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ELECTRON BEAM LITHOGRAPHY FOR LARGE AREA PATTERNING 1: DEVELOPMENT OF LARGE FIELD DEFLECTION E-BEAM LITHOGRAPHY SYSTEM

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Abstract

A novel electron beam system has been designed and developed specifically for large area patterning of electronic devices such as printed wiring boards. The prototyped system features a large field deflection, high scanning speed and stably focused beam in the large field. An electron gun with a LaB_6 flat cathode was used by operating at 1750-1800 K. The electron beam column provides an electron probe of less than 40 μm in diameter with a current of 50 μA at 60 kV. Fast and large field deflections by a magnetic deflection system enables an area of 104 mm x 104 mm to be covered. The scanning speed can range up to 254 m/s. Particular attention was paid to the materials and shapes of the optics column to minimize the influence of eddy currents from the point of view of controlling the dynamic behavior of beam deflection. It is confirmed that the system can provide accurate beam deflection within a ±20 μm (3σ) tolerance for the quite large field of 52 mm x 52 mm.

Key Words: electron beam lithography, electron gun, lanthanum hexaboride, emission property, optics column, large field scanning, magnetic deflection, beam focusing, eddy current, printed wiring board.

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Introduction

In the fabrication of such large area electronic devices as printed wiring boards etc., advanced technologies are required to meet the demands for finer circuitry, more diversified production lots and shorter turnaround. Until now, these devices have been fabricated mainly by photolithography with phototools and ultraviolet light. However, it has been becoming more and more difficult for this conventional process to satisfy the more stringent requirements mentioned above, due to the problems inherent in the processing and handling a phototool.

Direct writing technology represented by electron beam lithography is one of the most promising solutions for these requirements. Electron beam lithography has been widely accepted as the only means of producing high resolution structure for mask and direct fabrication of IC devices (Ballantyne, 1975; Moore, 1977). Typical performance of the lithography system has been reported as follows: a writing spot less than 125 nm in diameter (full width at half maximum; FWHM), with a beam current in excess of 250 nA at a beam energy of 20 keV, and a deflection system which covers 0.28 mm square (Thomson et al., 1987). Furthermore, some electron beam systems have been designed and developed for nanolithography (Lee and Ahmed, 1981; Gamo et al., 1985).

To apply this electron beam lithography to electronic devices with far larger areas than IC devices, however, it is necessary to develop the following novel technologies; (1) an electron source with a long service life and high brightness, providing higher current intensity of several tens of microamperes, (2) fast and accurate deflection for scanning a large field, to allow the writing of desired patterns in a reasonable time.

In the present work, a novel electron beam system has been designed and prototyped for large area patterning of electronic devices. We describe the basic configuration of the system with a specially designed electron gun and optics column, followed by experimental results on emission, focusing and deflection properties and on accuracy of resist patterns fabricated by the newly developed system. Finally, we summarize the present results.

Basic Configuration of Prototyped e-Beam Lithography System

System Overview

An outerview of the prototyped electron beam lithography system is shown in Fig.1. The system is mainly composed of the following three components; (1) data conversion and correction subsystem, (2) electron gun and optics column subsystem and (3) stage and evacuating subsystem.

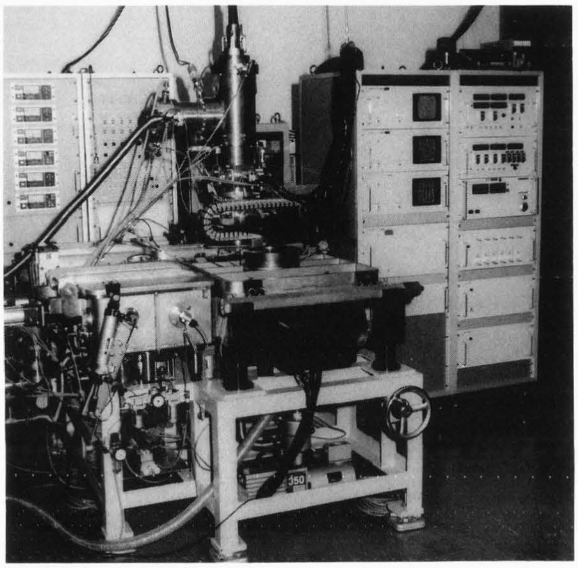

Fig.1 An outerview of the prototyped electron beam lithography system.

This system utilizes the vector scanning method for the main deflection of the electron beam. Figure 2 shows a functional block diagram of the deflection data generation and correction section. Various errors originating from the optics are measured in advance and the data to correct for these errors are calculated and stored. These data are output through the analog functional circuits to the optics column at a rate of up to 10 MHz. This has enabled the generation and correction of the deflection data to be executed in real time during the exposure. The deflector covers a field of either 104 mm x 104 mm or 52 mm x 52 mm by writing the individual pixels in a vector scan. In the present work, the latter field size was chosen. Each field has 4096 x 4096 pixels. So, the scanning speed can range up to 254 m/s or 127 m/s.

In the stage and evacuating subsystem, a mechanical stage positions each field. Sensors map the height variations of the substrate and provide the data to adjust the position of the beam for each field.

Electron Gun and Optics Column

Resists of several tens of micrometers thick are generally used in the fabrication of large area electronic devices. From the experiments and the simulations on incident electrons in such thick resists (Hoshinouchi et al., 1990), we have chosen 60 keV as a maximum primary beam energy.

Figure 3 shows a cross-sectional drawing of the gun and the optical components in the electron beam column. The column is composed of an electron gun, a condenser lens, a blanking electrode, two deflection coils, a stigmator, a dynamic focus lens and an objective lens. A backscattered electron detector is equipped for monitoring the beam profile and for the ease of aligning components. Magnetic deflection is utilized in order to realize the combination of large, accurate spot deflection together with high speeds. A dynamic focus lens is attached

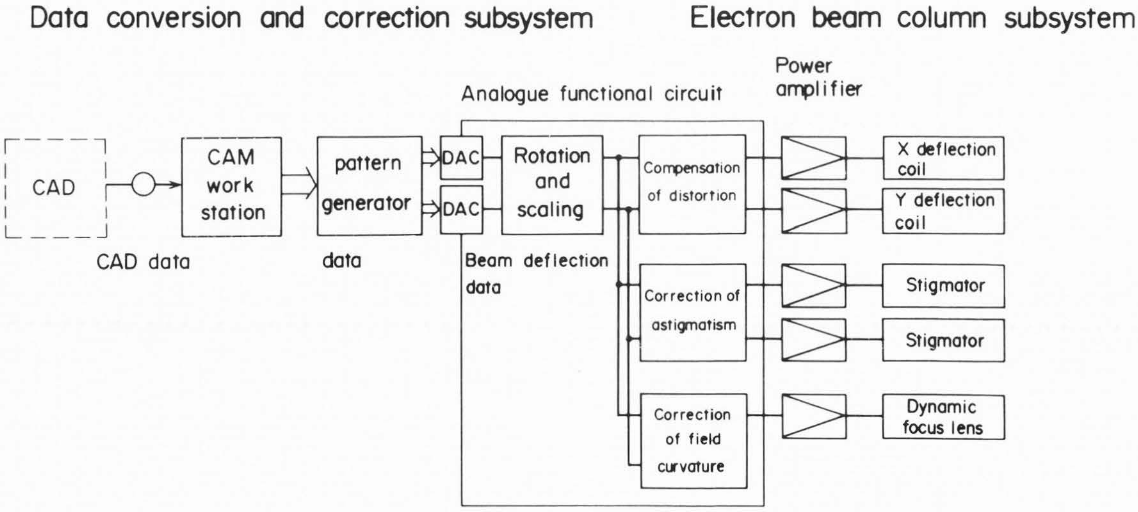

Fig.2 A functional block diagram of the deflection data generation and correction section.

to move the focusing position by up to 6 mm to correct for field curvature of the main-deflector. One of the features of this column is a sub-deflection coil superimposing high frequency magnetic field perpendicular to the direction of that of main deflection, which allows for controlling the line width with ease.

Figure 3 also shows the primary beam path. The electron gun with a mounted LaB_6 flat cathode (Shimizu and Hiraoka, 1989) was operated at 1700-1800 K to attain the brightness of 6 x 10^4 A/(cm^2·sr) at 60 kV. The cathode is imaged onto the writing surface by the focusing lenses with an overall magnification of about unity and an intermediate crossover allows the beam to be quickly blanked. The beam is blanked by deflecting it onto the knife-edge at the intermediate focus using an electrostatic blanker that can be turned on or off in less than 50 ns. No beam-limiting aperture is used; this allows a sufficient current in excess of several tens of microamperes to be obtained.

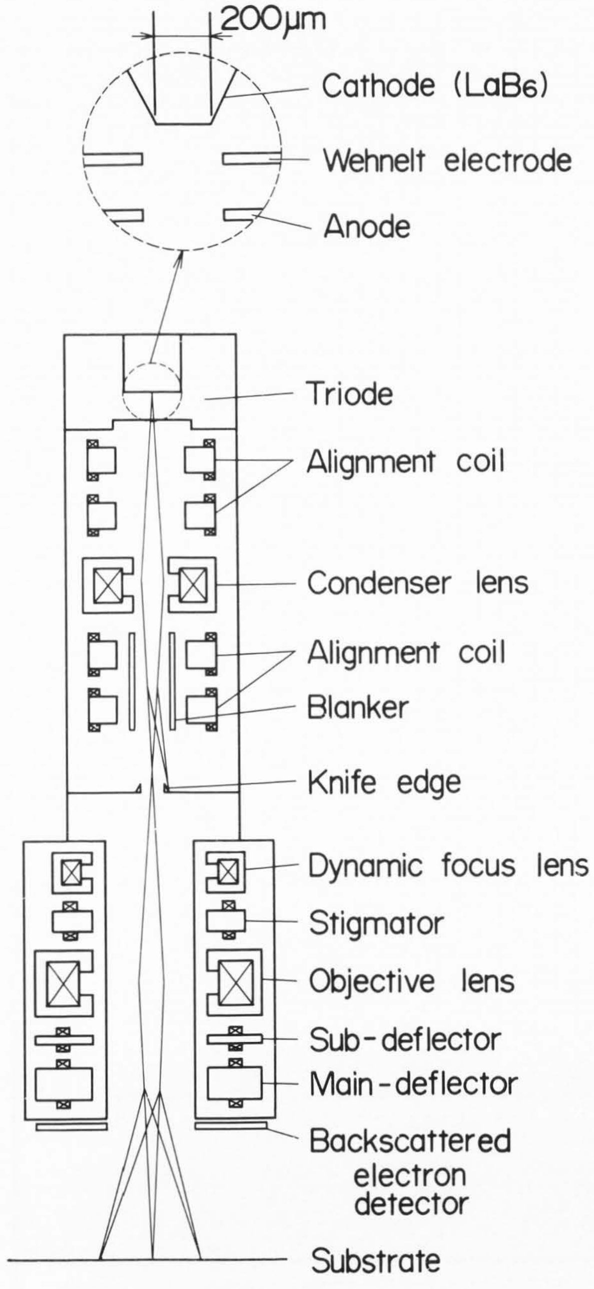

Fig.3 A cross-sectional drawing of the electron gun and the optical components in the electron beam column.

The main-deflector can be centered mechanically and is clamped very rigidly. The coaxiality between the condenser lens and the objective lens can be adjusted by an alignment coil.

Characteristics of The Electron Beam

Emission and Focusing Properties

A flat type lanthanum hexaboride (LaB_6) with 200 μm in diameter was adopted as a cathode for the electron gun, to obtain high emission.

Figure 4 shows the emission property of the LaB_6 electron gun, examined in terms of the relation between bias voltage, V_X , and beam current, I, at a temperature of 1770 K. The relation between V_X and I is linear. It is confirmed from these experiments that the tip operates in the space charge limited region at 1750-1800 K. The fluctuations of current measured at 100 μA are less than 0.4 % over a period of a few hours.

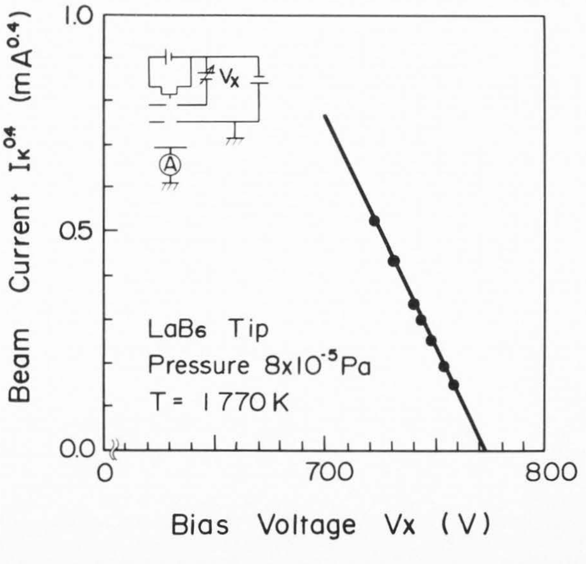

Fig.4 Emission property for LaB_6 tip at 1770 K.

The configuration of the condenser and the objective lenses is designed to minimize spherical aberration at a magnification of about unity. The beam intensity profile at the center of the field was measured on the basis of the time transient profile of backscattered electron current from a marker, as shown in Fig. 5(a). The marker was fabricated by depositing copper thin film on aluminum substrate and then etching the copper film to make a 200 μm wide groove. Electrons backscattered from the marker were detected with an annular detector mounted on the bottom of the final lens. The transient profile was then differentiated by time. Figure 5(b) shows a measured beam profile at a beam current of 50 μA. The beam profile is quite similar to Gaussian distribution with FWHM of 35 μm. Figure 6 shows the beam diameter vs. the beam current, clearly indicating that the diameter is kept almost constant up to 100 μA.

Figure 7 shows the beam size variation over the past 1500 h. This examination revealed that the emitter service life exceeds 1500 h at a tip-temperature of 1770 K in a vacuum of 8 x 10^{-5} Pa.

Deflection Properties

Aberrations caused by the magnetic deflection were estimated by assuming an ideal field. The results are as follows; (1) the sum of astigmatism and field curvature is 47 μm, (2) the coma is 2.6 μm and (3) the distortion is 380 μm. The coma and other higher order aberrations are small enough to neglect their influnce upon the beam spot. The astigmatism and field curvature were corrected by the stigmator and the dynamic focus lens. The octopole aberration originating from the coil windings, which deviated slightly from a sinusoidal distribution, was also corrected by the stigmator.

Beam diameters were measured at typical 9 points in the deflection field, as shown in Fig. 8. These measurements were made for two perpendicular directions and one diagonal direction. The beam diameters are less than 40 μm over the field. The diameter measurements for 3 directions defined in Fig.8 are summarized in Table 1, and they confirm that the measured beam spots are highly stable within a fluctuation of ±2 μm in diameter.

Great care was taken with the design to minimize the induction of eddy currents because eddy currents will generate overshoot and crosstalk deteriorating the accuracy of beam positioning. To avoid eddy currents, the pole pieces and the components adjacent to the deflection coil were constructed with low conductivity materials. It is confirmed that the overshoot and crosstalk is controlled to the degree of errors below that required in practice.

Accuracy of Resist Patterns

The novel lithography system developed for large area electronic devices was evaluated with regard to the stability of line width and accuracy of positioning in large field of 52 mm x 52

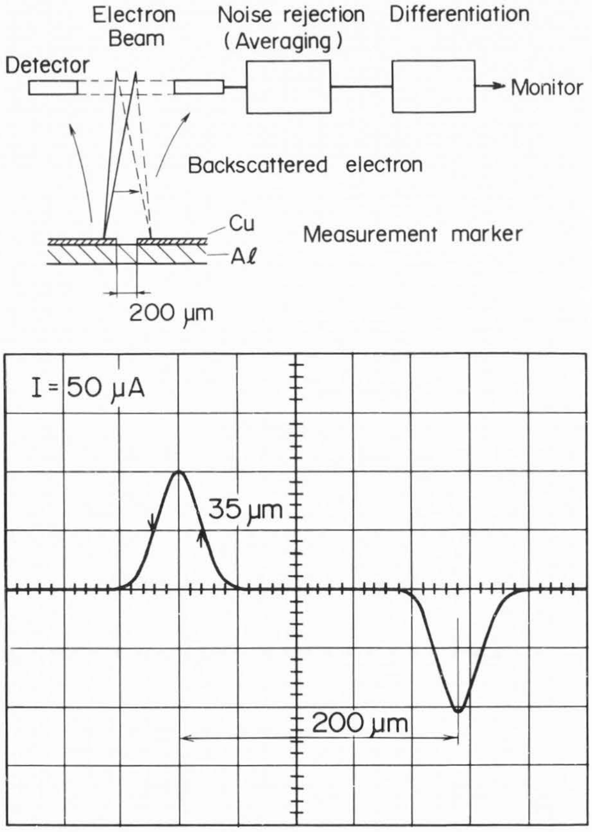

Fig.5 The measurement method for beam intensity profile (a;top) and a measured beam profile at a beam current of 50 μA (b;bottom).

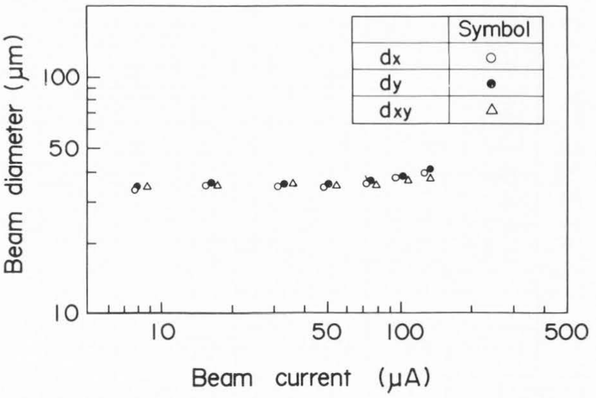

Fig.6 The dependence of the beam diameter (FWHM) on the beam current.

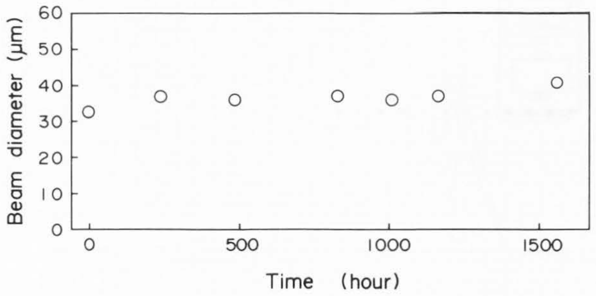

Fig.7 The beam size variation over the past 1500 h.

mm. Several mesh patterns were written on 20 μm thick electrodeposited resist prepared on Cu clad laminates under the following beam parameters: beam energy is 60 keV, line charge, q_l , is 2.0×10^{-9} C/cm (Hoshinouchi et al., 1990). Figure 9 shows an example of a SEM photograph of resist pattern obtained by this experiment.

The experiment has led to the conclusion that line widths less than 100 μm can be obtained with high stability within a fluctuation of less than ±10 %. Figure 10 shows the results on position accuracy. The position variations (3σ) on the X axis and Y axis are 19.3 μm and 20.9 μm, respectively. The position accuracy depends mainly on the accuracy of the D/A converter. It should be noted that this degree of errors are practically admitted in the fabrication of printed wiring boards.

A circuit pattern was written by this newly developed system. Figure 11 shows an example of patterns, written on a printed wiring board of 340 mm x 400 mm in size.

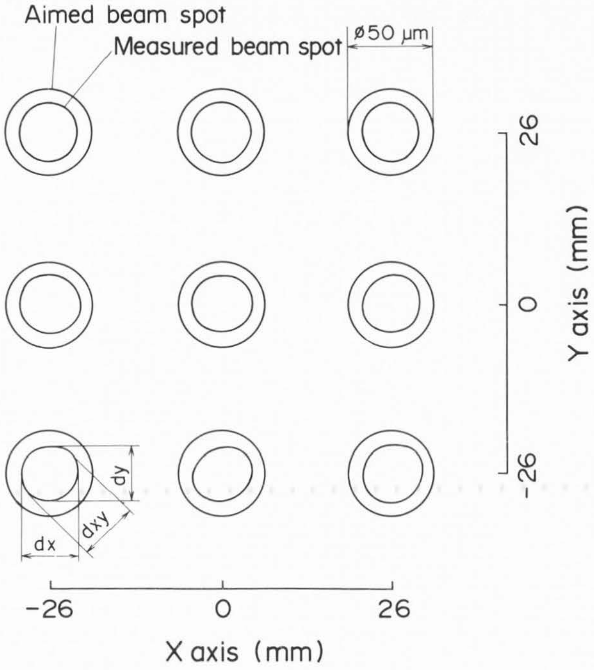

Fig.8 A plot of typical beam measurement.

Table 1. The variations of the beam spots over the field.

Direction	Beam diameter (μm)
dx	34^{+1}_{-0}
dxy	35^{+2}_{-0}
dy	34^{+0}_{-1}
Overall	35 ± 2

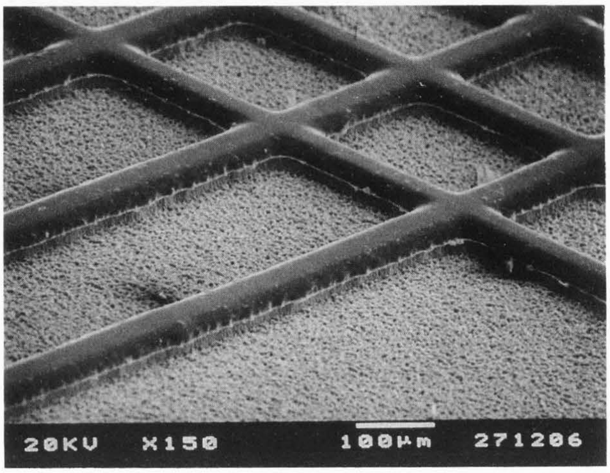

Fig.9 An example of a SEM photograph of a resist pattern.

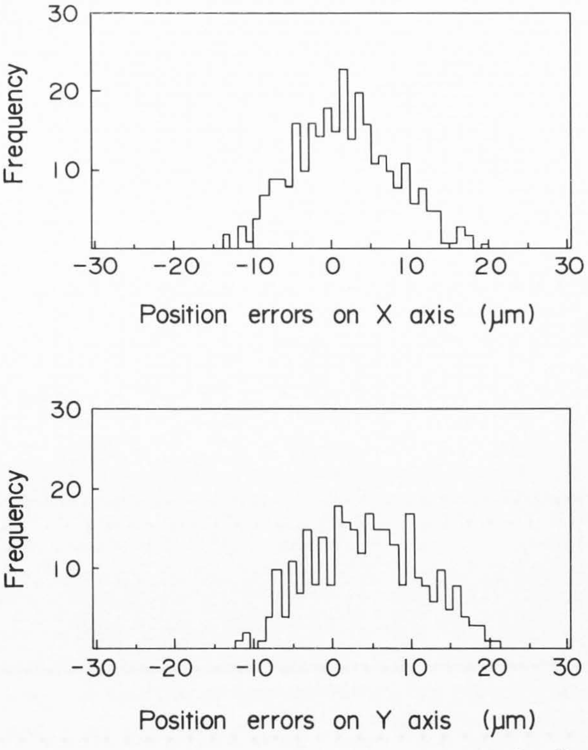

Fig.10 The positional accuracy measured in the field of 52 mm x 52 mm.

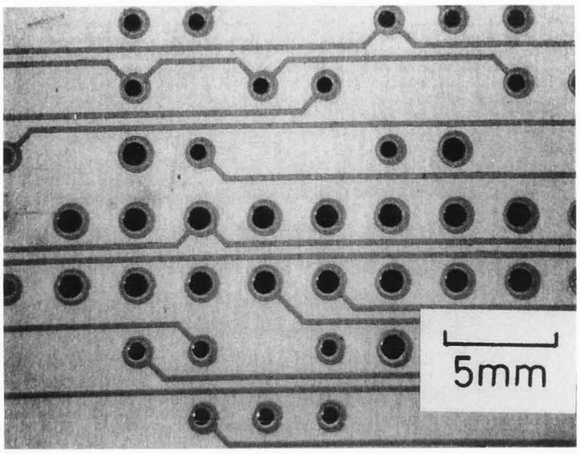

Fig.11 Resist patterns produced in electrodeposited thick resist by the newly developed system.

Conclusions

A novel electron beam lithography system has been designed and prototyped for large area patterning. The electron gun has assured a long service life and high brightness under high emission current, and the optics column has realized fast and accurate deflection over a large field. Long term operations have confirmed that it provides a stable beam spot, 35 μm in diameter (FWHM) with current intensity of 50 μA at 60 kV. The column designed with magnetic deflection covers a 104 mm square field. It is confirmed that the system can provide accurate deflection within a ±20 μm tolerance, together with high speeds, for the quite large field of 52 mm x 52 mm.

In conclusion, the present prototyped lithography system has proven to be a very powerful instrument for development and manufacture of large area electronic devices.

Acknowledgement

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References

Ballantyne JP (1975), "Electron-beam fabrication of chromium master mask" J. Vac. Sci. Technol. 12(6), 1257.

Gamo K, Yamashita K, Emoto F, Namba S, Samoto N, Shimizu R (1985), "Fabrication and resist exposure characteristics of 50 keV nanometer e-beam lithography system" J. Vac. Sci. Technol. B3(1), Jan./Feb., 117-120.

Hoshinouchi S, Yoshida A, Kawazu A, Sakurai K, Murakami H, Shimizu R (1990), "Electron Beam Lithography for Large Area Patterning 2. Exposure Characteristics of Electrodeposited Thick Resist" Scanning Micros. 4

Lee KL, Ahmed H (1981), "An e-beam microfabrication system for nanolithography" J. Vac. Sci. technol. 19(4), Nov./Dec., 946-949.

Moore RD (1977), "Reliability, availability and serviceability of direct wafer exposure electron beam system" Proc. Int. Conf. on Microlithography, Paris, 153.

Shimizu R, Hiraoka H (1989), "Cathode made of hexaboride single crystal" Japanese Patent No.1512501.

Thomson MGR, Liu R, Collier RJ, Caroll HT, Doherty ET, Murray RG (1987), "The EBES4 electron beam column" J. Vac. Sci. Technol. B5(1), Jan./Feb., 53-56.

Discussion with Reviewers

M.G.R.Thomson: What is the beam convergence semi-angle at the substrate, and what is the depth of focus? How is the height of the substrate measured?

Authors: The beam convergence semi-angle is 5 mrad, and the depth of focus is ±2 mm. Our system is equipped with laser displacement sensors to measure the height of the substrate. It is applicable to the substrates from 0.1 mm to 7 mm in thickness. The maximum variation of the height is 2 mm for these substrates.

M.G.R.Thomson: How are the astigmatism, field curvature, and deflection distortion measured? How are the corrections for these errors stored and computed?

Authors: We evaluate the aberrations by monitoring the beam profiles and the beam positions. The corrections are done automatically as follows: The beam profiles and the beam positions are measured with backscattered electrons from the markers. Our system is equipped with two markers; one is a cross-shaped marker for measuring the beam profiles, and the other one is a mesh-patterned marker for measuring the position accuracy. The correction data for the deflection errors are obtained and stored in the buffer memory. The correction data are read out from the memory and are added to or subtracted from the initial deflection data digitally.

M.G.R.Thomson: The blanking plates are not situated at a beam crossover. Are any deflection errors observed immediately after the beam is turned on?

Authors: The beam can be turned on or off in less than 50 ns. On the other hand, it takes 100 ns to deflect the beam from one pixel to the next pixel. So, no problems occur.

E.Munro: Your new large area lithography system uses a deflection arrangement which is relatively simple in electron optical terms. Have you considered the possibility of using a more

sophisticated arrangement, such as a VAIL (variable axis immersion lens) system, such as has been used in high resolution e-beam lithography? Would such an arrangement allow even larger field coverage in the present application?
<u>Authors</u>: We also consider that the VAIL will produce good results. However, there is not enough of the necessary basic data to introduce the VAIL into the large field deflection system.

<u>K.Murata</u>: Why does the beam change with time in the first and in the last stage in Fig.7?
<u>Authors</u>: We consider that the change is the error which arise in the measurement.

<u>K.Murata</u>: Please provide an overhead and a writing time per chip for a typical pattern exposure with your vector scan system.
<u>Authors</u>: The overhead and the writing time is 120 s and 20 s respectively for a typical printed wiring board with the size of 340 mm x 400 mm.