Technology for monitoring shot-level light source performance data to achieve high-optimization of lithography processes

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Masato Moriya*, Hideyuki Ochiai, Yoshinobu Watabe, Keisuke Ishida,
Hiroyuki Masuda, Youichi Sasaki, Takahito Kumazaki, Akihiko Kurosu, Takeshi Ohta,
Kouji Kakizaki, Takashi Matsunaga, Hakaru Mizoguchi
Gigaphoton Inc., 400 Yokokurashinden, Oyama-shi, Tochigi 323-8558, JAPAN

ABSTRACT

Gigaphoton has developed a new monitoring system that provides shot-level light source performance data to FDC systems during exposure time. The system provides basic monitoring data (e.g. Energy, Wavelength, Bandwidth, etc.) and beam performance data, such as Beam Profile, Pointing, Divergence, Polarization can also be monitored using a new metrology tool called the Beam Performance Monitor (BPM) module. During exposure time the system automatically identifies the start and end timing of the wafer and each shot based on the burst of firing signals from the scanner, and stores the measured data in sequence. The stored data is sorted by wafer or by shot, and sent to REDeeM Piece which in turn converts the data to the user's protocol and send it to the FDC system. The user also has the option to directly view or download the stored data using a GUI. Through this monitoring system, users can manage light sources data at the shot or reticle level to facilitate optimization of performance and running cost of the light source for each process. This monitoring system can be easily retrofitted to Gigaphoton's current ArF laser light sources. The beam splitter of the BPM was specially designed to bend only a small fraction of the source beam, so we are able to simply install the BPM without the need for special optical alignment.

Keywords: ArF excimer laser, 193nm lithography, FDC, monitoring system, beam performance metrology

1. INTRODUCTION

FDC (Fault Detection & Classification) systems are widely adopted by lithography processes in order to improve the yield rate and availability factor of facilities. Recently there have been some attempts to stabilize and optimize the lithography process by using the FDC system to read and analyze the light source performance data of each wafer[1] [2]. In addition to the three typical metrology items (Pulse Energy, Wavelength, and Bandwidth), the beam parameters (Beam Profile, Pointing, Divergence, and Polarization) of the light source are measured at the wafer level using a new in-situ metrology module and provided to the FDC system. It is expected that these enhanced monitoring capabilities contribute to

1) The ability to find correlations between light source parameters and lithography performance, such as CD control, and identify clues for improving stability or optimizing light source cost that is tailored to each user's process.
2) The ability to check or minimize the change of beam parameters before and after service events of the light source.

In this paper we report our new monitoring systems which provide shot-level light source performance data and the prospects of their advantages that will expand benefits of monitoring at the reticle level.

2. ENHANCED LASER MONITORING SYSTEM

2.1 System configuration

The new monitoring systems, which we call sMONITORING and eMONITORING, can be easily added to Gigaphoton's GT62A series ArF Excimer Lasers and successive models. Table 1 shows their system configuration, and Figure 1 shows their system overview diagram. The sMONITORING system intercepts and provides basic monitoring data, such as

*masato_moriya@gigaphoton.com; phone +81-285-28-8416; fax +81-285-28-8439; http://www.gigaphoton.com

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Wavelength, Energy, E95 Bandwidth, Chamber Gas Pressure and HV. The conventional Main Controller can retrieve this basic data every 5 seconds, but introducing additional control hardware (Control Box and Branching unit) will allow the system to acquire the data more frequently at shot-level intervals.

The eMONITORING system also provides shot-level beam performance data, such as Beam Profile, Pointing, Divergence, and Degree of Polarization. To obtain the beam performance data provided by eMONITORING, we have developed a new metrology module called the Beam Performance Monitor (BPM) module that can be retrofitted to our existing light source. Users are able to leverage the best configuration from these enhanced monitoring systems in terms of cost performance.

During exposure time, the Control Box automatically identifies the start and end timing of each wafer and each shot based on the burst of firing signals from the scanner, and stores the measured data in sequence. The stored data is sorted by wafer or by shot, and sent to the REDeeM Piece software which in turn converts the data to the user's protocol and sends it to the FDC system. The user also has the option to directly view or download the stored data through a graphical user interface.

Table 1. Configuration of enhanced laser monitoring system

Item		**sMONITORING**		**eMONITORING**
Data acquisition interval		every 5 sec.	by shot	
Key performance data monitoring -Energy -Wavelength -Bandwidth (E95, FWHM) -Chamber Gas Pressure, Life time etc.		✓	✓	✓
Beam performance data monitoring -Beam Pointing -Beam Divergence -Beam Size, Centre of Gravity Position -DOP (Degree of Polarization)		N/A	N/A	✓
Additional hardware	Control Box and Branching unit	N/A	✓	
	BPM (New metrology module)	N/A	N/A	✓

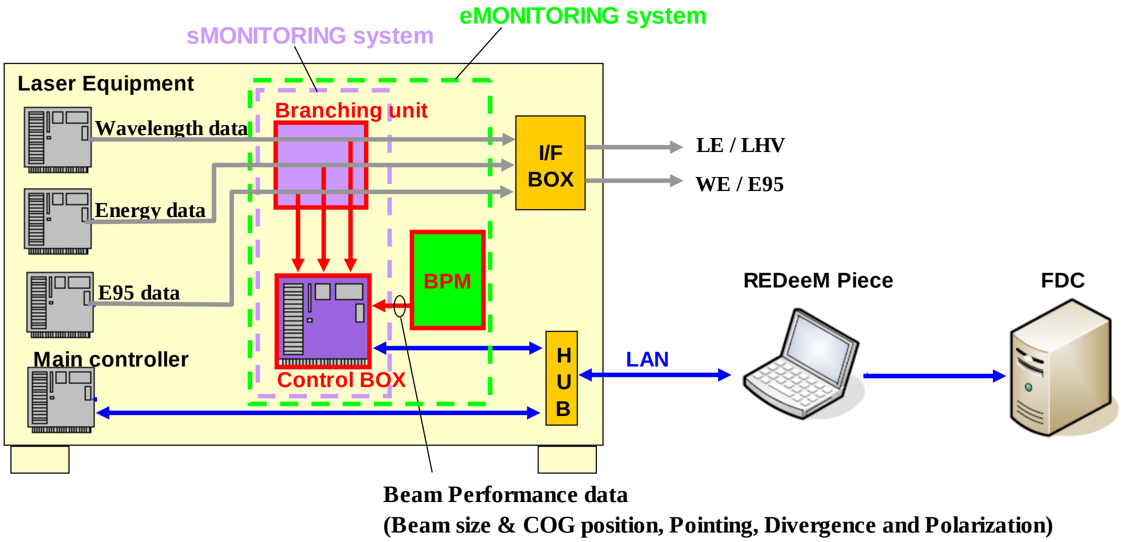


Figure 1. System overview diagram

2.2 The Beam Performance Monitor module

The BPM module is equipped with the following three sensors and functions.

Sensor	Function
1) BP sensor	Captures the near field image of the beam and measures Beam Size and COG Position
2) BD sensor	Captures the far field image of the beam and measure Beam Divergence and Pointing
3) Polarization sensor	Measures the beam's DOP

Figure 2 shows the actual captured images of the BP and BD sensors when the BPM module is installed in the GT63A laser. Images are captured during each shot, and the Control Box calculates the beam performance data through image processing.

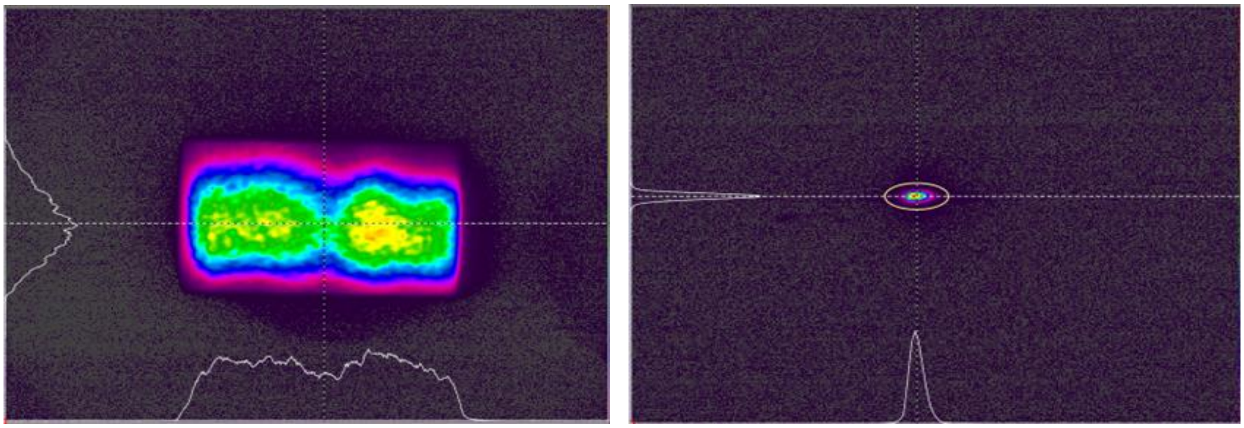


Figure 2. Captured images from the BP (left) and BD (right) sensors

When we define our laser's main polarization as p-polarized, the polarization sensor of the BPM will detect the s-polarized radiance of every pulse. For s- and p-polarized radiances, *Is* and *Ip*, respectively, the degree of polarization, or DOP, is calculated as follows:

$$\text{DOP} = \frac{Ip - Is}{Ip + Is} \tag{1}$$

Since the BPM measures the *Is* of every pulse, and the conventional Monitor Module measures total radiance (*Em*) of every pulse which is equivalent to *Ip+Is*, we can calculate DOP as follows:

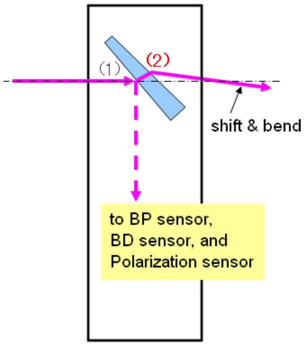
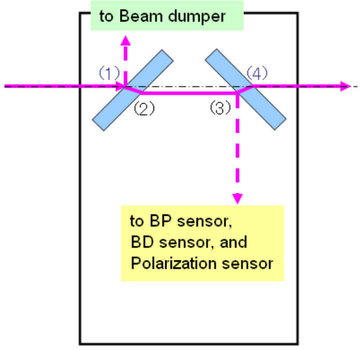
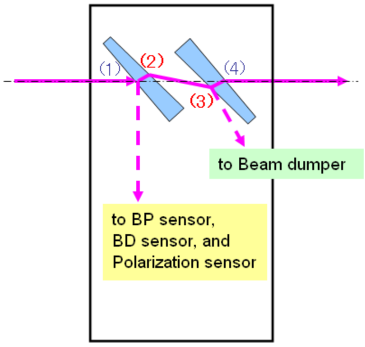
$$\text{DOP} = \frac{(Ip + Is) - 2Is}{Ip + Is} = \frac{Em - 2Is}{Em} \tag{2}$$

The Control Box calculates shot-level DOP data by using the *Is* data from the BPM and *Em* data from the Monitor Module.

The beam splitter (BS) in the BPM module was specially designed to bend only a small fraction of the source beam. This enables us to simply install the BPM without the need for special optical alignment and helps to reduce service time of the laser source conversion.

During our initial design of the BPM module's BS, we considered multiple design variations at shown in Table 2. The ultimate decision was to adopt the type 3 configuration. Type 1 is a typical design of a single BS that samples the near field image of the beam using a wedged substrate. It can reject ghost image reflected from back surface (4) of the substrate, but type 1 has a fatal problem where the wedged substrate shifts and bends the original beam. The type 2 configuration is able to keep the original beam from shifting and bending, but it is not able to adequately suppress back surface reflection, even if we adopt state of the art anti-reflection coating. In the type 3 design, the second wedge substrate compensates shift and bend of the beam due to the first wedged BS, but in order to minimize power loss, we positioned the angle of incidence on the surfaces (2) and (3) to Brewster's angle. This has proven to be the best solution.

Table 2. Configuration of the beam splitter

	Type 1	Type 2	Type 3
BS configuration	 One BS (wedged substrate) (1) AOI = 45 degree (2) AOI = Brewster's angle	 Two BS (parallel substrate) (1), (2), (3), (4) AOI = 45 degree	 Two BS (wedged substrate) (1), (4) AOI = 45 degree (2), (3) AOI = Brewster's angle
Shift and bend of beam	NG	OK	OK
Ghost image on BP sensor	OK	Not acceptable even if AR coating is adopted on (4)	OK
Power loss	～0.8%	−	～1.7%
Volume claim	Small	Large	Medium

We manufactured two identical wedged substrates and aligned surfaces (1) and (4) in parallel, as well as (2) and (3) simultaneously. To maintain the pointing and position of the original beam, we have to keep the above optical alignment intact. To achieve this, we designed special mounting holders for the BS optics that have enough stability against mechanical and thermal impact.

3. APPLICATION DATA

3.1 Light source performance data in shot-level

Figure 3 shows the acquired data scheme and its relationship to the shot map of a wafer. In our monitoring system, data is acquired at the shot-level, which means reticle-level monitoring. User can monitor or analyze data not only at the wafer-level, but also at the reticle-level in a wafer. In the shot map, the yellow colored reticles, which tend to be located at the edge of the wafer, are automatically excluded by the software. The Control Box sorts the effective shot data (shown in blue), calculates the wafer data, and sends both data to the user's FDC system through REDeeM Piece. Wafer data is an average of all the shot data in a single wafer. The maximum, minimum, and standard deviation are also calculated.

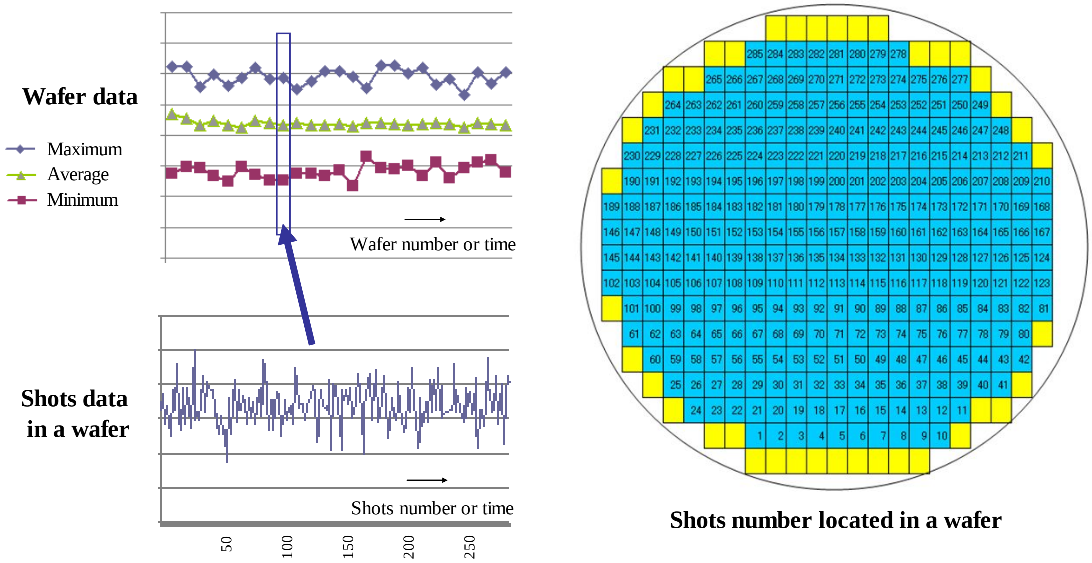


Figure 3. Scheme of acquired wafer- and shot-level data and example of shots map in a wafer

Figure 4 shows the actual shot data from the DOP. The data tends to get slightly worse through one wafer exposure. During the next wafer's initial shots, the DOP recovers and the trend is repeated as shown in Fig. 4. We know this trend is caused by the thermal transient of laser optics, but do not believe this fluctuation of the DOP affects lithography performance. But we expect that, with our new monitoring system, the user will investigate the trend of the shots data in a wafer, verify the stability of the beam parameters for each reticle, or determine whether the light source parameters play a critical role in affecting the outcome of a particular location on the wafer during exposure.

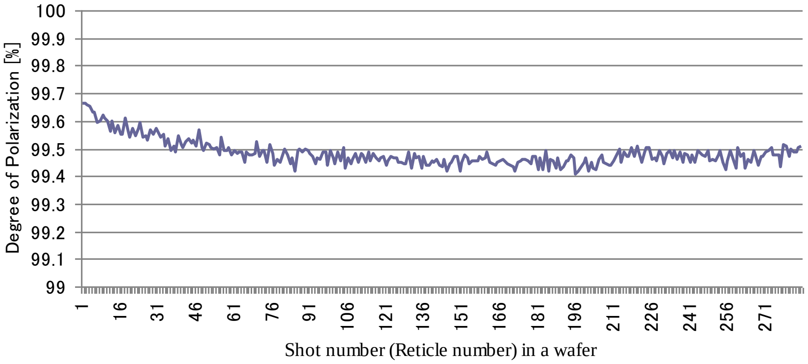


Figure 4. Actual DOP data of shots in a wafer

In Figure 5, we also added other beam performance shot data which were obtained using the BPM. We ran our laser through an emulated shot pattern of a chip maker and acquired the resulting laser parameters. The data is plotted in order of time. Each data block belongs to shots in a wafer, so seven wafer shots are shown in the graph.

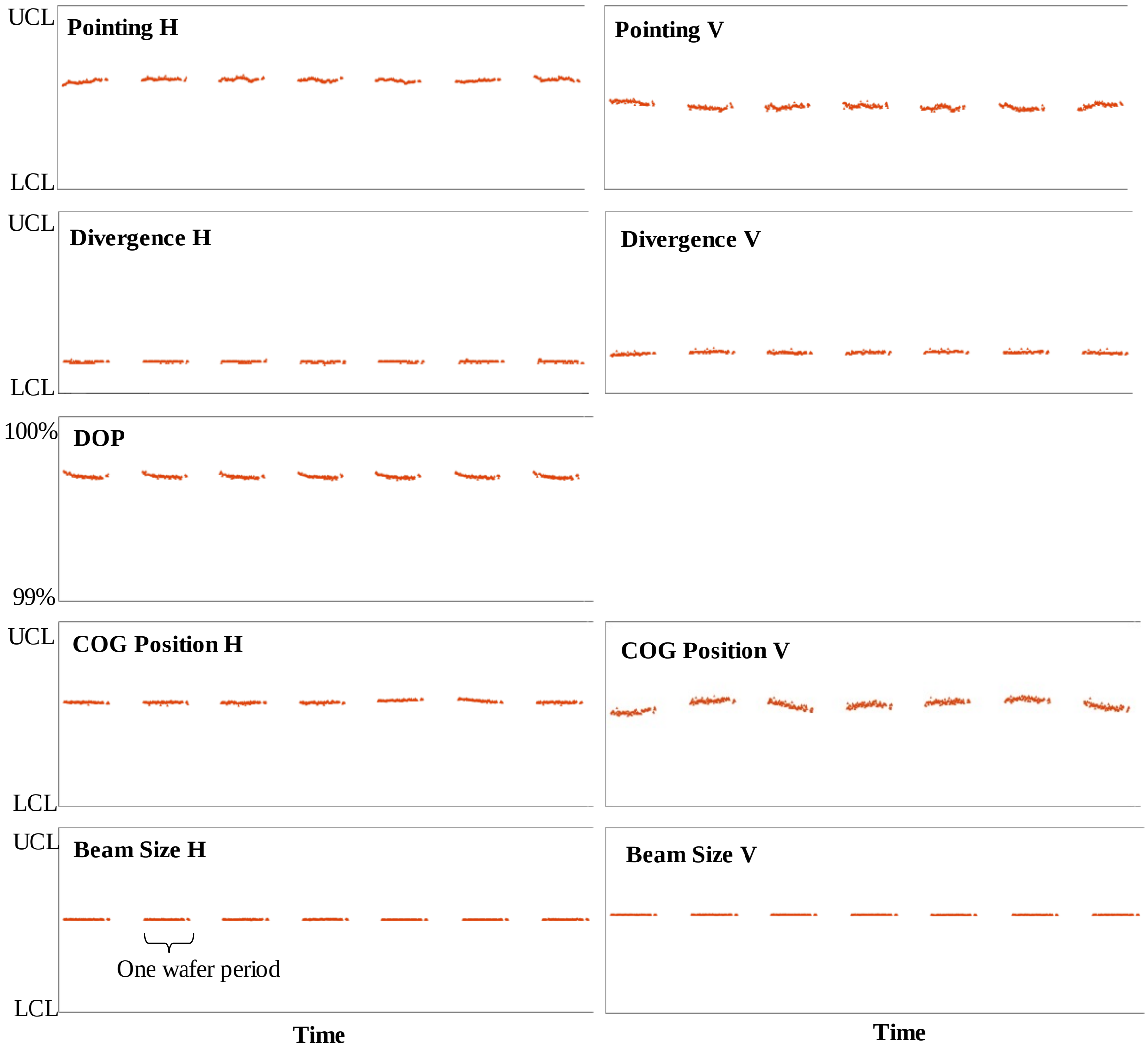


Figure 5. Other shot data measured using the BPM

3.2 Long-term source performance data

We installed the eMONITORING system into our GT63A laser and ran module life time tests to obtain the long term performance data of the light source. Figure 6 shows the obtained data during about a 2.5 month period. On November 12th we replaced the Line Narrowing Module (LNM), AMP chamber, and the Optical Pass Stretcher (OPS) module because they ran over their expected lifetimes. This monitoring data shows that this service event caused changes to the Beam COG position, Divergence, and DOP of the light source. Beam pointing, however, was precisely maintained during this replacement service.

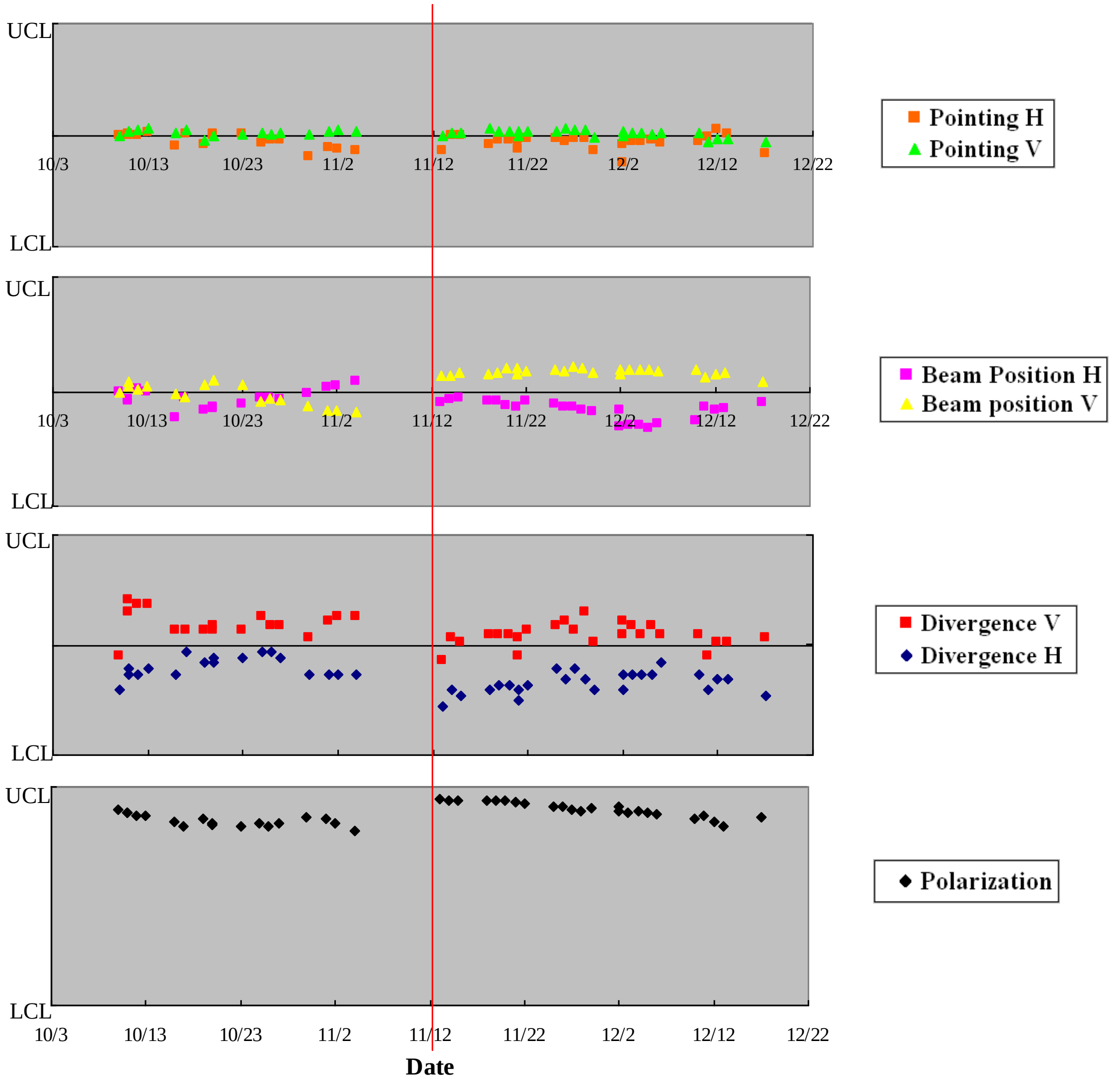


Figure 6. Long term data measured with BPM

In this way, we can check the long term light source performance stability and also change of beam parameters before and after service events. However all of obtained data were within the specified control range, but we can recognize drifts and gaps in the beam parameter. If these drift and gaps are critical for stability of the lithography process, we have to further improve stability of our light source or improve accuracy of adjustment procedure during service events. On the other hand, if users consider some parameters as being less strict in maintaining process performance of lithography, they will able to keep using the light source as long as its parameters are within their specified critical range – effectively reducing the overall running cost of light source and frequency of service events.

Since the wafer data includes not only the average of wafer shots but also its maximum, minimum, and standard deviation as shown in Figure 4, and we can also check the variations of the min-max differences and standard deviations over long term operation.

4. SUMMARY

Gigaphoton has developed a new monitoring system that provides shot-level light source performance data to FDC systems during exposure time.

The system provides basic monitoring data (e.g. Energy, Wavelength, Bandwidth, etc.) and beam performance data, such as Beam Profile, Pointing, Divergence, and Polarization monitored at the shot-level, using a new metrology tool.

Through this monitoring system, users can manage light source data at the shot or reticle level to facilitate optimization of performance and running cost of the light source for each process.

This monitoring system can be easily retrofitted to Gigaphoton's existing ArF laser light sources

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