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Recent Development in Excimer Laser Lithography for 64 M and 256 MBit DRAMs

Masaru SASAGO, Yoshiyuki TANI, Kazuhiro YAMASHITA, Masayuki ENDO, and Noboru NOMURA

Semiconductor Research Center, Matsushita Electric Ind. Co., Ltd.

3-15, Yagumo-Nakamachi, Moriguchi, Osaka 570, JAPAN

This paper describes the potential of excimer laser lithography for the development and production of 64M and 256Mbit DRAMs based on our recent developed results.

In lithography for the production of 64MDRAMs, a capability of 0.35 micron feature size is required. A new in-house positive resist with high sensitivity and stability named ASKA, Alkaline Soluble Kinematics using Acid generator positive resist, has been developed. It is the first case in positive resists to confirm that ASKA has the excellent lithographic and process compatible characteristics. A KrF excimer laser lithography system with wide projection field and high alignment accuracy has been also developed. 0.35 micron patterns were delineated with wide depth of focus about 2.5 micron at whole field on the developed system and resist. Form the results, we verified KrF excimer laser lithography is promising for 64MDRAMs production .

Quarter micron feature size is required to lithography for the development of 256MDRAMs. In order to study the feasibility of 0.25 micron lithography, we investigated and developed the ArF excimer laser projection system installing refractive monochromatic 5X reduction aspherical lens. For ArF excimer laser lithography a suitable resist material should be developed with high transparency, however, ArF excimer laser lithography with aspherical lens system has been proved to be more attractive 0.25 micron lithography tool for 245MDRAMs.

1. INTRODUCTION

Recently, optical lithography has been able to push its limits down to sub-half micron resolution. The fabrication of deep submicron design rule devices such as 64MDRAMs and 256MDRAMs by optical lithography requires two approaches of increasing NA value and shorter wavelength. However, NA value of I-line is almost facing to the limit[1]. Therefore, I-line lithography combined with phase shifting mask technique[2] is growing as another candidate. However, phase shifting mask has the restriction of pattern layout and cannot be applied for various real LSI pattern such as microprocesser[3].

KrF (248nm) excimer laser lithography is most exciting technology for deep submicron VLSIs such as 64MDRAMs[4]. The technology has a resolution capability below 0.35 micron. The introduction of KrF excimer laser lithography for mass-production is being accelerated by resolved several technical barriers. These are two two main barriers. First, stability and CD controllability of positive resist. Second, power and life of the narrow band excimer laser system. This paper describes a new positive resist with high sensitivity and stability named ASKA, Alkaline Soluble Kinematics using Acid generator positive resist; a KrF excimer laser with a maximum laser power of 10W and more than 10^9 pulses named PCR, Polarization Coupled Resonator; and the result of KrF excimer laser lithography for 0.35 micron VLSI using this combination of ASKA and PCR technologies indicates improved throughput over conventional i-line lithography. And a KrF excimer laser lithography system with wide projection field and high alignment accuracy has been developed. The system newly employed a quartz lens with NA 0.42 and 20 mm-square field and a new heterodyne holographic TTR (Through The Reticle) alignment system.

This technology was successfully applied to the fabrication of 64M DRAM with KrF excimer laser stepper (N.A 0.42). This paper also describes the lithographic characteristics of the combination of ASKA and the developed system, followed by the demonstration of actual pattern fabrication of 64M DRAM.

In lithography for 256MDRAMs, the extension of KrF excimer laser lithography has to be overcome the resolution capability. ArF (193nm) excimer laser lithography has capability to realize quarter micron pattern fabrication[5]. In order to study the feasibility of ArF excimer laser lithography, we developed the projection system installing refractive monochromatic 5X reduction aspherical lens. To realize ArF excimer laser lithography, the development of wider exposure field lens and high transparency resist are needed. We also report on the progress of ArF excimer laser lithography.

2. KrF Excimer Laser Lithography for 64MDRAMs

2.1 The positive chemically amplified resist

The chemically amplified positive resist developed here is named ASKA2 (Alkaline Soluble Kinematics using Acid generating positive resist, 2nd version)[6]. ASKA2 is composed of a polymer, a photo acid generator and a solvent. The polymer is polyvinylphenol-type polymer, which becomes alkaline soluble by an acid through the photo acid generator upon KrF excimer laser irradiation. The transmittance of ASKA2 for 248nm is 65% [7] . To obtain the excellent stability, ASKA was designed by following concepts: the acid generating reaction only occurs during deep UV exposure and the alkaline soluble reaction of the polymer only occurs during the post exposure bake process.The post exposure bake (PEB) temperature is the key factor in controlling the sensitivity and pattern profile.

2.2 Lithographic characteristics of ASKA2

2.2.1 Resolution and pattern profile

Resist pattern profiles of ASKA2, thickness of 1.0 micron, are shown in Fig.1. The SEM photographs represent 0.4 micron down to 0.3 micron line-and-space patterns on Si substrate by exposed KrF excimer laser stepper with NA0.42. ASKA2 can successfully fabricate sub-half micron patterns with high aspect ratio. ASKA2 exhibits rectangular pattern profile without resist thickness loss, to which the higher transmittance of ASKA2 contributed.

2.2.2 Linewidth control

The linewidth control of ASKA2 on depth of focus are investigated in Fig.2. It is seen that there is 2.1 micron budget of depth of focus. These values are much lager than a case of exposure by i-line. ASKA2 attained the advantage of KrF excimer laser exposure. The relationship between the mask and pattern size was linear down to 0.4 micron on ASKA2. 10% mask vias can lead it to 0.3 micron pattern fabrication.

2.2.3 Stability

Unstability of a chemically amplified resist on a delay time after exposure has been indicated[8]. Fig.3 shows the excellent stability of ASKA2. The 0.4 micron patterns of ASKA2 do not change at all during a half hour delay. This means that this resist could be easily used for production of LSI.

2.3 Improvement of Excimer Laser Performance

Fig-4(a) is a schematic representation of a conventional spectral narrowing excimer laser with etalons. In this type of laser, the etalons cannot maintain initial optical performance due to thermally induced distortion and heavy load to the etalons themselves. So, the maximum laser power is restricted in order to limit damage to the etalons. To reduce the laser load on the etalons and to increase the output power, PCR[8] has been developed. Fig-4(b) shows the schematic representation of PCR. In the new resonating cavity, P polarized spectral narrowed seed light oscillates weakly and is partially converted to S polarized light. The S polarized light is amplified to intense light in the same cavity and extracted by a polarizing beam splitter. Fig-5 shows the output power vs. repetition rate for the PCR laser with 2.8pm spectral narrowing. The power increases linearly with the rate and reaches 10W at 200Hz with 1.3W etalon-load. At the output level of 5W, the etalon-load is only 0.75W. Therefore, the etalon-life of a PCR system is drastically extended to over than 10^9 pulses.

2.4 KrF excimer laser lithography system

The indispensable requirement to chip size on 64MDRAM is 20 mm-square in order to adopt two die. Thereupon, only remaining issue was focused on a KrF excimer laser lithography system with high accuracy, high speed alignment system and wider exposure field projection lens. We have developed a new KrF excimer laser lithography system[9] for sub-half micron devices. Features of the lithography system are summarized as the following: Wide field projection lens; 20mm-square field with 0.35 micron resolution. 9-axis high precision stage for 8" wafer; Positioning accuracy less than 30nm by adoption of double-V guide. Excimer laser image reticle alignment; Auto focus calibration, TTL base-line measurement. TTR wafer alignment system; Heterodyne holographic alignment[10] with a He-Ne laser. High quality beam PCR excimer laser; High illuminance on wafer. High resolution (0.30 micron) positive resist ASKA.: Figure-6 shows schematic diagram of the TTR alignment system. The TTR alignment sensor has the stability of less than 11 nm. The reticle alignment mark is observed with excimer laser light in order to make simple system. This high quality image has enabled the reticle alignment repeatability of 25 nm with an image recognition and electro-optical detection method. The system has the overlay accuracy of 0.09 micron and also the throughput of 15 slices/h at 8" wafer. The throughput of the combination of ASKA with $32mJ/cm^2$ sensitivity and the developed system with PCR laser is higher than conventional i-line lithography with $100mJ/cm^2$ sensitivity resist.

2.5 Application to the actual fabrication of 64MDRAM

2.5.1 Specification of the 64M DRAM

The specification of 64M DRAM developed in our laboratory is as followings[11]:

* Design rule --------- 0.4 micron
* Cell size ---------- 1.0 x $2.0um^2$
* Cell type ---------- stacked storage
* Chip size ---------- 10.85 x $21.60mm^2$

2.5.2 Actual device patterns

Fig.7 (a) demonstrates the separation pattern of ASKA2. Rectangular 0.4 micron line and 0.5 micron space patterns on SiN/SiO_2 were fabricated.

Fig.7 (b) exhibits 0.4 micron line and space connection patterns of ASKA2 on TiN/AlSiCu. This SEM shows patterns on 0.7 micron step. One of the most difficult pattern fabrication in making 64M DRAM was easily done with steep wall profile. It is found in Fig.7 (c) that the excellent etching patterns reproduced the straight resist pattern profile.

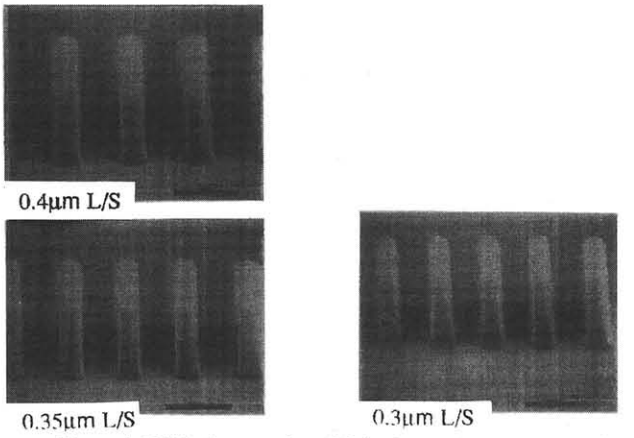

Figure-1 SEM photographs of 0.4 micron down to 0.3 micron line and space pattern ASKA2, thickness of 1.0 micron, on Si substrate by exposed KrF excimer laser stepper with NA 0.42.

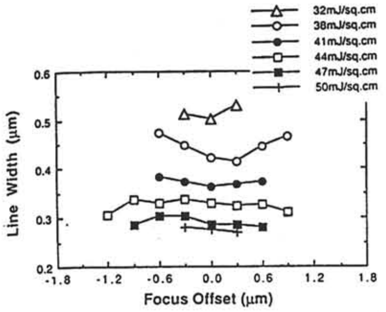

Figure-2 The relationship between depth of Focus and linewidth of ASKA2.

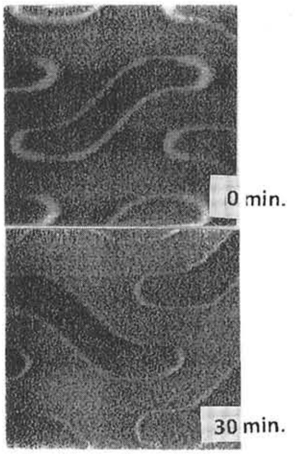

Figure-3 SEM photographs of delay time comparison on ASKA2.

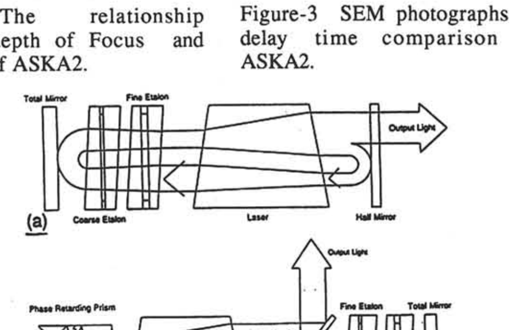

Figure-4 Schematic representation of spectral narrowing lasers with intra cavity etalons: (a) a conventional laser, (b) a new laser polarization coupled resonator.

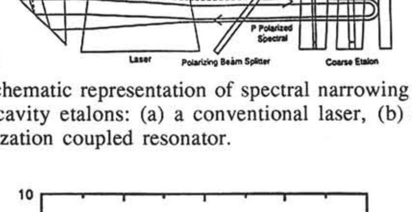

Figure-5 Output power vs.repetition rate in the new PCR laser.

3 ArF Excimer Laser Lithography for 256MDRAMs

ArF excimer laser lithography has been considered to be one of break-throughs to achieve quarter-micron pattern for a production of 256MDRAMs, although KrF excimer laser lithography combined with phase shifting technique is growing an another candidate. Main difficulties of ArF excimer laser lithography are the optical absorption of resist material and lens material (the resultant lens design) , and the optical projection exposure system[12]. Resolution of ArF excimer lithography was compared with many types [13] of phase shifting mask, (alternating, edge enhancement, unattenated, etc.). Alternating and unattenated phase shifting mask only provide the enhancement of the image contrast, but these give rise to the restriction of pattern layout and cannot be applied for various real LSI pattern. On the other hand, the image contrast of ArF excimer laser was enough high to realize 0.25 micron L/S pattern without pattern-restriction.

To reduce the total lens thickness and improve the transmittance of projection lens, we proposed a new projection monocromatic lens type having aspherical lens. Figure 8 shows the newly designed aspherical projection lens. The lens system is composed of 7 elements with 15mm square field size and NA0.45. Total quartz thickness of the aspherical lens system was successfully decreased to 16cm. Figure-9 shows the SEM photograph of 0.23 to 0.30 micron line and space patterns in 0.5 micron thickness. This result was good agreement with the designed result.

4. CONCLUSION

We have developed high performance KrF excimer laser resist, laser and lithography system. The positive chemically amplified resist, ASKA, long life excimer laser, PCR, and lithography system showed excellent lithographic characteristics, which meet the requirements for the fabrication of 64M DRAM. 0.4 micron-rule 64M DRAM was successfully fabricated on KrF excimer laser lithography. We verified KrF excimer laser lithography is very promising for 64MDRAM production.

ArF excimer laser lithography has been proved to be more attractive 0.25 micron lithography tool for 256MDRAMs, compared with KrF excimer laser lithography combined with phase shifting technique. And also, it has been confirmed that aspherical projection lens system could be designed and manufactured for ArF excimer laser lithography. We'll develop 256MDRAMs with the extension of this excimer laser lithography.

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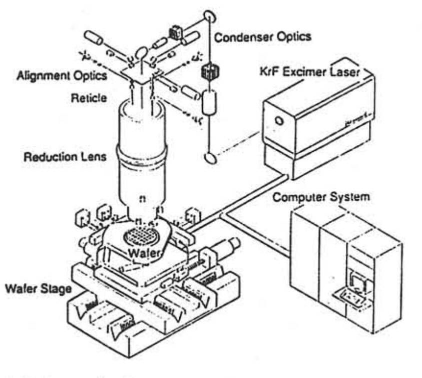

Figure-6 Schematic diagram of the TTR alignment system.

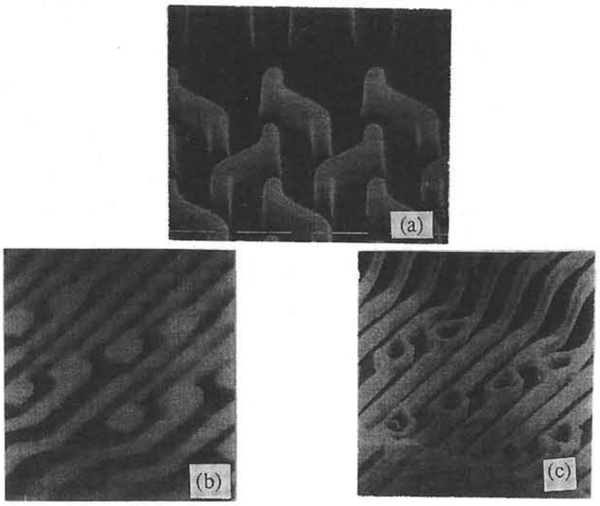

Figure-7 SEM photographs of the demonstrated pattern for a proto-type 64MDRAMs: (a) isolation pattern on SiN/SiO2, (b) connection pattern on TiN/AlSiCu, (c) connection pattern after etching.

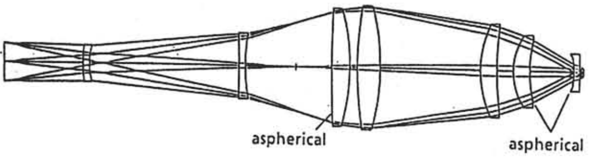

Figure-8 The newly designed aspherical lens system with 15mm-square and NA0.45.

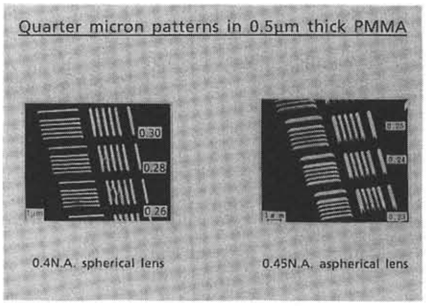

Figure-9 SEM photographs of 0.23 micron to 0.30 micron patterns in 0.5 micron thick PMMA ; (a) spherical lens, (b) aspherical lens.