# High Reliability ArF Light Source for Double Patterning Immersion Lithography

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## ABSTRACT

Double patterning lithography places significant demands not only on the optical performance of the light source (higher power, improved parametric stability), but also on high uptime in order to meet the higher throughput requirements of the litho cell. In this paper, we will describe the challenges faced in delivering improved performance while achieving better reliability and resultant uptime as embodied in the XLR 600ix light source from Cymer, announced one year ago. Data from extended life testing at 90W operation will be shown to illustrate these improvements.

KEYWORDS: immersion lithography, double patterning, excimer laser, deep ultraviolet

## 1. INTRODUCTION

Double patterning (DP) lithography is gaining widespread use in 32 and sub-32nm technology nodes as an extension to immersion lithography. While many resolution enhancement technologies (RET) have been developed recently, including source-mask optimization (SMO)[1], and pixilated illumination[2] schemes for the scanner, the overarching requirement for the light source in double patterning has been a need for improved optical performance stability and higher power. With the introduction of the XLR 600ix light source from Cymer last year, these requirements have been met and integrated on the most advanced DP immersion scanners on the market. Key areas of improvement include higher power with flexibility to address a wide range (60 to 90W), improved energy stability, improved bandwidth stability and improved wavelength stability. The details of these improvements were reported on a previous paper[3]. These characteristics have enabled improved CD uniformity along with higher throughput operation for the litho cell to counteract the impact of the higher cost of DP lithography.

In addition to providing improved performance, the light source needs to have higher reliability and uptime in a DP environment, as the impact of down time is magnified further when the litho cell throughput is increased dramatically. In this area, the XLR 600ix was designed to address this need by building on a proven platform and introducing features that further enhance reliability and uptime. In this paper, we will describe the challenges faced in delivering improved performance while achieving better reliability and uptime on the XLR 600ix. Areas of improvement include development of advanced optics materials and coatings to provide stable performance over a wide power range (60 to 90W), an improved control system delivering faster closed-loop feedback for optical stability over extended periods, and 'smart' on-board diagnostics with predictive capability to prevent unscheduled downtime. Data from extended life testing as well as field performance data will be presented to illustrate these improvements.

## 2. TECHNOLOGY ADVANCEMENTS

Several technologies have been introduced in this light source to enable not only high power operation, but sustained performance stability under continuous operation at high power. The development of optical materials and coatings that can endure fluences in excess of 20mJ internal to the light source (in order to deliver an output of 15mJ) while staying impervious to thermal effects has been a key enabling technology. Similarly, advanced control algorithms that further reduce parametric variability in wavelength, bandwidth and energy have enabled the use of fewer pulses to achieve a desired on-wafer dose stability, which in turn leverages the use of higher energy to improve wafer throughput at the scanner. An example of such performance improvements is shown for four different light sources tested under varying repetition (rep) rates from 1.5 to 6kHz in Figure 1, where energy stability is measured.

Optical Microlithography XXIII, edited by Mircea V. Dusa, Will Conley, Proc. of SPIE Vol. 7640,
76401Q · © 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.849065

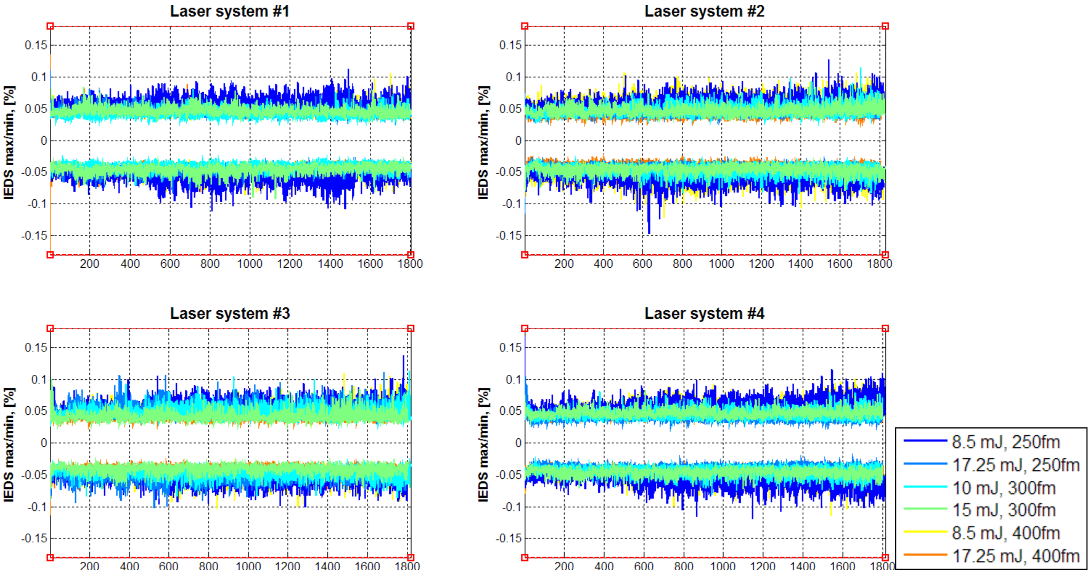

Figure 1 – Dose stability of 4 different light sources measured across various energy and bandwidth settings varying from 8.5mJ (51W) to 17.25mJ (103.5W), which covers the nominal 60 – 90W operation. The horizontal axis represents a sequence of 'bursts' or firing patterns of the test suite that include variations in rep rate, starting with 6kHz (leftmost data) and decreasing to 1.5kHz.

More recently, a new advancement in excimer laser discharge chamber technology was introduced in the XLR 600ix to further improve performance stability over life. Excimer discharge chambers have a finite operating life that is modulated by several key aging mechanisms: (a) discharge electrode erosion, (b) chamber window damage due to DUV exposure, and (c) accumulation of particulate debris, or 'dust' that are byproducts of gas interaction with chamber materials. While advances in chamber design and material selection have progressively extended the life of discharge chambers by minimizing or mitigating the aging mechanisms, they have not fundamentally addressed the observed trending of operating parameters that result from aging. For example, while electrode erosion rates can be reduced with the appropriate selection of materials and design, the change in electrode gap due to erosion is still present and can result in beam property changes over time. The new technology recently introduced with the XLR 600ix includes a new discharge chamber design that automatically compensates for electrode erosion by simply moving the electrodes physically to maintain a constant gap (Figure 2). While this concept is not new, the ability to realize it in a production-worthy light source has been elusive until now. The benefit of maintaining a constant gap between electrodes in the discharge chamber is a more stable beam characteristic in physical dimensions, and the secondary effects that can contribute to parametric stability. This translates to better stability in pupil fill, less variation in bandwidth and a resulting improved focus, overlay and CD control on the wafer.

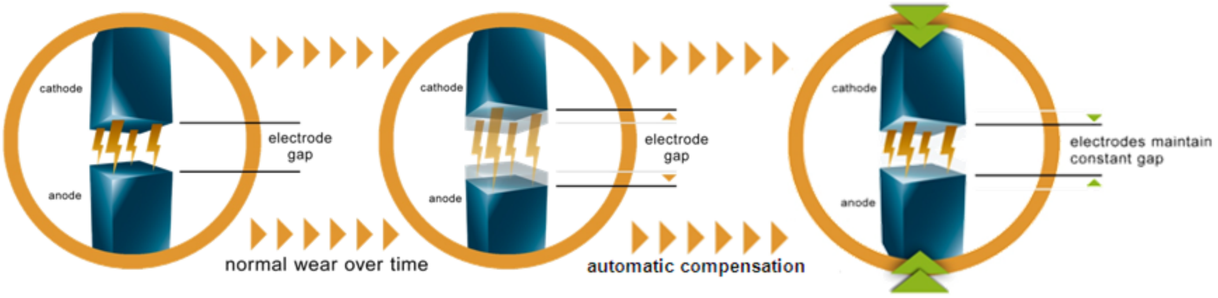

Figure 2 – Discharge chamber electrode aging results in a change in the electrode gap over time; new chamber technology recently introduced automatically compensates for this effect to maintain a constant gap as illustrated here, resulting in more stable performance over the life of this chamber.

## 3. EXTENDED RELIABILITY TESTING

While performance testing and reliability have been extensively demonstrated for light sources operating at 10mJ, 6kHz (60W), this is the first instance where extensive testing has been performed and demonstrated on a light source running 15mJ, 6kHz (90W). Previous reports on the XLR 600ix have centered on the challenges of maintaining improved light source stability while achieving higher power (90W). We report here, for the first time, extensive testing that represents ~ 1year of continuous operation at a high utilization memory fab.

In the aforementioned extended testing, a XLR 600ix light source operating at 90W was subjected to continuous operation similar to a high utilization fab environment, simulating about 1 year of operation. This testing was performed in an accelerated manner to enable completion of this test within 30 weeks, accumulating 30 billion pulses of DUV light. Interspersed with the continuous operation were periodic test suites that collected detailed parametric data to monitor light source performance. Figure 3 illustrates an example of this data set where wavelength stability is analyzed in terms of average wavelength error around the central wavelength, where the data is clustered mostly within ±5fm compared to a performance requirement for the scanner of ±12fm. Improved wavelength stability directly affects on-wafer contrast and focus, that results in improved CD uniformity.

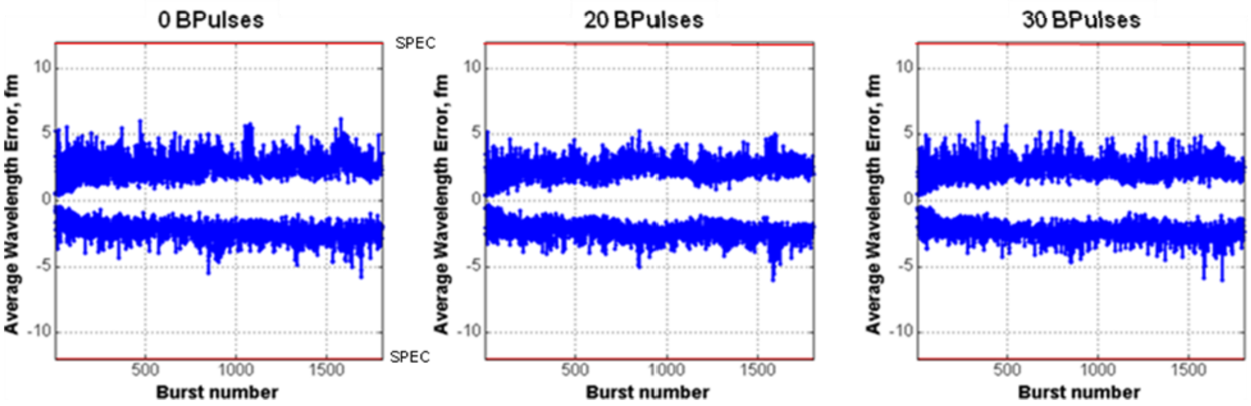

Figure 3 – Average wavelength error measured at the beginning of the extended test (0 Bpulses), at 20Bpulses and at the end of the test (30Bpulses). Wavelength error remains unchanged and mostly clustered within ±5fm around the center wavelength. The horizontal axis represents a sequence of 'bursts' or firing patterns of the test suite that include variations in rep rate, duty cycle and energy to test the effects of wavelength stability across all operating conditions.

The test suites used to evaluate light source performance periodically include subjecting the light source to variations in rep rate, duty cycle and energy to capture the performance across all operating space. Figure 4 further explores wavelength stability through wavelength sigma, indicating that most of the data across all operating conditions is clustered below 30fm, with a scanner requirement of <50fm for this technology generation.

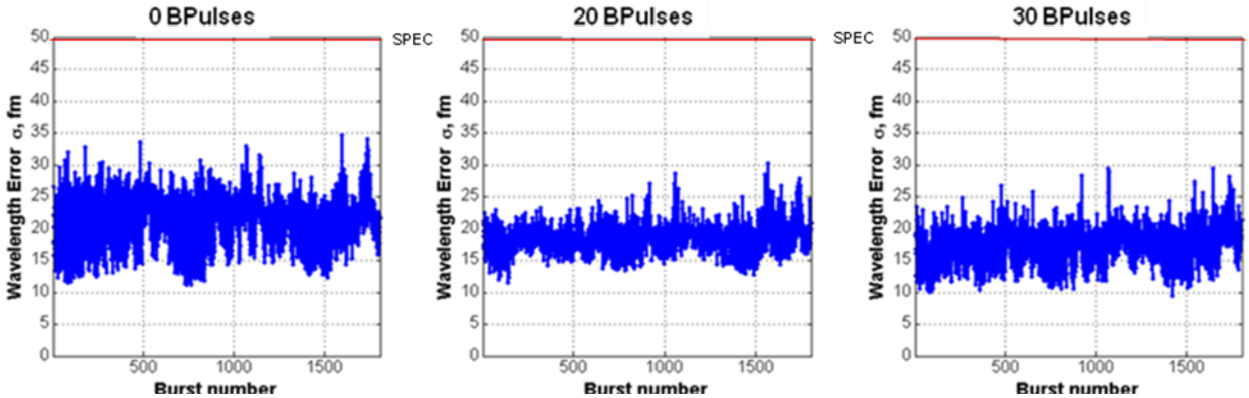

Figure 4 – Wavelength sigma measured at the beginning of the extended test (0 Bpulses), at 20Bpulses and at the end of the test (30Bpulses). Wavelength sigma remains unchanged and mostly clustered below 30fm. The horizontal axis represents a sequence of 'bursts' or firing patterns of the test suite that include variations in rep rate, duty cycle and energy to test the effects of wavelength stability across all operating conditions.

In addition to wavelength stability measurements, bandwidth stability was similarly evaluated, as shown in Figure 5. Here, the nominal bandwidth target is 300fm and is maintained through the use of active controls to support optical proximity correction (OPC) design features in the mask set with minimal variation. This in turn results in the high contrast necessary on-wafer to achieve the desired CD uniformity. The data shown in Figure 5 shows that throughout the extensive testing, the nominal bandwidth stays centered at 300fm and the variation observed across varying operating conditions (rep rate, duty cycle and energy) are mostly within 25fm.

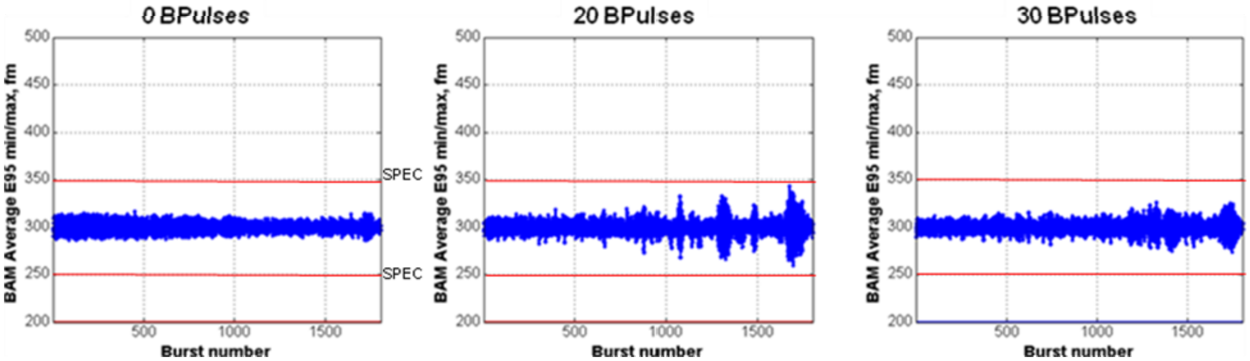

Figure 5 – Bandwidth stability measured at the beginning of the extended test (0 Bpulses), at 20Bpulses and at the end of the test (30Bpulses). Nominal bandwidth target is remains unchanged at 300fm and bandwidth variation is mostly within 25fm. The horizontal axis represents a sequence of 'bursts' or firing patterns of the test suite that include variations in rep rate, duty cycle and energy to test the effects of bandwidth stability across all operating conditions.

Energy stability was also monitored throughout the extended testing and the calculated dose stability based on a 35-pulse window was well below ±0.1%, especially at the high rep rates (Figure 6). Raw energy sigma also showed low values, mostly below 3%, with some deviations to 4% at the lower rep rates and near the end of the test period (Figure 7).

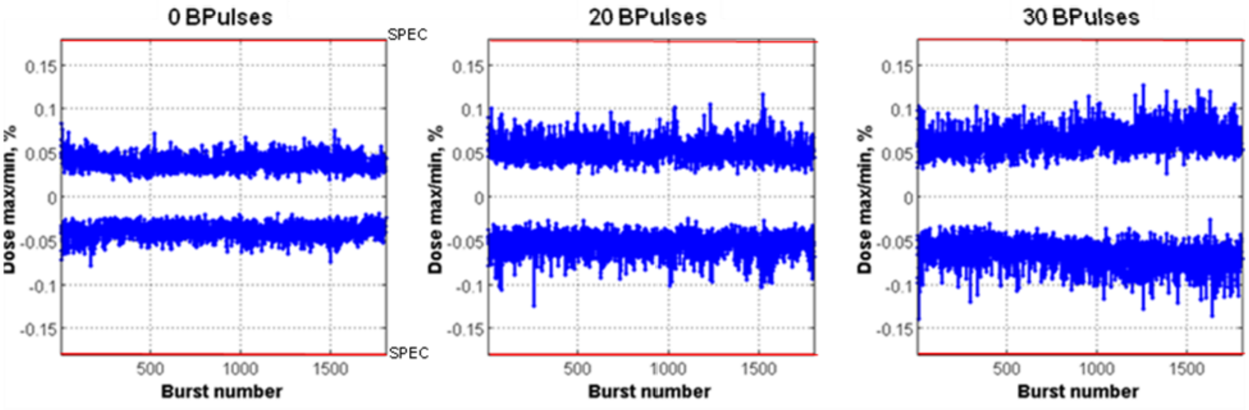

Figure 6 – Dose stability measured at the beginning of the extended test (0 Bpulses), at 20Bpulses and at the end of the test (30Bpulses). Dose variation is mostly below ±0.1%, especially at the high rep rates (6kHz) that are captured at the leftmost set of data. The horizontal axis represents a sequence of 'bursts' or firing patterns of the test suite that include variations in rep rate, duty cycle and energy to test the effects of bandwidth stability across all operating conditions.

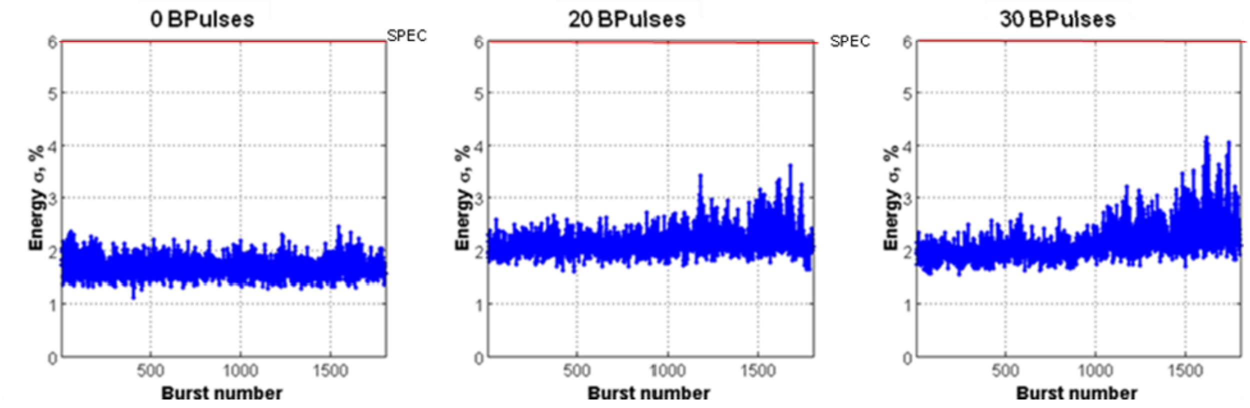

Figure 7 – Raw energy stability (sigma) measured at the beginning of the extended test (0 Bpulses), at 20Bpulses and at the end of the test (30Bpulses). Energy sigma is mostly below 3%, especially at the high rep rates (6kHz) that are captured at the leftmost set of data. The horizontal axis represents a sequence of 'bursts' or firing patterns of the test suite that include variations in rep rate, duty cycle and energy to test the effects of bandwidth stability across all operating conditions.

## 4. PERFORMANCE MONITORING

While fundamental improvements in performance and reliability have been introduced with this light source, a complementary, an operational infrastructure is key in maximizing uptime and utilization. In particular, serviceability and maintainability of the light source can dramatically enhance the litho cell performance with better performance and productivity. Cymer light sources have historically been 'connected' to provide near-real-time performance data to a centralized monitoring station. Initially, this connectivity enabled remote monitoring by experts who could better direct field service personnel on a particular maintenance activity, based on symptoms and their experience. Statistical-process-control (SPC) type charting augmented this capability by flagging light sources that were showing signs of less than ideal performance, helping proactively schedule maintenance before an unscheduled event occurred. More recently, we introduced algorithms that mine this data to extract unique performance signatures, essentially automating the analysis and providing specific guidance to the field service engineer. The on-board light source control system continuously monitors the system state for anomalous behavior. When an anomaly is encountered, a high-data-rate log of key signals is automatically sent to the central monitoring station. Sophisticated fault-signature detection (FSD) algorithms that reside on the central station that employ pattern recognition functions analyze this data to identify known patterns associated with a particular subsystem. As this data is amassed, a picture of the health of the system is developed and a maintenance action can be scheduled to proactively correct the issue. The net result of this approach is that fewer unscheduled events occur, and when a maintenance action is required, it can be scheduled to ensure the proper resources and parts are in place to minimize down time (Figure 8).

Figure 8 – Down time reduction through automation of data analysis of light source performance data. Centralized data collection and warehousing enables the use of fault signature detection (FSD) to automate knowledge derived from laser experts, which can trigger a scheduled maintenance action. Continuous diagnostics generation shortens or eliminates the time required to troubleshoot a fault.

In parallel, a routine that runs periodically on the light source collects a 'fingerprint' or performance state of the system which can be used during a service event to quickly identify the source of degraded performance, thereby minimizing the time required for troubleshooting. This function tracks key performance indicators so that once a service event is concluded, the light source can be restored back to its 'healthy' state.

## 5. SUMMARY

As 193nm immersion lithography is further challenged with double patterning applications, stringent demands are placed on the light source to enable improved CD uniformity, overlay and OPC performance. The XLR 600ix light source described here exceeds these requirements and further enhances the lithographer's toolbox by providing flexibility in power output. Demonstrated extended performance at 90W supports the requirements of high-throughput double patterning applications, where high uptime and utilization are expected. Such high uptime has been achieved through the use of new optics and chamber technology, as well as a data infrastructure and analysis capability.

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