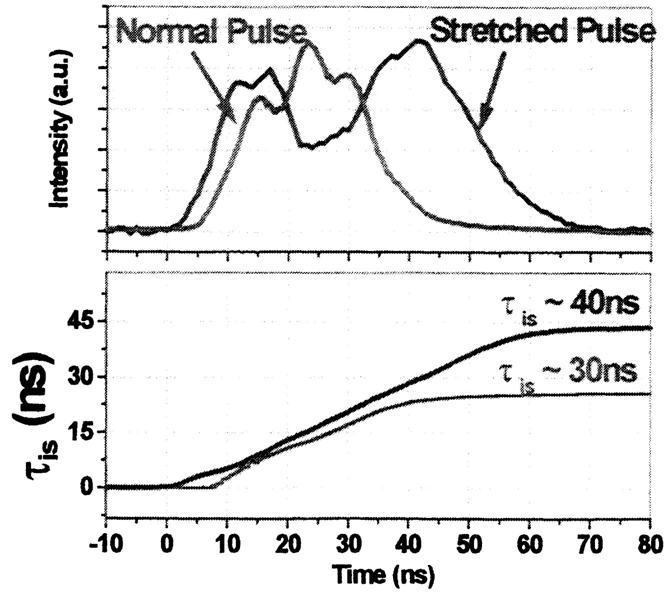


Figure 5. Comparison of the spectrum obtain with a regular cavity and with the Etalon Output Coupler.

3.3 Pulse duration

The realization of longer pulse duration, considered to reduce laser assisted optics damage, requires the implementation of a special pulse stretching technology.



Fused silica compaction model follows:

$$\delta n(\bar{x}) \propto \left(\frac{N I^2(\bar{x})}{T_{is}} \right)^{0.6}$$

Tis (total integral square pulse duration) is determined by formula

$$\text{TIs} = \frac{\left(\int I(t)dt \right)^2}{\int I(t)^2 dt}$$

Figure 6: Pulse Stretching

While the feasibility of Cymer's proprietary pulse stretching technique has been proven (cf. Fig. 6), a final answer is still missing to what extend the longer pulse duration, defined as total integral square time (Tis), will reduce optics damage and hence help to reduce the cost for optics replacements. Cymer is investigating this subject of 'low fluence compaction' in a project supported by Sematech. Its answer will be important for making the right decision for the final laser design.

4. CONCLUSION

The results presented in this paper show that scaling ArF laser from 2kHz to 4kHz without degradation in stability appears to be promising. The bandwidth target of 1pm (I95%) can be achieved. We also show that the pulse lengths (Tis) can be stretched beyond 30ns if it is actually needed.

Although no showstopper has been identified to meet the ambitious goal, Cymer is committed to an aggressive plan to complete the development and engineering work in the near future and to start volume shipment of this new generation production laser.

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