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Studies on Wehnelt of Electron-Beam Accelerator *

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Abstract Electron beam can be focused into a small spot with the diameter of only about nanometers theoretically, and easily controlled. It cannot be replaced by any other micro fabrication techniques in mask-making of VLSI (Very Large-Scale Integration). Based on the electron gun of SDS-3 electron beam lithography machine, the concave hyperboloid Wehnelt (oxide-coated cover) of accelerator is discussed. The electron trajectories and potential distribution are given. Electrons from the gun accelerated by a high voltage reached a target of silicon piece (in front of the aperture) via the Wehnelt. Finally, spots of electron-beam in the silicon piece and the geometry schematics for Wehnelt of accelerator are given.

Key words accelerator, electron beam, brightness, scatter, Wehnelt, cathode

1 Introduction

Nanometer lithography has become a reality due to the improvements of direct writing electron beam system. However, in MEMS (Microelectromechanical System) fabrication, our problem is not to obtain such small structures but to define the conditions needed to realize such a tool[1]. Every electron beam system of whatever type must have a source of high energy primary electrons—an electron gun[2—4]. The function of the gun is to produce a fine beam of electrons of precisely controlled energy (i.e. velocity) all coming from a small source region. In the electron beam system, higher energy electrons permit direct writing of thicker specimens, but may cause specimen damage[5—7]. Most electron beam systems have a maximum voltage. In the narrow electron beam system, the maximum voltage is usually ~ 50kV and its choice is determined by a compromise between penetration and beam diameter. An electron gun is used to produce a stream of electrons with a well defined kinetic energy. To meet the urgent need of smaller tip radius, a new cathode is often changed. The tip radius is too small to use for a long time. An electron gun is to put 0.5 mA cathode current at 25 kV through an aperture with an angular spread of 0.3 radian. The cathode current density is to be 0.8 A/cm^2. What should the aperture size be? Meanwhile a large amount of experimental work has been done and quite a number of data on the characteristics of electron guns have been published[8—9]. Nevertheless, the reported data, such as the value of brightness and the influence of various gun parameters, are spread widely as a result of the complicated experimental conditions which are dependent on the orientation of the gun geometry, the vacuum environment, the temperature of cathode, the area and the acceptance angle of aperture used in brightness measurements, etc. Therefore, an analysis independent of these conditions is needed for the evaluation of the effect of electron gun geometry on the properties.

2 Current density of electron-beam (E-beam)

In order to discuss the behavior of an ideal electron

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beam, assume that the E-beam forms a real crossover outside the anode. This ideal crossover is a point; therefore, the current density over the cross section of the beam can be represented as simple function, as shown in the low inset drawing in Fig. 1. Unfortunately, this ideal beam cannot exist even in the optical system. The reason for this nonideal behavior is that electrons emitted from a cathode held at the same point of cathode surface to the aperture where the same point will be changed form a scatter round as shown in Fig. 1. In the theory of quantum mechanics, electronic landscape orientation velocity is produced from both main cases: First, electron is of fluctuating identity, secondly, electron movement observe Fermi law. With the help of a computer program suitable for the calculation of a point electron gun the influence of gun geometry on the properties is evaluated. The computational results are reported, mainly the dependence of crossover and brightness on the tip radius and cathode-Wehnelt separation, which are the most important parameters of an electron gun. By filtering the astigmatism at the aperture from the final output of the machine, an output E-beam with higher stability was obtained, and hence the pattern quality and the line resolution of the mask were improved. Is the size of the E-beam at the aperture limited by thermal velocities or by space charge? The answer is yes. If the Wehnelt is changed, the size of the E-beam at the aperture will be changed. As the current is increased, the potential at the center of the beam will fall because of the negative space charge of the electrons[10]. The current at which collapse occurs depends on the geometry. In axially symmetrical flow, it depends on the Wehnelt and the aperture. For a high brightness gun, the emitter tip radius is as small as a few microns. Thus the geometrical difference between electrodes is very large. The brightness is calculated by

$$B \equiv \frac{J_{\max}}{\Omega} = \frac{J_{\max}}{\pi A_{\max}^2}, \tag{1}$$

Where $J_{\max}$ is the maximum axial density, Ω is per unit solid angle and $A_{\max}$ is the maximum divergence semiangle. As the electrical field on the emitter surface increases with the decrease of tip radius, the emission current density will increase according to the formula:

$$J = AT^2\exp\left[\frac{-(e\varphi - 3.8\sqrt{F})}{KT}\right]. \tag{2}$$

Where A, T, φ, F and K are the Richarson's constant, cathode temperature, work function, surface field and Boltzmann's constant respectively. The term $\exp(3.8\sqrt{F/KT})$ is called the Schottky factor. Thus, the brightness for a smaller tip is higher than that for a larger one.

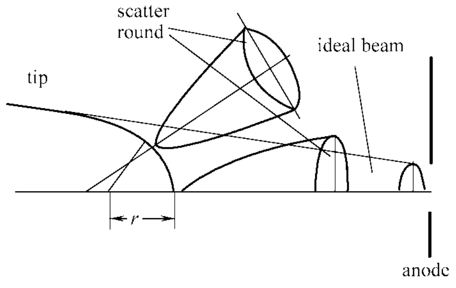

Fig. 1. The electrons of cathode surface emitted.

3 Wehnelt of hyperboloid frame

Based on the electron gun of SDS-3 E-beam lithography machine, the requirements that the electron trajectories and potential distribution must realize for Wehnelt of hyperboloid are discussed[11]. If V is the potential with respect to the cathode, we let:

$$V_r = \partial V/\partial r,\ V_z = \partial V/\partial z,\ V_{rr} = \partial^2 V/\partial r^2,$$
$$V_{zz} = \partial^2 V/\partial z^2,\ V_{zr} = V_{rz} = \partial^2 V/\partial r\partial z.$$

The meridian curvature is $1/R_m$ (R_m is the meridian radius) and the arc curvature $1/R_s$ (R_s is the arc radius), gives:

$$\frac{1}{R_m} = -\frac{V_{zz}V_r^2 - 2V_{zr}V_zV_r + V_{rr}V_z^2}{(V_r^2 + V_z^2)^{3/2}}, \tag{3}$$

$$\frac{1}{R_s} = -\frac{V_r}{r}\frac{1}{(V_r^2 + V_z^2)^{1/2}}, \tag{4}$$

If $1/R_0$ is the curvature of hyperboloid in the center. E_c the is field intensity in the center. Distribution of the potential in hyperboloid field will be:

$$V(z, r) = -\frac{E_c}{R_0}z^2 - E_c z + E_c\frac{r^2}{2R_0}, \tag{5}$$

In Descartes right angle coordinate (x, y, z), Distribution of the potential in hyperboloid field will be:

$$V(x, y, z) = -\frac{E_c}{R_0}z^2 - E_c z + E_c\frac{x^2 + y^2}{2R_0}, \tag{6}$$

In the hyperboloid (z_0, r_0). we let $V(z_0, r_0) = 0$ from (5) we obtain the structure equation of hyperboloid

$$r_0 = \pm\sqrt{2(z_0^2 + R_0 z_0)}, \tag{7}$$

Any altitude of hyperboloid is r_0, the angle of normal and axes is φ_0, where

$$\mathrm{tg}\varphi_0 = \frac{-r_0}{\sqrt{2r_0^2 + R_0^2}} \tag{8}$$

In Fig. 2 we have represented the configuration and parameter

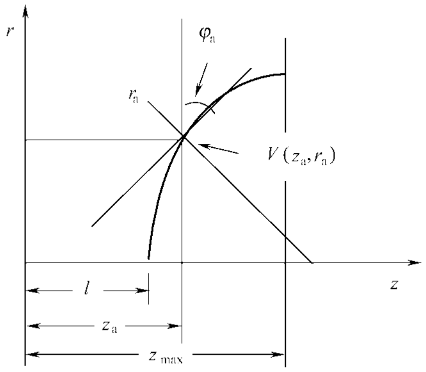

Fig.2. The configuration and parameter of concave hyperboloid Wehnelt.

of concave hyperboloid Wehnelt.

4 Examination and Results

The accelerating voltage is 30kV, the new tip radii of 80μm, in SDS-3 E-beam lithography. The distribution of the scattering electrons' energy deposition on silicon piece(Front the aperture) in cone Wehnelt of electron gun is shown in Fig.3.

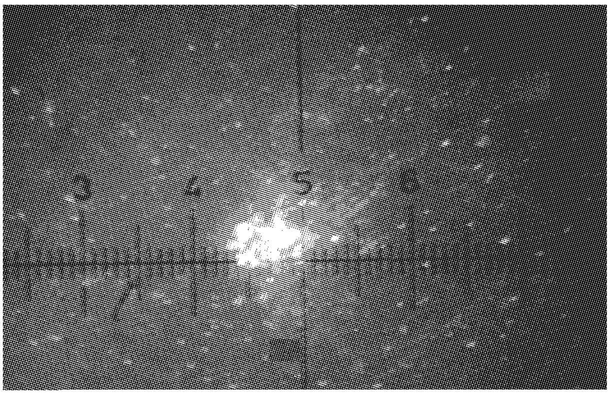

Fig.3. The silicon piece(in front of the aperture) is directly written by the cone Wehnelt (New tip. The accelerating voltage is 30kV. scale 1:100).

Fig.4 shows the scattering electrons' energy deposition on silicon piece in cone Wehnelt of electron gun (The tip be used after 20 hours, all conditions are equal to Fig.3). Fig.5 shows the scattering electrons' energy deposition on silicon piece in concave hyperboloid Wehnelt of electron gun(The tip be used after 100 hours, all conditions are equal to Fig.3). The results of examination show that the brightness of the gun is dependent on direct written radius: the smaller the radius,

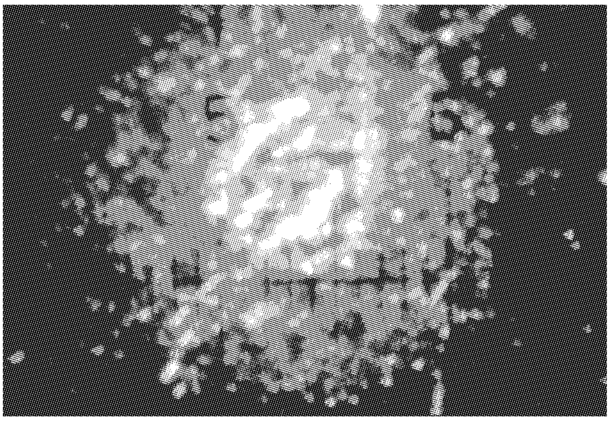

Fig.4. The silicon piece(in front of the aperture) is directly written by cone Wehnelt (The tip be used after 20 hours, the accelerating voltage is 30kV. scale 1:100).

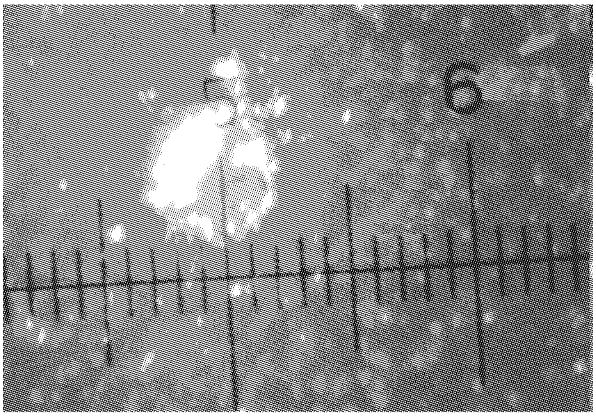

Fig.5. The silicon piece(in front of the aperture) is directly written by cone Wehnelt (The tip be used after 100 hours, the accelerating voltage is 30kV. scale 1:100).

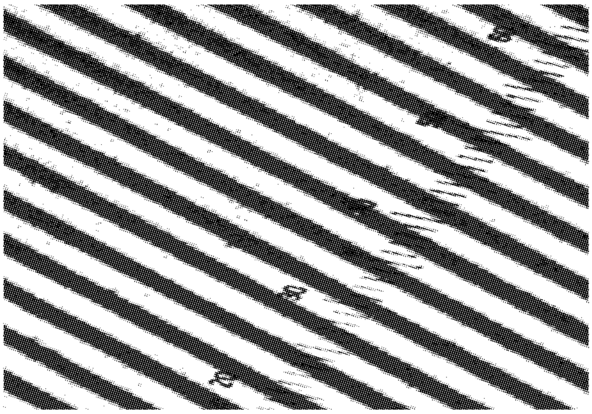

Fig.6. Resolution test 1μm wide line(the accelerating voltage is 30kV. scale 1:1500) in SDS-3 electron beam lithography machine with hyperboloid Wehnelt.

the higher the brightness. Distinctly, it is the distribution of the scattering of which hyperboloid Wehnelt is much smaller than the cone one. An electron gun is to put at least 90 per cent of 5 mA through an aperture 100μm in diameter. To allow errors in lineup and design, the electron gun is to be designed to put 90 per cent of the current through the 50μm diameter hole for a long time. The film of resolution test 1μm wide line in SDS-3 E-beam lithography with hyperboloid Wehnelt is shown in Fig.6.

5 Conclusions

The results for a large number of practical computations of hyperboloid Wehnelt show that under the same condition of required accuracy of iterations, especially for the optimization design of it, hyperboloid Wehnelt can be used not only for solving the Laplace field, but also for solving the Poisson field. After hyperboloid Wehnelt is used, the size of the distribution of the scattering is decreased by 40%. The result of scanning systems of this E-beam indicates that the aberration of superimposed focus-deflection is so small that dynamic correction is unnecessary.

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电子束加速器维纳尔的研究*

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摘要 由于电子束理论上可聚成直径小于1nm的束斑,易于控制,在超大规模集成电路掩模制造中起的重要作用,目前仍无法用其他方法所代替.以SDS-3电子束设备的电子枪为基础,讨论了双曲凹面加速器维纳尔(外敷碱土金属氧化物盖)的电子轨迹与能量分布.通过这一维纳尔电子被送达硅片靶心(置于光阑前).最后给出了刻蚀硅片的束斑和加速器维纳尔的图.

关键词 加速器 电子束 亮度 散射 维纳尔 阴极

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