Extending The Performance Of KrF Laser For Microlithography By Using Novel F_2 Control Technology

Paolo Zambon, Mengxiong Gong, Jason Carlesi, G. G. Padmabandu, Mike Binder, Ken Swanson and Palash Das

Cymer Inc., San Diego, CA 92127

ABSTRACT

Exposure tools for 248nm lithography have reached a level of maturity comparable to those based on i-line. With this increase in maturity, there is a concomitant requirement for greater flexibility from the laser by the process engineers. Usually, these requirements pertain to energy, spectral width and repetition rate. By utilizing a combination of laser parameters, the process engineers are often able to optimize throughput, reduce cost-of-operation or achieve greater process margin. Hitherto, such flexibility of laser operation was possible only via significant changes to various laser modules. During our investigation, we found that the key measure of the laser that impacts the aforementioned parameters is its F2 concentration. By monitoring and controlling its slope efficiency, the laser's F2 concentration may be precisely controlled. Thus a laser may tuned to operate under specifications as diverse as 7mJ, $\Delta\lambda_{FWHM}<0.3$pm and 10mJ, $\Delta\lambda_{FWHM}<0.6$pm and still meet the host of requirements necessary for lithography. We discuss this new F_2 control technique and highlight some laser performance parameters.

Keywords: KrF laser, 248nm microlithography

1. INTRODUCTION

Lithography engineers optimize process parameters for numerous reasons. For an excellent discussion about litography process control, consider the recent informative book by Dr. Harry Levinson [1]. For example, consider the situation involving critical dimensions (CD). Linewidths are determined by number of factors, such as exposure dose, resist thickness, post exposure bake temperature etc. At the same time, the throughput of the scanner must be maximized for the process. The throughput (WPH) depends on the sensitivity of resist, the scanner parameters and the laser repetition rate (Figure 1). Finally, the process must be optimized for lowest cost-of-operation (CoO). This is done by using minimum number of pulses for exposure for a given resist sensitivity.

Typically, we find that a process may require controlling one or several factors to optimize a parameter. These factors could be quite varied. For example, for tighter CD control the dose stability at the wafer may need to be optimized by optimizing the scanner speed. In another instance, for lower resist sensitivity, the power from a 2kHz laser may be too high, requiring optical attenuation by scanner optics. The engineer is faced with the situation in which optimization of a process may require operating laser at repetition rate and output energy other than its nominal design parameter. But, lasers are optimized for performance (dose stability etc.) at a fixed repetition rate and energy. Usually, performance degrades when either energy or repetition rate is change (Figure 2). This laser limitation severely restricts the process engineer in optimizing the process for throughput, CD control or CoO.

If a laser supplier such as Cymer were to guess what a procees engineer requires, it would be a microlithography laser with variable repetition rate and energy. With variable repetition rate, the scanner stage speed and laser repetition rate would be perfectly matched. Thus, for example, the process engineer can now slow down the stage speed and the corresponding laser repetition rate to improve control of some parameter such as CD and still retain the laser's performance parameters (dose stability, wavelength stability etc.). With variable energy, the laser may be matched to the dose required at the wafer, without the use of scanner attenuation optics. If a process requires only 8mJ (target energy) from a 10mJ laser, the laser

In *Optical Microlithography XIII*, Christopher J. Progler, Editor, Proceedings of SPIE Vol. 4000 (2000) • 0277-786X/00/$15.00

could be operated at that target energy. Without the laser's energy flexibility, the reduction in energy would be achievd by the scanners's attentuator. Often times, the attentuator may not be able to adjust to the target energy. In such cases, the laser is operated at 10mJ, the attentuation reduces the output to 7mJ and then the number of pulses from the laser is increased by the factor 8/7 or 14% to provide the necessary dose at the wafer. With the flexibility of tuning the laser in energy, now, just the right number of pulses are used, which could lead to increased throughput or reduced cost-of-operation (since the number of pulses used from the laser matches dose requirements).

In this work, we show that indeed variable repetition rate and energy is possible, if some simple optimization of the laser is done prior to exposing a the lot of wafers. This optimization procedure takes < 1 minute which is usually less than the lot exchange time As a result, the laser's operating range in greatly increased and provides increased flexibility to the proces engineer.

2. PROPOSED TECHNIQUE FOR VARIABLE REPITITION RATE, VARIABLE ENERGY OPERATION

Tests at Cymer show that by changing the laser's operating conditions, the laser's performance paraemeters could be changed. Thus, prior to exposing a lot, the scanner could inform the laser about the laser's required repetition rate and energy (determined by the process engineer). We refer to this as a "LOT CHANGE" signal, as this signal would indicate to the laser that the laser would indeed be operated differently for the subsequent lot, and that the laser would not be used for exposure in the imminent future for a period of few minutes. The laser could then use the lot change signal to optimize its conditions. Examples of parameters used for laser's internal optimization are the following: Total gas pressure, F2 partial pressure, speed of the laser's blower (lower repetition rate requires lower blower speed) and adjustment of laser's energy control algorithm. The laser will then check itself for optimum parameters and inform the scanner when it is ready for exposure. Tests show that this process takes less than 1 minute, which is usually less than the time taken to change the lot.

It should be noted that variable repetition rate and variable energy operation is achieved without any change to laser modules. The optimization process described here could be completely automated and does not require user intervention.

The principle of variable repetition rate and variable energy laser, under command from scanner (via the LOT CHANGE signal) is shown in Figures 3 & 4. For a given F2 pressure, the laser's output energy depends on the total gas pressure. Thus, the laser's output energy may be changed by adjusting the total pressure of the laser. This takes less than 30 seconds. Also, the linewidth shows a slight dependence on energy, but this appears to be small. **Note that the change in gas pressure is not a gas refill!**
The laser's blower speed decreases with reduced repetition rate. Reduction in blower speed takes less than 2 seconds. The laser's self-learning dose control algorithms must learn about the change in energy and repetition rate. This takes less than 30 seconds.

3. RESULTS

Table 1 shows the changing conditions of a 2kHz, KrF (Cymer ELS-6000) laser used for lithography. The laser's energy, repetition rate were varied and for each energy or repetition rate the gas pressure, blower speed and the "self learning" dose control algorithm was varied. In recent months, Cymer has developed a new F2 injection technique that locks the laser's F2 concentration to within about 1 or 1.5kPa. This new technique is able to compensate for changing F2 concentration and gas pressures. In Figure 5 we show how the laser's operating voltage varied. The cause of the variation is due to te change in laser's energy (or repetition rate) and depletion of F2 as laser operates. The F2 concentration is maintained automatically by periodic F2 injections. In the case when the energy of the laser is increased (say from 7 to 10mJ), the total gas pressure is increased. When energy is decreased (say from 10 to 7mJ), the total gas pressure is decreased and a small amount of F2 is added to compensate for the loss of F2 during the reduction of total pressure. Thus, when the totall pressure is reduced from 290kPa to 250kPa, the initial F2 concentration reduces by 24 – 24*250/290 or 3.3 kPa. This is the amount of F2 that is injected to compensate for the loss of F2 due to the process of gas pressure change. Figure 6 shows the variation of gas pressure during this variable energy and repetition rate demonstration. Figures 7, 8 and 9 show the dose stability, linewidth and wavelength stability are maintained during the tests. Variations in linewidth due to energy are small, and the improvement in wavelength stability at higher repetition rate is also observed.

4. CONCLUSIONS AND COMMENTS

We show that the process engineer has increased latitude from the laser due to the laser's operation at variable repetition rate and energy. This is expected to increase process control (such as CD) or minimize number of pulses required to expose resists. We show that this laser operation is possible without a change in the laser's core modules (chamber, optics, SSPPM). Instead, it requires a LOT CHANGE signal from the scanner in which the laser is informed about the exact exposure conditions. We also show that, by adjusting gas pressure, F2 pressure, blower speed and the laser's self learning energy control algorithm, a 2kHz 10mJ ELS-6000 can be operated from 7mJ, 750Hz to 12mJ, 1500Hz. The estimated time to optimize laser after LOT CHANGE signal is less than 1 minute. The optimization procedure is completely automated. A point worth noting is that the variable repetition rate and variable energy operation of the laser is not expected to have any adverse affect on the laser's cost-of-operation if the energy is at 10mJ or below. This is because, variable energy operation is achieved by adjusting laser's operating conditions to meet all conditions (dose stability, linewidth, wavelength stability etc.)

5. REFERENCES

1. Harry Levinson, Lithography Process Control, SPIE Press Vol. TT28, (1999).

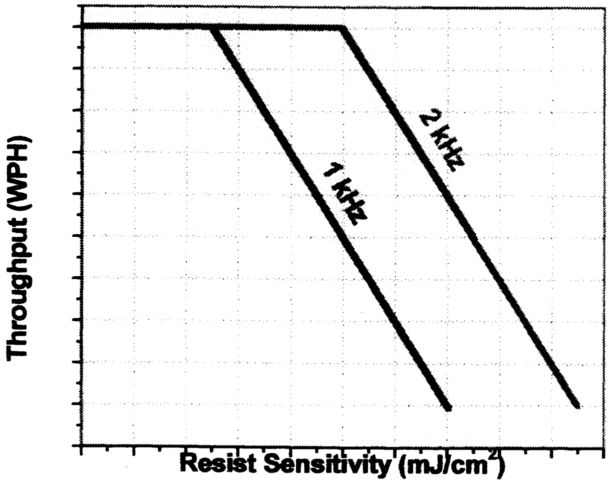

Figure 1. The throughput, measured in terms of Wafers per hour depends on laser repetition rate as well as resist sensitivity.

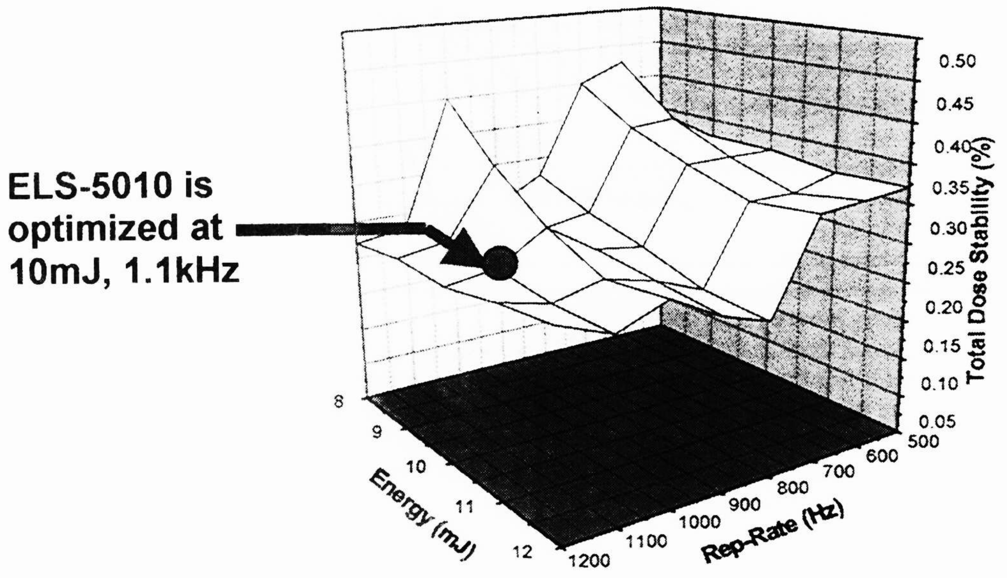

Figure 2. Lasers are usually optimized at a given energy and repetition rate.

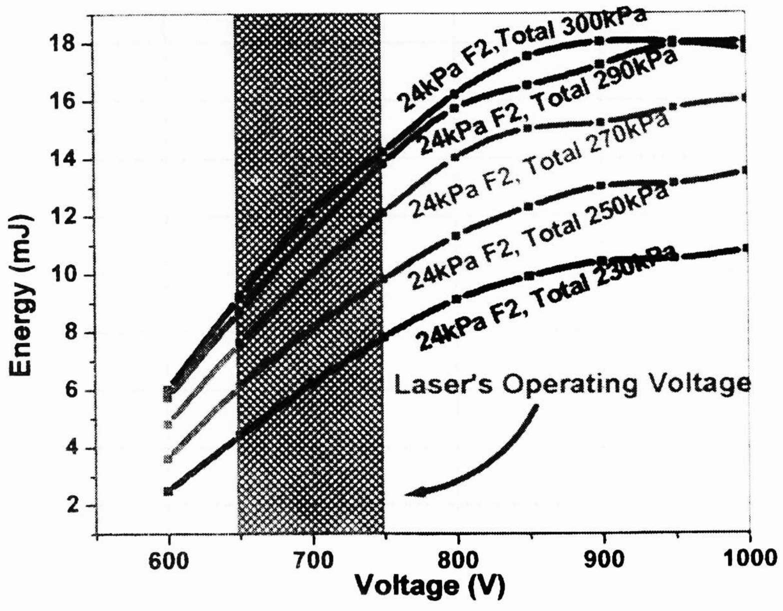

Figure 3. For a given F2 pressure, the laser output depends on total fill pressure.

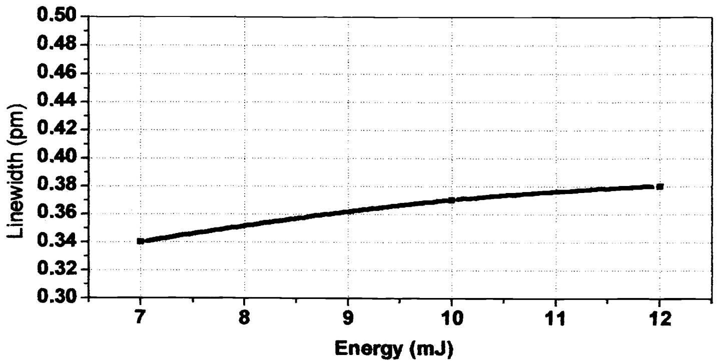

Figure 4. The laser linewidth is slightly sensitive to laser energy.

A	➡	7mJ, 2kHz, F2=24kPa, Total Pressure = 250kPa
B	➡	10mJ, 2kHz, F2=24kPa, Total Pressure = 290kPa
C	➡	12mJ, 1.5kHz, F2=24kPa, Total Pressure = 300kPa, blower speed optimized
D	➡	10mJ, 1kHz, F2=24kPa, Total Pressure = 290kPa, blower speed optimized
E	➡	7mJ, 2kHz, F2=24kPa, Total Pressure = 250kPa, blower speed optimized
F	➡	7mJ, 0.75kHz, F2=24kPa, Total Pressure = 250kPa, blower speed optimized

Table 1: Changing operating conditions (energy, repetition rate, total fill pressure, blower speed).

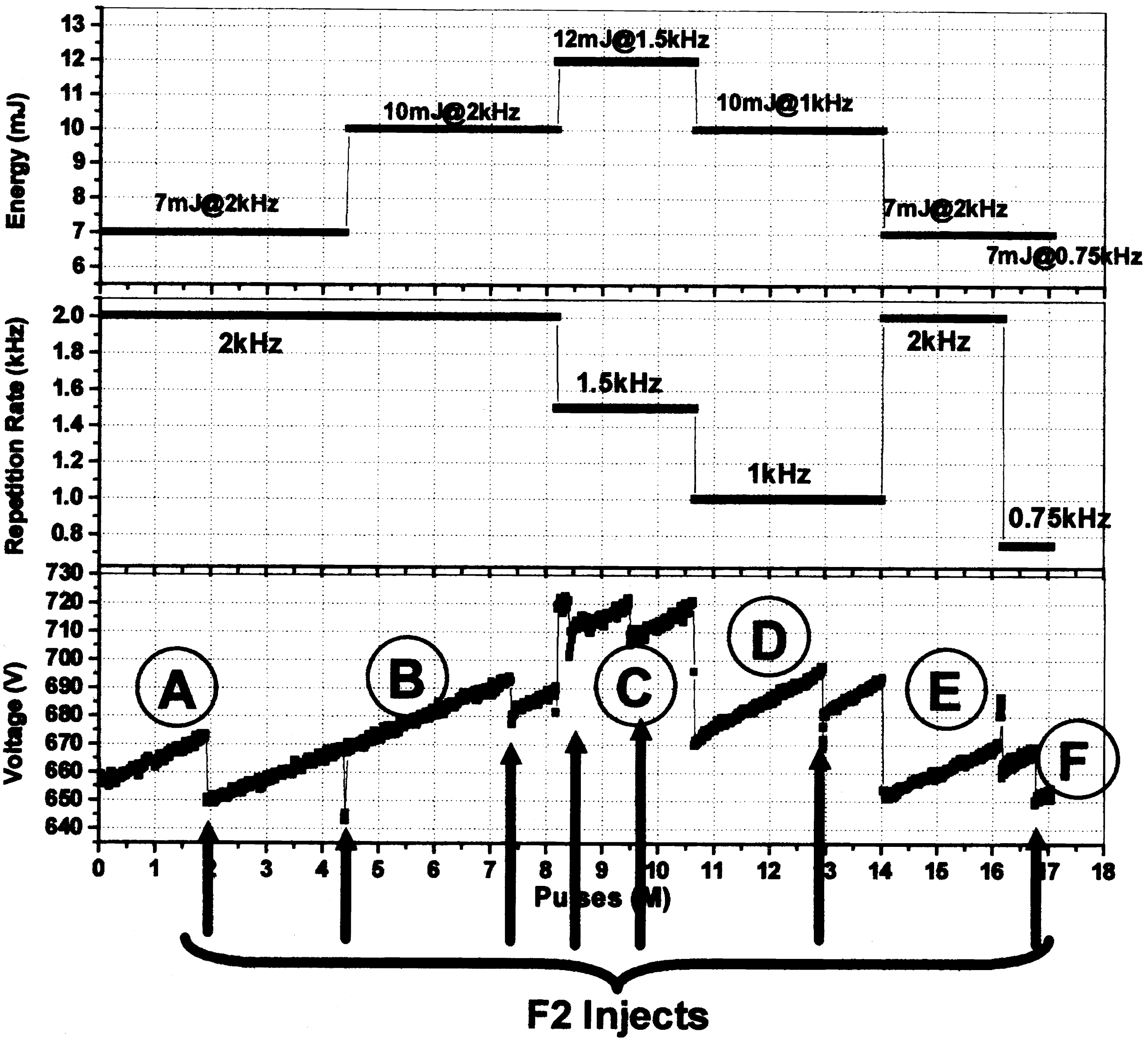

Figure 5. Effect of laser voltage on changing gas pressure, energy and repetition rate. Note that A and E are under identical conditions, and that the fact that the laser performed identically under A and E conditions proves that the gas mixture retained its appropriate concentrations between A and E.

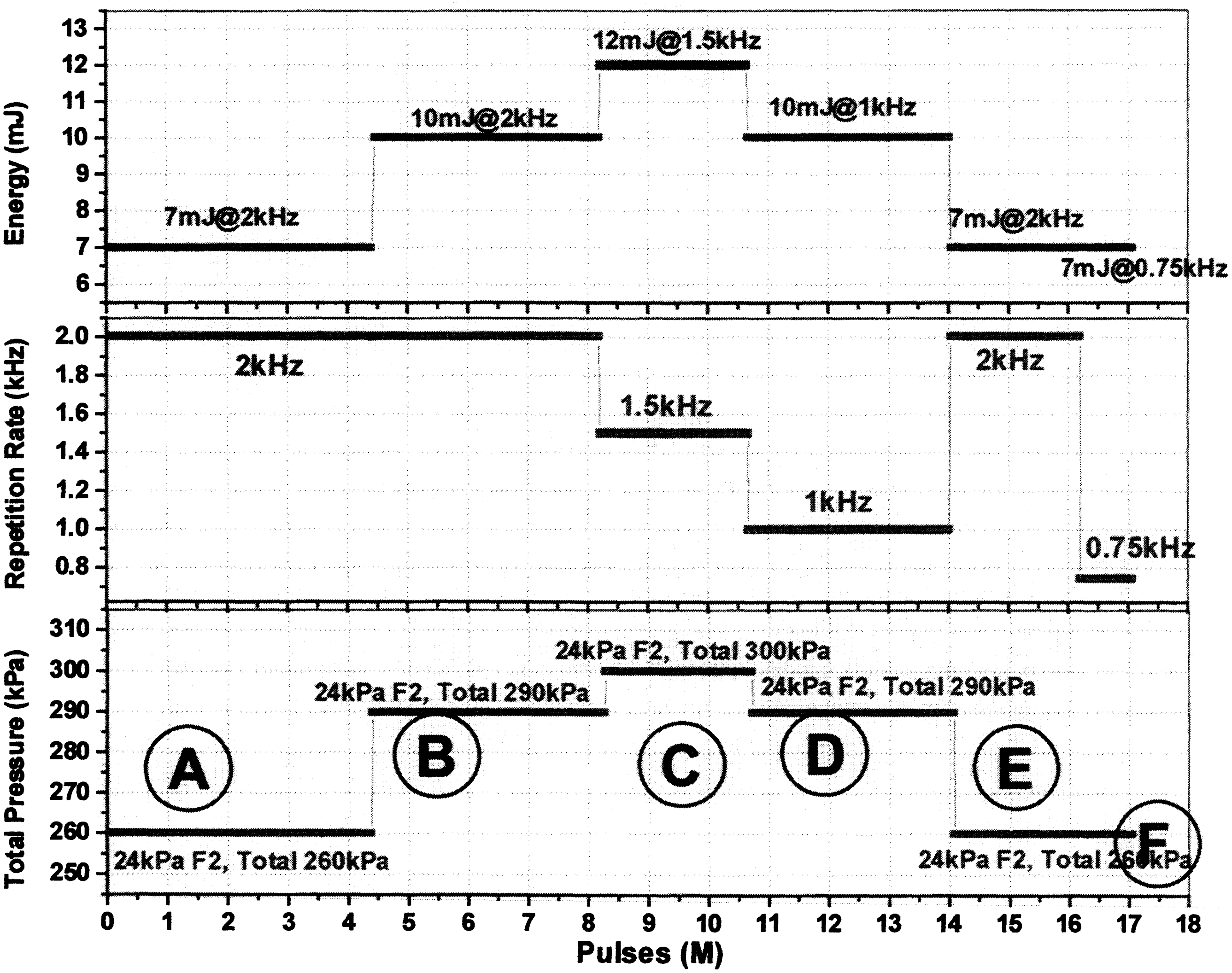

Figure 6. Details about the changing gax mixture and pressure during variable repetition rate and variable energy operation.

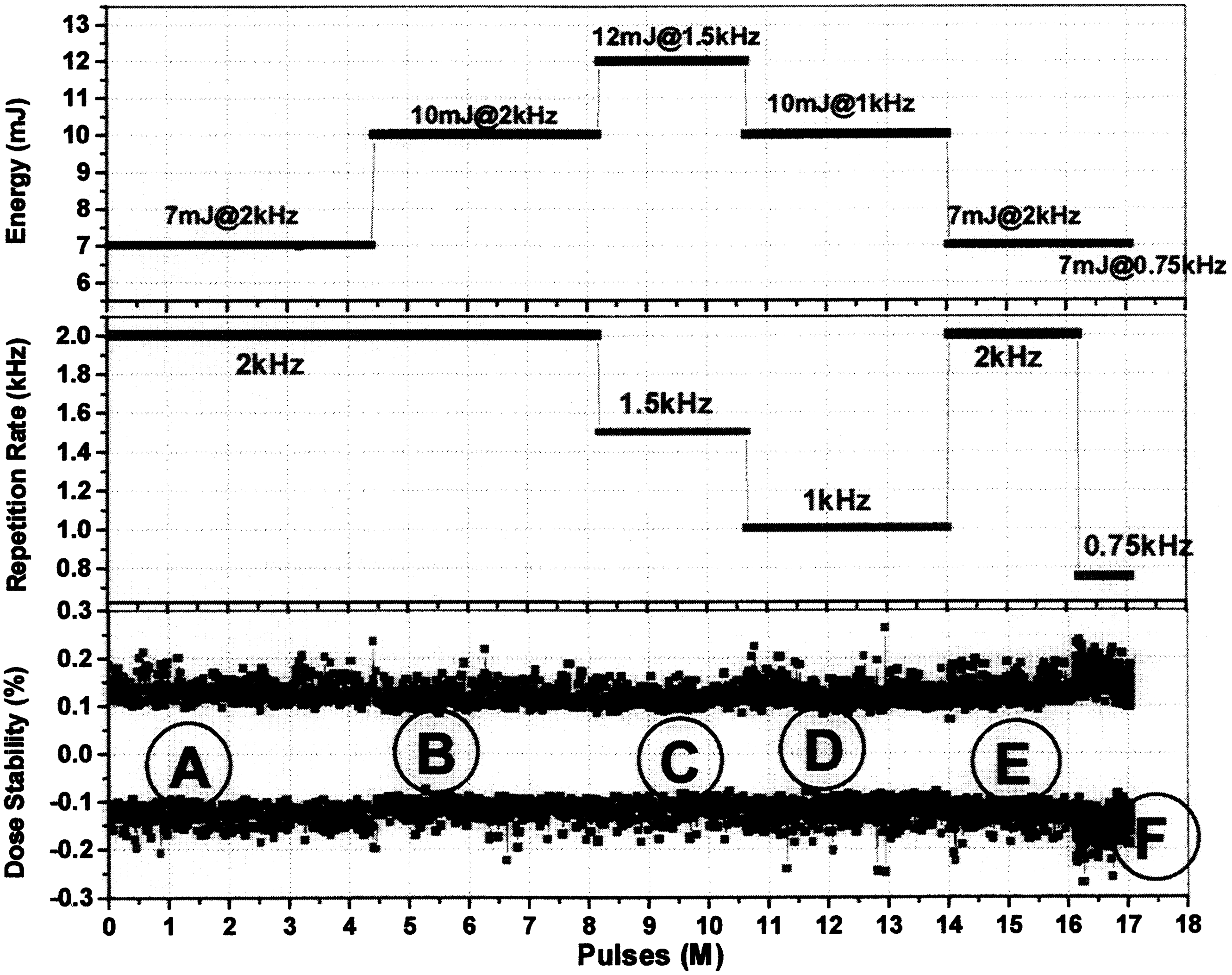

Figure 7. Details about the dose stability during variable repetition rate and variable energy operation.

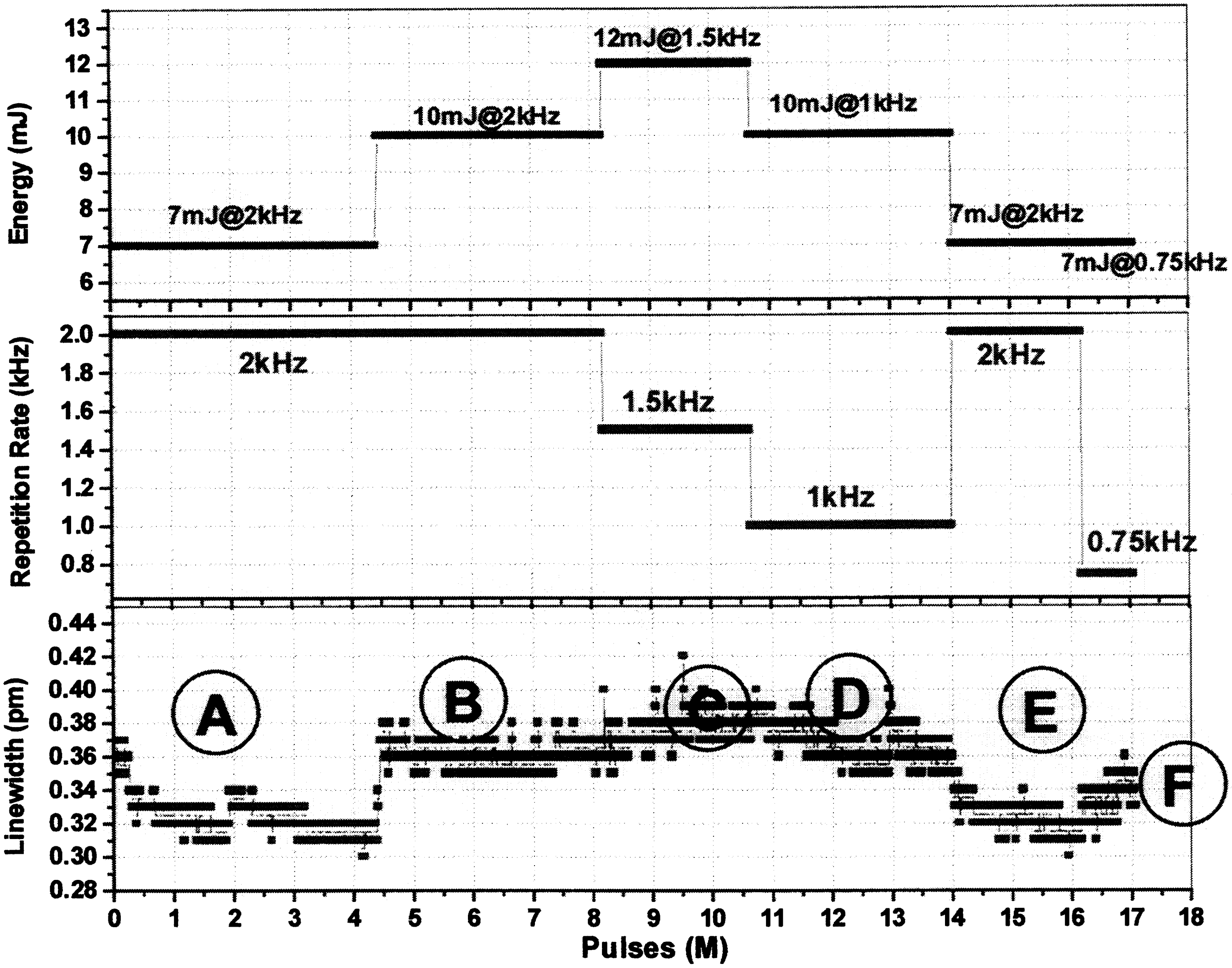

Figure 8. Details about the linewidth stability during variable repetition rate and variable energy operation.

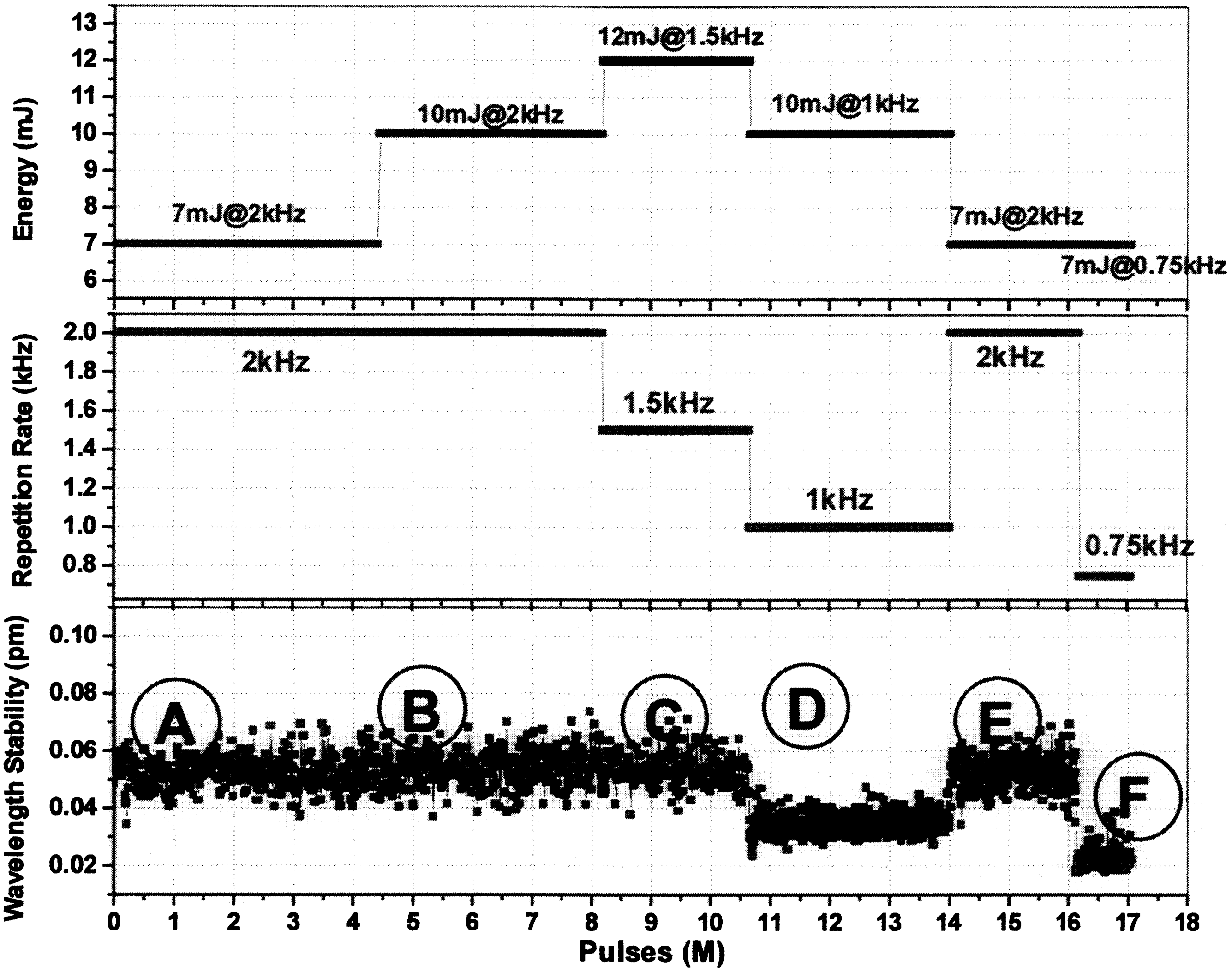

Figure 9. Details about the wavelength stability during variable repetition rate and variable energy operation.