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Improvement in instable analysis of heat inflation induced line-width after replacing pellicle with diamond film on reticle (photo-masks)

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Abstract

A new reticle is designed that takes advantage of the high value of thermal conductivity of diamond to add a layer of diamond film to the bottom of traditional pellicle-reticle; that is, the new reticle replaces the pellicle with a diamond material. This method may help maintain the future manufacturing process of photo-lithography below 35 nm and can improve the problem of slightly out of shape reticle caused by the long-term effects of light and thermal energy. © 2004 Elsevier B.V. All rights reserved.

1. Introduction

Recently, interest in the research and applications of diamond has increased significantly due to the development of the chemical vapor deposition (CVD) technique for producing diamond films. Since diamond has the highest thermal conductivity of all known substances, it has numerous potential applications. However, this high thermal conductivity creates a problem in measuring the

thermal conductivity of diamond materials [1,2]. Numerous techniques exist for measuring the thermal conductivity of solid materials [3–6]. This study proposes a two layer model based on the principle of heat diffusion to determine the thermal conductivity for various CVD diamond thin films based on the effective thermal diffusivity of a diamond film on a silicon substrate measured using a holographic interferometric technique [7]. The main sources of distortion for soft pellicle systems include temperature changes and the attachment of curved frames to non-flat reticles, with the latter being the inevitable consequence of the stressed chrome pattern [8,9].

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2. The heat conduction equation

For one dimensional heat flow along the y -direction, the rate change of heat transfer can be expressed as

$$\frac{dQ}{dt} = -k_s A \frac{dT}{dy}, \quad (1)$$

where k_s denotes the thermal conductivity along the y -direction in the unit of W/m K, dT/dy represents the temperature distribution along the y -direction of $K m^{-1}$, A is the cross-sectional area of the sample perpendicular to the heat transfer direction of m^2 , and dQ/dt denotes the thermal power of W. Notably, thermal conductivity, k_s , is a heat transfer value per unit temperature gradient per unit time through unit cross-section, which is perpendicular to the heat transfer direction. The temperature gradient through the unit cross-section then can be measured by introducing a known quantity of heat to the solid material to determine the value of k_y from Eq. (1).

Modeling of thermal conductivity in a solid begins with the diffusion equation

$$\nabla^2 T - \frac{1}{\alpha} \frac{\partial T}{\partial t} = -\frac{1}{k_s} Q(x,y,z,t). \quad (2)$$

When α denotes the thermal diffusivity, for a long, thin film of a homogeneous material, with one end of the thin film held at a constant temperature and the other end heated at a known rate, the steady state, one dimensional temperature distribution is determined by the familiar expression from Eq. (2).

Fourier's law, Eq. (1), can be used to determine the conduction heat transfer rate. That is,

$$q_y = -kA \frac{dT}{dy} = \frac{kA}{L} (T_{\text{material},1} - T_{\text{material},2}). \quad (3)$$

Particularly, an analogy exists between heat diffusion and electrical charge. Just as an electrical is associated with the conduction of electricity, a thermal resistance may be associated with the conduction of heat. Defining resistance as the ratio of a driving potential to the corresponding transfer rate, Eq. (3) shows that the thermal resistance for conduction is

$$R \equiv \frac{T_{\text{material},1} - T_{\text{material},2}}{q_y} = \frac{L}{kA}. \quad (4)$$

3. Comparisons between traditional pellicle-reticle model and diamond film-reticle thermal conductivity model

Equivalent thermal circuits may also be used for more complex systems, such as composite walls. Such walls may involve numerous series and parallel thermal resistances due to layers of different materials. Consider the series composite wall of Fig. 1(a) and (b). The one dimensional heat transfer rate for this system can be expressed as

$$q_y = \frac{T_1 - T_n}{\sum R}. \quad (5)$$

Consider the traditional pellicle-reticle of a two-layer composite, as illustrated in Fig. 1(a) Each layer is characterized by an individual thickness, y density, heat capacity, and thermal conductivity, k , where $T_1 - T_3$ is the overall temperature difference and the summation includes all thermal resistances. Consequently,

$$q_y = \frac{T_1 - T_3}{\left(\frac{L_{\text{quartz}}}{k_{\text{quartz}} A} + \frac{L_{\text{chromium}}}{k_{\text{chromium}} A} \right)}. \quad (6)$$

Alternatively, the heat transfer rate can be related to the temperature difference and resistance associated with each element

$$q_y = \frac{T_1 - T_2}{\left(\frac{L_{\text{quartz}}}{k_{\text{quartz}} A} \right)} = \frac{T_2 - T_3}{\frac{L_{\text{chromium}}}{k_{\text{chromium}} A}}. \quad (7)$$

Consider the diamond film-reticle thermal resistances of a three-layer composite, as shown in Fig. 1(b),

$$q_{y'} = \frac{T_{1'} - T_{4'}}{\left(\frac{L_{\text{quartz}}}{k_{\text{quartz}} A} + \frac{L_{\text{chromium}}}{k_{\text{chromium}} A} + \frac{L_{\text{diamond}}}{k_{\text{diamond}} A} \right)}. \quad (8)$$

Alternatively, the heat transfer rate can be related to the temperature difference and resistance associated with each element

$$q_{y'} = \frac{T_{1'} - T_{2'}}{\left(\frac{L_{\text{quartz}}}{k_{\text{quartz}} A} \right)} = \frac{T_{2'} - T_{3'}}{\frac{L_{\text{chromium}}}{k_{\text{chromium}} A}} = \frac{T_{3'} - T_{4'}}{\frac{L_{\text{diamond}}}{k_{\text{diamond}} A}}. \quad (9)$$

The initial temperature is the same for the traditional pellicle-reticle and diamond-reticle, so $T_1 = T_{1'}$. However, due to the effects of the thermal conductivity of diamond film, $T_2 \neq T_{2'}$,

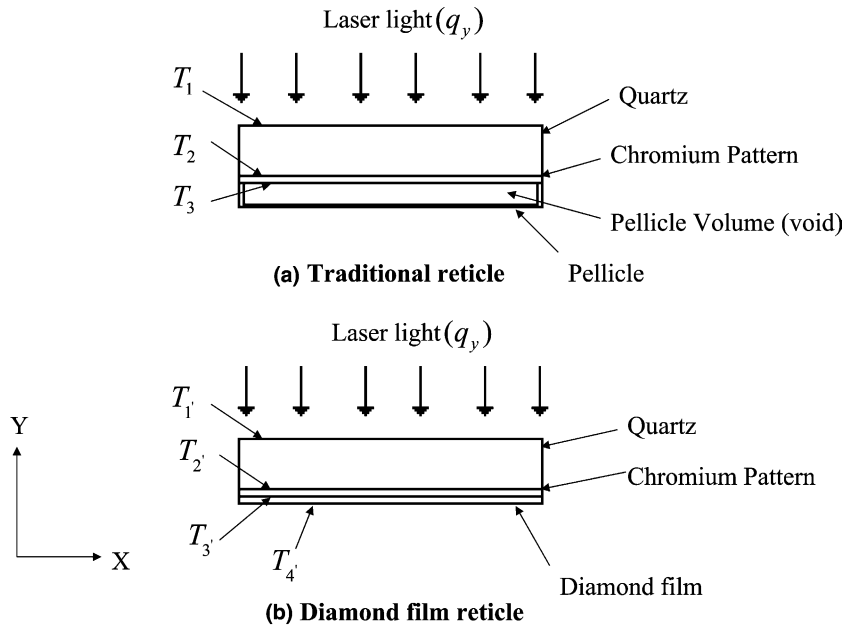


Fig. 1. Route map of laser beam used in experiment.

Table 1
Thermal properties of film and substrate

Material	Thickness	Thermal conductivity (W/m K)
Quartz	6.30 mm	4.8
Chromium pattern	100 nm	93.7
Pellicle	0.08 mm	–
CVD Diamond film (Type II a)	10 μm	1193

$T_3 \neq T_{3'}$. Putting Table 1 into Eqs. (7) and (9) demonstrates that a diamond film-reticle has better heat radiation.

4. Experimental method

A 10-μm thick layer of diamond film (Type II a) is deposited on a chromium layer on the bottom of a reticle via CVD using Cymer KrF Laser as the source of photo exposure. Fig. 2 describes the laser route in which the Cymer machine shoots a highly homogeneous light that could control uniformity below 0.3% via a fly eye. The homogeneous laser light obtains zero order and 1st order light via annular aperture. The laser beam of zero order

and 1st order light could be controlled under experimental size following going through a reticle exposure blind. Subsequently, through the main condenser lens, the main condenser lens is the final optical element for the exposure beam before entering the reticle and reduction projection, the condenser lens to ensure beam telecentricity. The final lens is the projection lens. The main function of the projection lens is to reduce the laser ratio to 4:1 and project it onto the wafer surface.

5. Results

5.1. Diamond reticle thermal conductivity

When the reticle receives extended light energy, it will be out of shape due to thermal inflation. The critical dimension (CD) bar from coating positive resist on the wafer of inflated reticle thus will shrink. Fig. 3 may prove that traditional pellicle-reticle is four times the quantity of out-of-shape than diamond thin film under continuing photo exposure for 200 h. At this point, the temperature of the traditional pellicle-reticle increases from

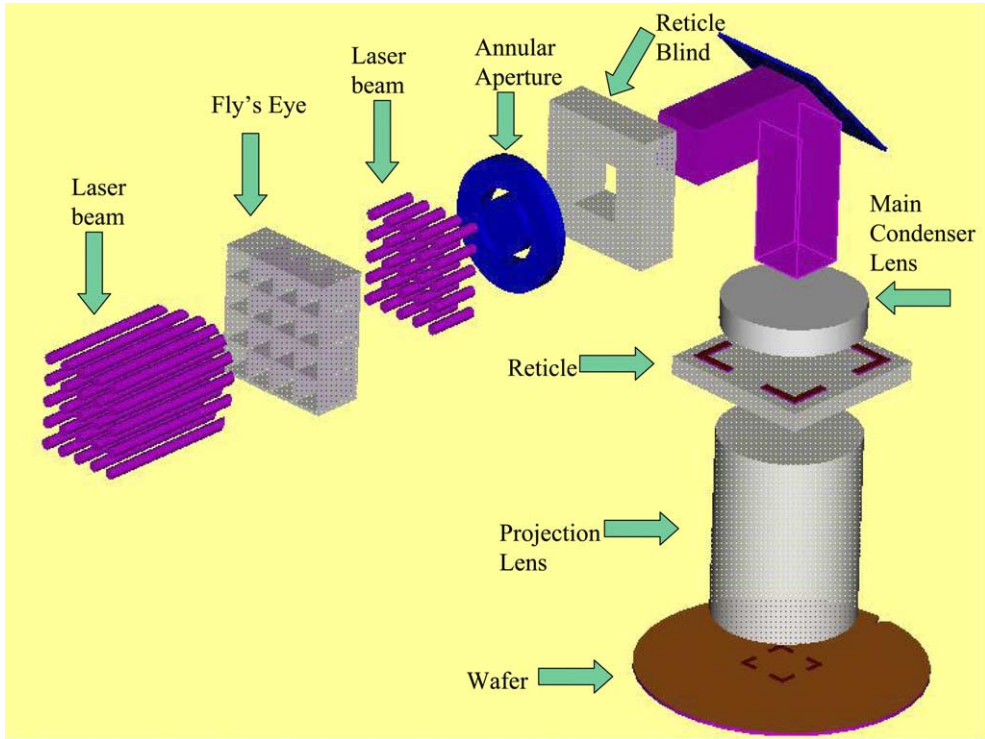


Fig. 2. Traditional reticle and diamond film-reticle composite.

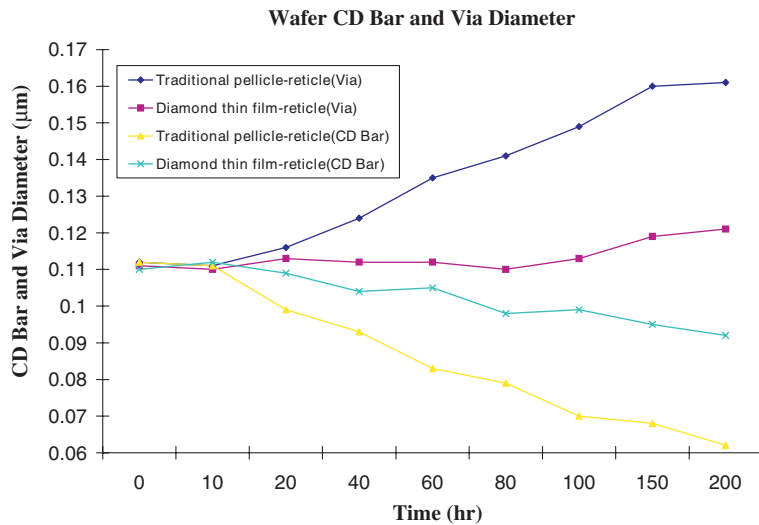


Fig. 3. Variances of line-width/diameter of wafer CD bar/via in different types of reticles following continuing 200-h photo exposure.

23.01 to 24.34 °C while the temperature of the diamond thin film-reticle increases from 23.00 to 23.03 °C. The increase of 1.33 °C reduces the CD

bar by 0.05 μm. If this shape change is applied to photo-lithography of 35-nm line-width, 30 nm of CD bar can be obtained. Fig. 3 shows that the

Table 2
Various types of reticle intensity

	No Pellicle-reticle	Pellicle-reticle	Diamond film-reticle
Intensity (mW/cm ²)	227.6	226.5	186.7

increase of just 0.03 °C has almost no effect on 35-nm process. This result demonstrates that diamond is a new and ideal replacement for pellicle in both theory and practice.

5.2. Diamond reticle intensity

Table 2 shows that the value of measurement of intensity of reticle of quartz and chromium is 227.6 mW/cm² and following adding a layer of pellicle, the value of intensity reduces by 0.483% while the value of intensity of diamond-reticle reduce by 17.97%. The loss of energy after light increase the medium of diamond is the weakness that will make throughput of scanner slow down.

5.3. Effects of improved oxide layer on diamond reticle on CD bar

According to the research by Mikkelson in 2001 [10], the reticle oxide layer thickness may reach 20 nm, adding 5 nm to the wafer, if optical reducing ratio is used. The 35-nm via (hole)-process increases the size to 40 nm and reduces the CD bar to 30 nm.

Because chromium wire of diamond-reticle is wrapped up between diamond and quartz, the chromium does not contact with air, and no oxide phenomenon occurs. The design of diamond-reticle provides a method of preventing reticle from producing an oxide layer.

6. Conclusions

Today's photo manufacturing process has not had ability to produce 35-nm line-width, so the

experiment used 0.11- μ m manufacturing technology to act as quantity of transformation of thermal inflation and applied the quantity of transformation to future 35-nm manufacturing process.

Presently, the tolerable standard of error of margin of semiconductors is 3σ . In the 65-nm process, the error of margin 5 nm is within 3σ while the error margin in 35-nm process exceeds 3σ . Therefore, when a semiconductor process is developed to 35 nm, the slight shape change due to heat must be resolved. However, until now, no paper or patent has offered a solution. Diamond film-reticle may provide a solution for achieving slight shape change in the future.

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