A 193NM EXCIMER LASER MICROSTEPPER SYSTEM

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ABSTRACT

An excimer laser microstepper, intended for R&D studies of 193nm lithography, is described. System details such as the laser performance, beam transport, wafer handling and photoresist processes are outlined.

Keywords: 193nm lithography, excimer laser, 300mm wafers, photoresists.

1. INTRODUCTION

The desire for ever-smaller feature sizes in the photolithographic manufacture of integrated circuits has led to the development of sources of increasingly shorter wavelengths. Commercial steppers using krypton fluoride lasers (at 248nm) are already available and their implementation in production lines has taken place. It appears that I-line and DUV laser technology will be used in tandem for feature sizes from ~0.25μm down to ~0.2-0.18μm. Below features of 0.18μm, argon fluoride lasers (at 193nm) are likely to be the sources of choice.

There are a large variety of issues concerned with the use of 193nm lasers in production steppers which need to be addressed. These include: laser performance; the characteristics of the optics (including material data, long-term stability, damage assessment); projection lens developments; coatings for 193nm (high reflecting, anti-reflecting and partially transmitting); testing of new photoresists (sensitivity, resolution, stability).

Another aspect which is now being actively pursued by consortia in the USA, Europe and Japan is the development of 300mm wafer technology. It is predicted that there will pilot 300mm fab lines in place in 1998/99, leading to full-volume production facilities around the turn of the century.

A small-field, 193nm microstepper has been developed by Exitech to evaluate some of these lithographic issues and this microstepper is also capable of handling 300mm wafers. This tool - the Series 8000 Microstepper - is intended to serve as a R&D workstation for 193nm lithography and its performance is described here.

2. SYSTEM DESCRIPTION

The microstepper tool comprises a Lambda Physik LPX210i excimer laser, beam transport and homogenisation system, mask stages, an all-refractive 0.5NA, x10 imaging lens and XYZθ wafer tables. It is shown in Figure 1 and drawn schematically in Figure 2.
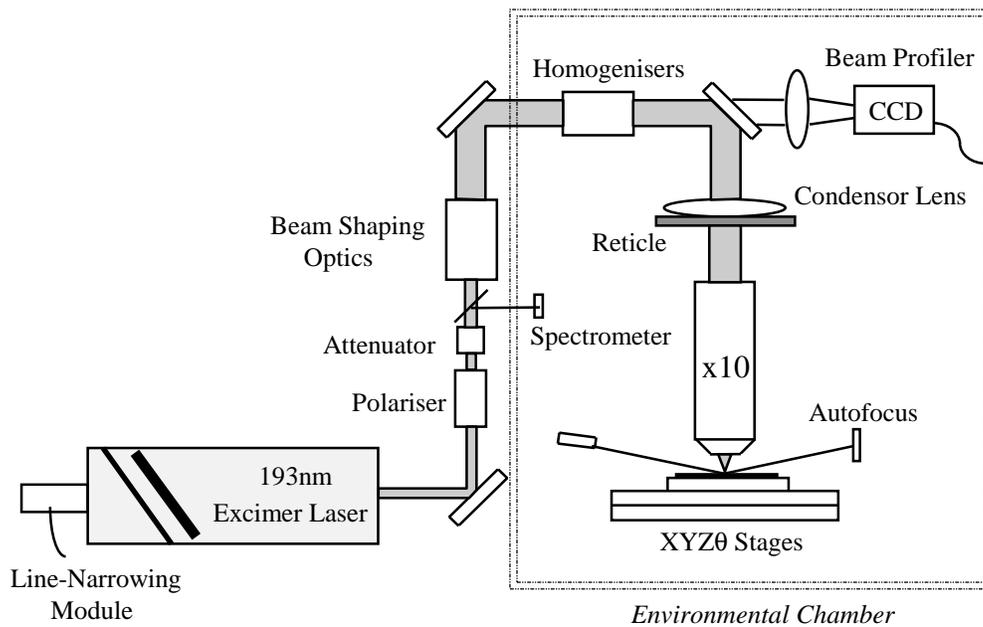

Figure 1. The Series 8000 193nm Microstepper

Figure 2. Schematic diagram of 193nm Microstepper

2.1 Line-narrowed excimer laser

The use of an all-refractive imaging lens requires a line-narrowed laser source for chromatic correction. The Lambda Physik LPX210i laser, which operates at a maximum repetition rate of 100Hz, is line-narrowed by Exitech. The line-narrowing technique utilises an all-reflective arrangement using gratings. The use of transmissive etalons in the laser cavity for line-narrowing can lead to severe optical damage problems of the bulk silica and the etalon coatings, thereby greatly reducing their lifetime.

It can be shown that where a grating is employed in a laser cavity, the linewidth per pass, $\delta\lambda$, is a function of the grating resolution and dispersion and can be represented as:

$$\delta\lambda \approx \frac{\lambda}{2\tan\theta}\left\{\left(\frac{\Delta s}{L}\right)^2 + \left(\frac{\lambda}{\omega}\right)^2\right\}^{\frac{1}{2}} \quad , \tag{1}$$

where λ is the wavelength of light, L is the distance between the grating and an aperture of size Δs, θ is the angle of incidence on the grating and ω is the width of the beam on the grating. The output laser linewidth is related the above expression but also affected by the number of round-trips in the laser cavity.

It can be seen from equation (1) that increasing the width of the beam on the grating reduces the linewidth per pass, and hence the total linewidth. One method of achieving this is to expand the beam size on the grating by the use of one or more prisms. The amount of magnification given by a prism is a function of the prism material, the apex angle of the prism and the angle of incidence of the beam on the surface. This is plotted in Figure 3.
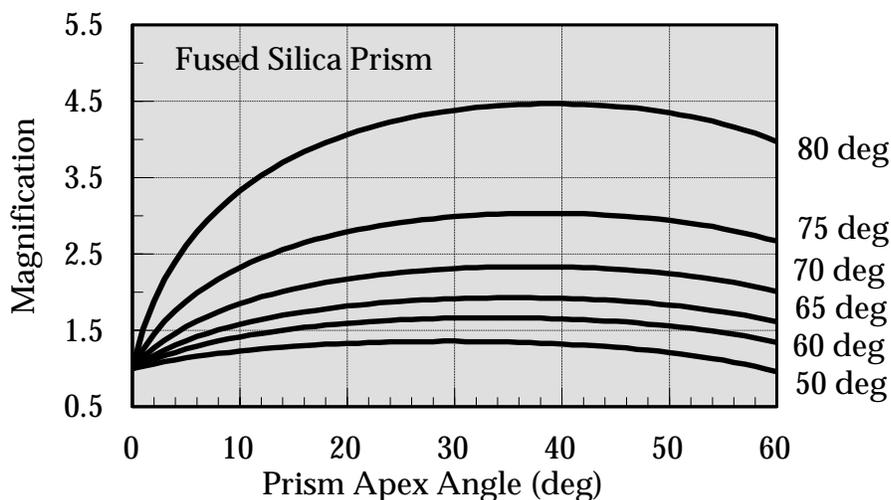

Figure 3. Prism beam expansion for different incidence angle on prism for line-narrowing.

The decrease in linewidth is, of course, gained at the expense of the more limited lifetime of the prism. We have evaluated the performance of the laser using prism beam expansion and the results in terms of energy and linewidth are shown in Figure 4.
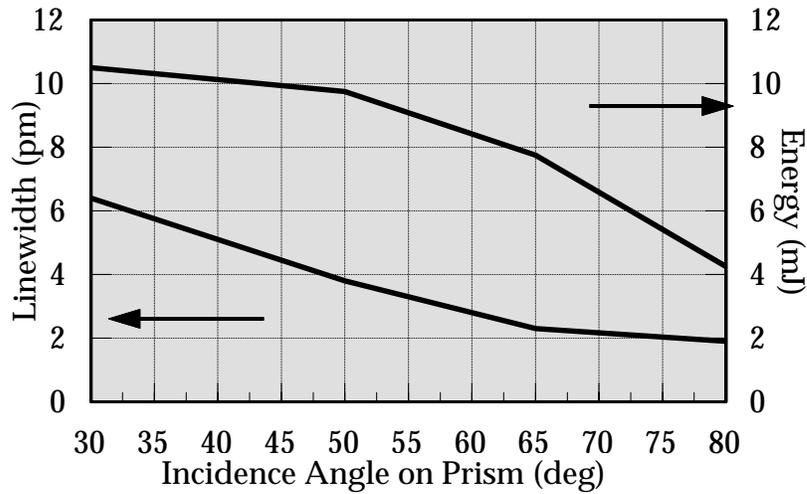
Figure 4. Performance of line-narrowed excimer laser with prism beam expansion.

The standard operating linewidth used in the microstepper tool is ~5pm and this is achieved without the use of any prism expansion. The line-narrowed spectrum is shown in Figure 5. There is an active wavelength stabilisation system on the laser which locks the peak wavelength position to ±1pm of the chosen peak wavelength.
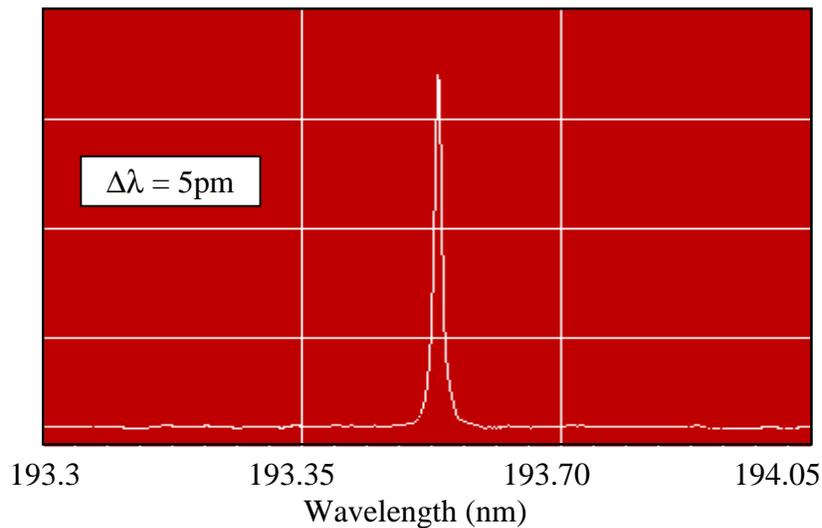

$\Delta\lambda = 5pm$

Figure 5. Line-narrowed spectrum.

This ensures stability and reproducibility of the laser's spectral output during exposures and nullifies any thermally- or mechanically-induced variations in the laser wavelength.

2.2 Illumination optics

The output beam from the laser is shaped to be 20mm x 20mm at the reticle plane and a double fly's eye homogeniser arrangement is used to produce a reticle illumination uniformity of < ± 5% RMS/pulse. A CNC-controlled variable attenuator in the beam line is used to set the single pulse exposure dose on the wafer. For

carrying out exposures with either s- or p-polarized 193nm radiation, a removable polarizer can also be inserted into the beam train. All mirrors are coated with high damage threshold dielectric coatings while lenses and other transmissive optics are AR-coated to minimise Fresnel reflection losses. To reduce the absorption by atmospheric oxygen and to prevent the formation of ozone and contamination of the optical train, the entire system from the laser to the condenser lens is purged with dry nitrogen gas. The partial coherence factor σ can be varied continuously from 0.3 to 1.0.

2.3 Wafer handling

The reticle, imaging lens and the wafer tables are all mounted on a common granite block structure to provide precise mechanical stability. The wafer chuck can accommodate either 150mm, 200mm or 300mm wafers. The chuck is constructed from a low expansion ceramic material and the wafers are held in place by vacuum action. The wafer tables have lateral (X & Y) travel of 350mm x 350mm and at any one position, the lateral stability of the tables is ±10nm. The elevator (Z) motion is 5mm with a resolution of 50nm. There is also a rotary stage with ±45° travel.

The chuck holder also incorporates a sensitive energy detector for calibration of the dose at the wafer and an embedded transmissive imaging system for fluorescent imaging. This fluorescent imaging allows a coarse focal position to be determined to ~50μm by imaging of the focal plane in the visible using a CCD camera. A diode laser-based autofocus system is used to control the focal position of the wafer and this achieved with a resolution of ~50nm. The entire exposure section, including homogenisation optics, reticle, imaging lens and wafer tables, is housed in an environmental chamber which maintains the temperature inside to ±0.2°C.

Typical single-pulse exposure doses at the wafer are ~0.25mJ/cm^2, which leads to maximum exposure intensities of ~25mW/cm^2.

2.4 Alignment

The reticle holder contains two alignment cameras to enable the reticle to be aligned. This is done manually using piezo-electrical controls to within 2μm. The wafer uses two separate cameras for alignment but its routine is performed automatically and to an accuracy of <500nm.

2.5 Diagnostics and Control

A CCD camera-based Exitech P256NG 193nm laser beam profiling system is incorporated in the microstepper for monitoring the illumination profile at the reticle plane in real time during an exposure.

A high-resolution Exitech Minispec laser spectrometer monitors the laser output to provide measurements of the laser wavelength, linewidth and stability. When line-narrowed, the centre wavelength of the laser output is maintained to within ±1pm by a computer-controlled active feedback system developed by Exitech.

The temporal characteristics and energy of the laser pulses are measured using a silicon PIN photodiode and a joulemeter respectively and a dose controller system monitors and controls the exposure dose at the wafer. The dose level can be controlled to less than 2% RMS with this system.

All the functions of the tool are controlled using a PC Windows™ platform via a touch-screen interface. These controls include: laser control (gas fills, energy monitoring, change of laser parameters such as repetition rate and HV); beam profiler; spectrometer; dose monitor; autofocus system; mask and wafer alignment controls; wafer table controls; exposure process selection and logging; monitoring of the environmental conditions inside tool.

3. RESIST CHARACTERISATION

A major issue in the development of 193nm lithography is still the scarcity of suitable photoresists. Many groups have recently reported their 193nm resist programs and a number of new lines of research are now being pursued [1]. Early work on our microstepper was performed with either polymethylmethacrylate (PMMA) or polyvinyl phenol (MX-P8, from Microlithography Chemical Corporation, USA) resists [2]. A typical result from the top-surface imaging (TSI) of MX-P8 is shown in Figure 6 which shows 0.2μm lines and spaces. There are still issues with the silylation and etching processes to be resolved but, generally, consistent results are obtainable with these TSI resists [3].

Recently, MCC have released a new single-layer, wet-developable, chemically-amplified resist which is an acrylic terpolymer. This TER-1 resist is specifically intended as an evaluation resist for R&D purposes. Although its sensitivity has been found to be good (~10mJcm^2), environmental contamination effects have been observed. These effects lead to problems in development and "T-topping" has been seen.
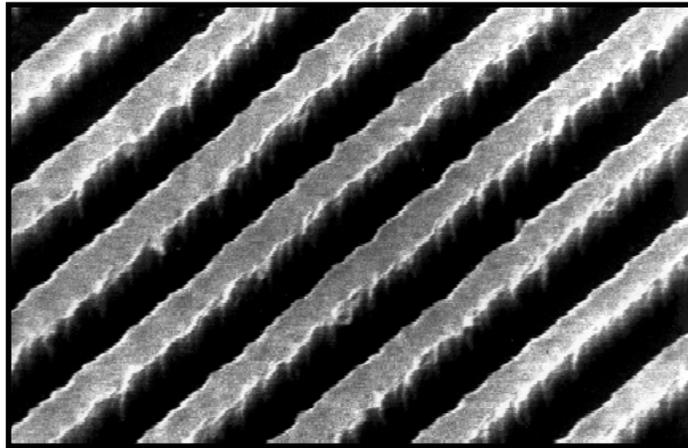

Figure 6. 0.2μm lines and spaces in MX-P8 exposed at 193nm

We performed 193nm exposures on early samples of TER-1 and a typical contrast curve is shown in Figure 7. It should be noted that these exposures were not performed under conditions of amine. Nonetheless, a high sensitivity was observed, though other groups have obtained better developmental conditions with TER-1.

The conditions of use for the TER-1 were:

Spin:	500 rpm / 5 sec 3000 rpm / 60 sec
Soft-bake:	90°-110°C / 60-90 sec
Expose:	2-50mJ/cm^2
PEB:	80°-100°C / 60 sec
Develop:	PG developer, 0.0001-0.02N, 2-60 sec

The soft-bake and PEB were varied with the developer concentration and time in an effort to find the best conditions.

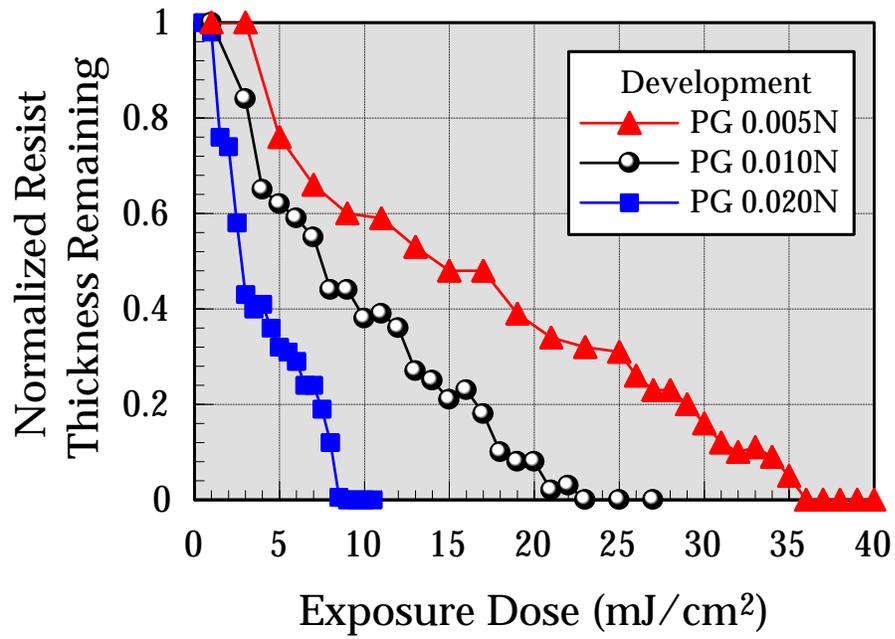*Soft-bake: 120C 60sec Post-exposure bake: 97C 60sec Develop: 15sec*
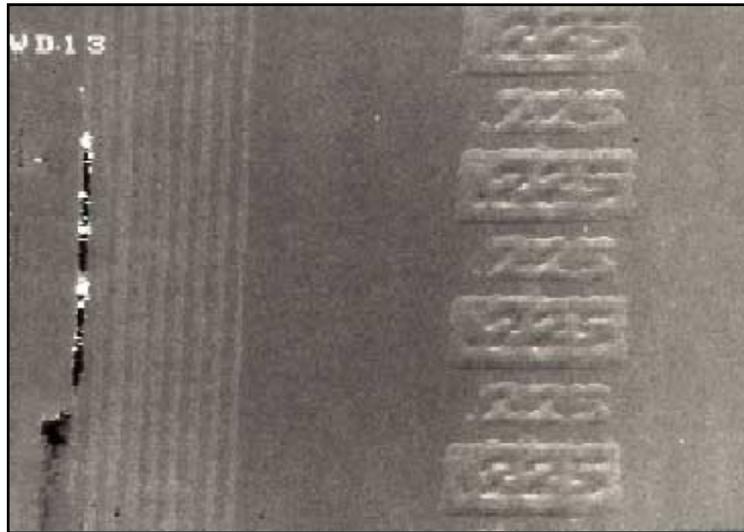
Figure 7. Contrast curve for TER-1 at 193nm

Figure 8. Dense lines and spaces in TER-1 (under-developed)

Figure 8 shows an exposure with TER-1 at 11mJ/cm^2 showing 0.225μm lines. Due to the problems with contamination and development, these features were under-developed but they do show that the resolution with TER-1 does appear to be good.

4. SUMMARY

A small-field microstepper has been developed for assessing the R&D issues for 193nm lithography. The tool uses a refractive, 0.5NA imaging lens with a field of 2mm x 2mm. One of the uses for the tool has been to assess new experimental resist and this work will continue as resist suppliers accelerate their development programs and new resists become available.

ACKNOWLEDGEMENTS

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