ANAYSIS OF AN ELECTRON BEAM HEATING OF A SILICON WAFER

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1. Introduction

The semiconductor element has been integrated highly every year. Recently, the 90 nm level is produced. At the lithography process which makes the patern of a semiconductor device, electron beam drawing system (EB) is bearing the big role. With electron beam drawing system, the silicon wafer which is excellent in processability as aperture or a mask material which determines the form of an electron beam is used in many cases[1]~[4]. Since the electron beam of high energy is directly irradiated to aperture or the mask, the temperature analysis is indispensable in order to maintain stable operation of EB system and accuracy. However, since about one digit of heat conduction coefficients of silicon changed from room temperature between the melting point, temperature analysis was not easy. Consequently, the temperature of the silicon wafer which the electron beam irradiates was analyzed in considering of the radiation and the heat conduction.

2. Shape of silicon wafer

The sectional view of the silicon wafer heated by the electron beam is shown in Fig. 1. The radius *r* of the silicon wafer is 25 mm. A thick film part is between the radius of 25 mm and the radius of 10 mm with 500 µm thick. A thin film part is to the radius of 10 mm and the thickness is 20 µm. However, there is aperture (hole) between the radius of 1.55 mm and the radius of 1.63 mm with average thickness of 4 µm. The power of the electron beam is 2.5 W. When the electron beam is irradiated to the silicon wafer, the thin film part is heated and becomes high temperature. Therefore, the most of power is radiated from the irradiation area. The heat conduction which passes along the thin film occurs and radiates the heat due to high temperature. When the temperature is high in places other than an irradiation area, heat is radiated from the place.

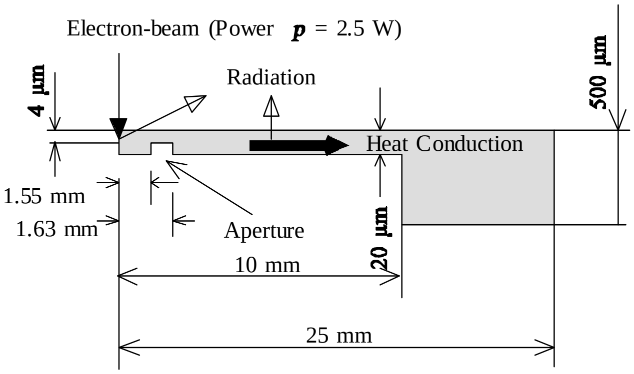

Fig. 1 Sectional view of a silicon wafer

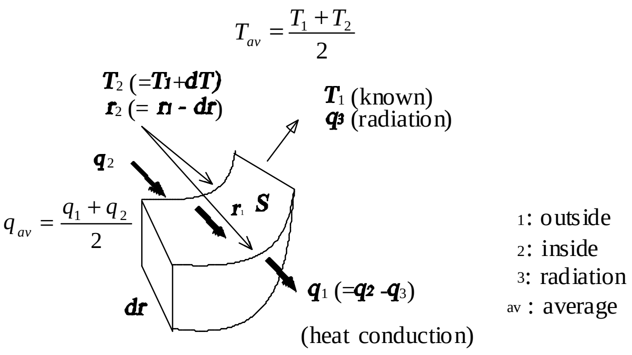

Fig. 2 Model of heat transmission

3. Model of heat transmission

The model of heat transmission of the silicon wafer is shown in Fig. 2. Subscript 1 which is shown in Fig. 2 is shown as outside of the silicon wafer. In addition, subscript 2 is shown as inside of the silicon wafer. Furthermore, subscript 3 is shown as radiation. Subscript av is shown as average. *S* is the area of radiation. The shape of the silicon wafer was assumed to be round. the passage quantity of heat is shown as:

$$q = -2prl\,l\,\frac{dT}{dr} \qquad (1)$$

Equation (1) has to add negative sign due to (*dT*/*dr*) is negative. From Equation (1) we get

$$dT = \frac{q}{2prl\,l}\;\frac{dr}{r} \qquad (2)$$

By integraling Equation (2) we obtain

$$T_1 - T_2 = \frac{q}{2pr_2 l\,l}\;\ln\left(\frac{r_1}{r_2}\right) \qquad (3)$$

where *T* is the temperature of silicon wafer, T_1 is temperature of outside of silicon wafer, T_2 is the temperature of inside of silicon wafer, *dT* is increase of the temperature, *dr* is increase of the radius, *q* is the passage quantity of heat, *r* is the radius of silicon wafer, r_1 is the outer radius of silicon wafer, r_2 is the inner radius of silicon wafer, *l* is the thickness of silicon wafer. *?* is the heat conductivity. Unknown temperature T_2 can be defined by equation (3). The quantity of heat q_2 which flowed into the area of inner radius of silicon wafer r_2 emits the quantity of heat of q_3, becomes $q_1=(q_2-q_3)$ and flows out of outer radius of silicon wafer r_1. The value of $T_{av}=(T_1+T_2)/2$ is used for the average temperature for determining the amount q_3 of the radiant energy. The value of $q_{av}=(q_1+q_2)/2$ is used for average quantity of heat for determining unknown temperature T_2.

4. Heat conductivity

The heat conductivity of the silicon is dependent on the temperature. The main temperature and the heat conductivity[5] are as follows. The heat conductivity is 148 W/mK at the temperature of 300 K, and is 61.9 W/mK at the temperature of 600 K. The heat conductivity is 42.2 W/mK at the temperature of 800 K and is 31.1 W/mK at the temperature of 1000 K. Furthermore, the heat conductivity is 25.8 W/mK at the temperature of 1200 K. The relationship between the heat conductivity and the temperature can be assumed as the following equation by making a and b into a constant.

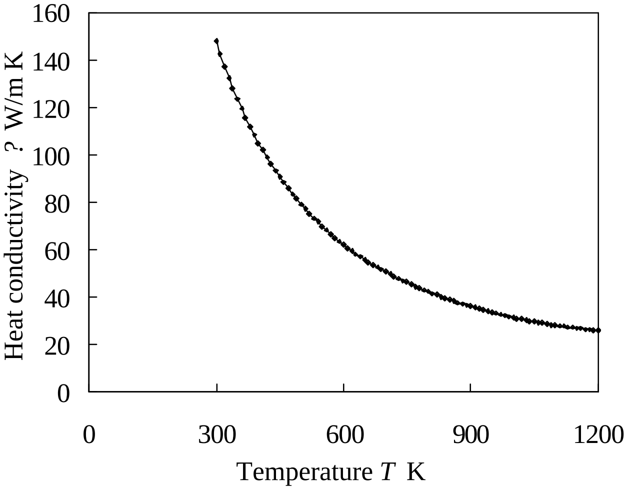

Fig. 3 Heat conductivity

$$l = \frac{a}{T} + b \qquad (4)$$

The heat conductivity other than main temperature was calculated from the formula (2) using the heat conductivity of main temperature. The relationship between the heat conductivity and the temperature is shown in Fig. 3. Notice that the heat conductivity is inversely related to the temperature.

5. Radiant energy

Quantity of heat q_3 which is a certain temperature T and is radiated from the area of S is shown as:

$$q_3 = e s T^4 S \qquad (5)$$

where S is the radiation area, s is the Stefan-Boltzmann constant, q_3 is the radiant heat and e is the total emissivity. The radiant heat can be calculated from a formula (5).

6. Temperature and total emissivity

The relationship between the passage quantity of heat q and the temperature T is equivalent to the relationship between the current I and the electric potential difference V. The temperature difference T is equivalent to the electric potential difference V. In addition, the heat resistance is equivalent to the electric resistance R. The heat conductivity ? which is a factor in heat resistance changes a lot with the temperature T. Therefore, the heat resistance has to be changed, whenever it cannot consider as a constant but the temperature changes. In the high temperature part, since the heat is radiated, the passage quantity of heat is decreasing rather than the quantity of heat which is fixed. The boundary condition is as follows. Temperature T_1 of the circumference part was assumed to 300 K. The temperature of the silicon wafer heated by the electron beam was calculated. Temperature calculation is begun from the place which the temperature of the outermost circumference (r_1=25 mm) is fixed as T_1=300 K. Concerning the selection of the radius of r_2, the radius of r_2 has to be chosen so that temperature difference becomes not large. If the electron beam is extracted to the radius of 1.5 mm and is

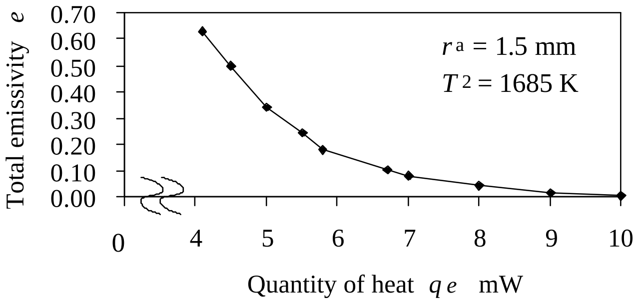

Fig. 4 Relationship between total emissivity and quantity of heat

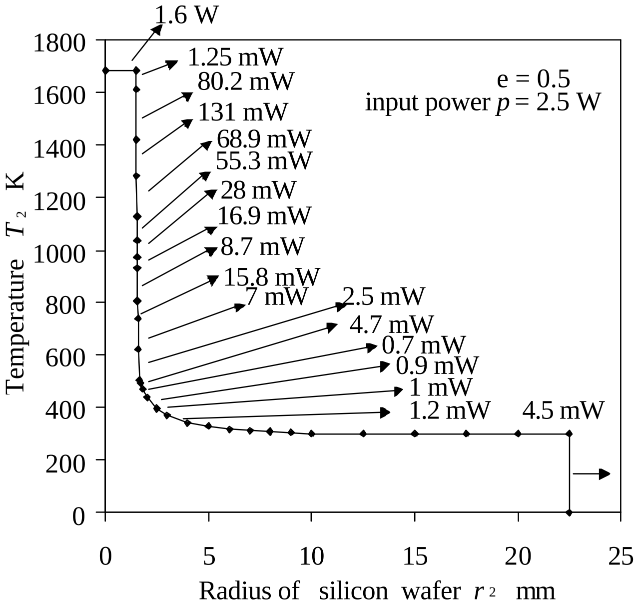

Fig. 5 Temperature of silicon wafer

irradiated, the silicon wafer will melt. The temperature distribution of the silicon wafer when the electron beam was extracted to the radius of 1.5 mm was calculated. In addition, The outermost circumference quantity of heat was changed. The total emissivity was changed so that the irradiation side temperature might be set to 1685 K which is melting point of silicon. The relationship between the outermost circumference quantity of heat *q*e and the total emissivity is shown in Fig. 4. When the outermost circumference quantity of heat *q*e is 4.5 mW, the total emissivity is about 0.5. In addition, when *q*e is 5 mW, the total emissivity is about 0.3. The temperature of a silicon wafer is influenced by outermost circumference quantity of heat and the total emissivity was confirmed. The actual outermost circumference quantity of heat *q*e is considered to be 4.5 mW from contact thermal resistance. The temperature distribution of a silicon wafer in case the outermost circumference quantity of heat *q*e is 4.5 mW was calculated. The result is shown in Fig. 5. We confirmed that when the outermost circumference quantity of heat *q*e is 4.5 mW, the total emissivity is about 0.5, and the heat of 1.6 W (64 % of input power) is radiated from an irradiation side. Furthermore, The irradiation side temperature in which electron beam is extracted and irradiated was calculated. The result is shown in Fig. 6. It is confirmed that if the electron beam is extracted and irradiated, the irradiation area becomes gradually high temperature.

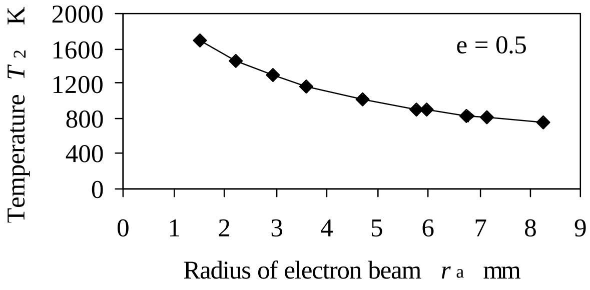

Fig. 6 Relationship between temperature and electron beam

7. Conclusion

(1) The temperature of silicon wafer which the electron beam which is extracted to the radius of 1.5 mm irradiates was analyzed in considering of the radiation and the heat conduction.
(2) We confirmed that when outermost circumference quantity of heat was 4.5 mW, the total emissivity was about 0.5, and the heat of 1.6 W (64 % of input power) was radiated from an irradiation area.
(3) The irradiation area temperature in which the radius of the electron beam is changed was confirmed.
(4) We confirmed that if the electron beam is extracted and irradiated, the irradiation area becomes gradually high temperature.

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