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Evaluation of Alignment Accuracy for Wafer Bonding Using Moiré Technique

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1. Introduction

Wafer-scale bonding of micro-electromechanical systems (MEMS) devices has been considered as a promising method to realize low-cost mass production. Precise alignment of bonding apparatus is highly restricted to achieve well-aligned bonding of MEMS devices over entire wafers. Alignment accuracy of wafer bonding apparatus thus ought to be sufficiently evaluated before its commercialization. H.Takagi et al fabricated line-and-space patterns on 4-inch silicon wafer to measure alignment accuracy of bonded wafers by using IR microscope and cross-sectional SEM observations [1]. But it is time consuming to dice wafers and seek the worst aligned-region by cross-section, moreover, by this method it is also hardly to evaluate misalignments of X, Y and θ axis simultaneously.

Moiré fringes created by two similar linear gratings or concentric circular gratings have been commonly used to measure linear displacements, since very small relative displacements enable to be manifested in large movements of the moiré fringes [2]. And infrared (IR) camera or microscope are often utilized to examine whether two bonded silicon wafers are aligned well or not because IR light enable to transmit silicon wafers but reflected by metal patterns [3]. Therefore, moiré fringes could be also observed by using IR transmission images when patterns on upper and lower wafers are overlapped. Several types of moiré patterns superimposed by two radial gratings, skewed-radial gratings [4], Fresnel zone plates [5], as well as elongated circular gratings were also investigated to measure planar displacements [6]. However, misalignments of θ axis, i.e. two wafers rotated after bonding, usually have been neglected in most of cases, and it is still difficult to distinguish the difference between well-aligned moiré patterns and slightly misaligned ones within sub-pitch misalignments obviously by an observer's eyes.

In this paper, moiré fringes produced by two centro-symmetric gratings on upper and lower wafers respectively are designed to overcome the problem of conventional moiré patterns. Furthermore, misalignments of bonded wafers are expected to be evaluated in X-Y-θ axis in wafer-scale simultaneously by IR microscope without requiring any other new equipment.

2. Moiré pattern of centro-symmetric gratings

Currently alignment accuracy of wafer bonding apparatus is usually around ±1μm in X and Y axis [1]. And there are several requirements that must be considered in choosing optimum parameters for moiré patterns, which adapt to evaluation of alignment accuracy in wafer-scale. For instance, the pattern should be a whole one on the wafer, and does not consist of many small parts, in order to obtain consistent results for evaluation of X-Y-θ axis. Although concentric circles are least affected (of any other shapes) by rotation, unfortunately masks of concentric circle geometry are quite difficult to be drawn and fabricated by electron beam or other micromachining methods. So we prefer to square patterns. In this paper, we develop two identical centro-symmetric patterns of square gratings with line-width of 10μm in the center of upper wafer and lower wafer respectively, as illustrated in Fig.1 (a). And the pitches of grating in the first and third quadrants are same, designated p_1 (p_1=19.5μm in this case), whereas ones in the second and fourth quadrants are designated p_2 (p_2=20μm). Δp ($\Delta p>0$) is the discrepancy pitch between them, i.e. $\Delta p = p_2 - p_1$. The upper wafer is turned over during pre-alignment process, thus patterns on two wafers with different pitches enable to be overlapped each other and moiré fringes are achieved.

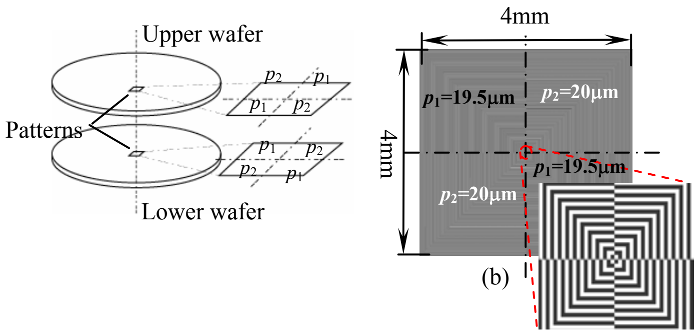

Fig.1 (a) schematic diagram of patterns on two wafers respectively (b) a centro-symmetric pattern of square gratings with line width of 10μm in the center of the wafer

Superposition the gratings on two wafers after bonding results a pair of moiré fringes with period, designated P

$$P = \frac{p_1 p_2}{\Delta p} = 780\mu m \tag{1}$$

The principle of moiré fringes is similar to vernier caliper. It allows small displacements to be measured using moiré fringes formed by two line-patterns with different pitches. To the patterns we designed, the ratio of moiré fringe displacement to actual displacement, i.e. Z, is

$$Z = \frac{2 \cdot p_2}{\Delta p} = 80 \tag{2}$$

Fig.2 shows moiré fringes produced by three different misalignments. In Fig.2 (a), the two gratings are well matched; moiré fringe period is 780μm. For the upper wafer misaligned 1μm in X-axis, one vertical moiré fringe evolved two ones whose distance is enlarged to 80μm distance by moiré principle as shown in Fig.2 (b). And any planar misalignment without rotation could be projected along two orthogonal directions, for instance, misalignments with 1μm and 2μm in X and Y axis respectively result in moiré fringes mismatched (ΔX=80μm ΔY=160μm) in Fig.2 (c). For IR microscope, it also seems no problem to obtain alignment accuracy of 0.5μm in X-Y anxis. In addition, fabrication errors of this moiré pattern must be within ± 0.2μm, otherwise Δp would be an unstable value after fabrication and moiré fringes are hardly produced uniformly.

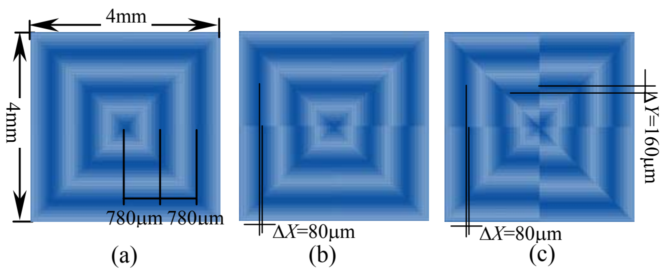

Fig.2 Computer generated moiré fringes produced by superimposing two centro-symmetric patterns of square gratings with different misalignments without rotation; (a) well-matched (b) Δx=1μm (c) Δx=1μm, Δy=2μm

We may expect to optimize parameters of patterns, e.g. p_2 and Δp, to achieve more precise accuracy regardless of fabricated errors in the future. However, the accuracy of this method is also limited the resolution of IR microscope and its visual field. For an example, using an IR microscope with 10× objective, we assume its resolution L_{min} is 5μm and diameter of visual field D is 1mm. A limitation of accuracy is approximately estimated by Eq.(3)

$$Accuracy \geq \Delta p = \frac{p_2^2}{P} \geq \frac{p_2^2}{D} \geq \frac{L_{min}^2}{D} = 0.025\,\mu m \qquad (3)$$

It illustrates that values of Δp and P should also be appropriate to IR microscope resolution and its visual field respectively; otherwise it is insignificant to improve accuracy of measurement through merely reducing fabrication errors.

3. Moiré pattern in circumference

In order to measure misalignments of θ-axis, duplex radial gratings in the circumference of wafers, similar to vernier, are also developed, as shown in Fig.3. And when these vernier patterns on two wafers superimpose without any rotation, 0° angle is between radial moiré fringes of outer and inner rings. But if two wafers are bonded with 0.02° or 0.05° rotation, for an example, the moire finges of outer and inner rings evolve to two moiré fringes enlarged to 4° or 10° rotated, see Fig.4 (b)(c). And 0.01° rotation can also be measured using this circumference pattern. And for evaluation in wafer-scale, it should be combined with moiré pattern by centro-symmetric gratings as mentioned above to measure misalignments of X-Y-θ axis simultaneously.

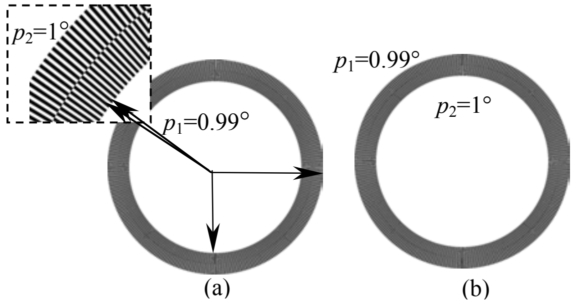

Fig.3 vernier-like duplex radial gratings in the circumference of 4-inch (a) upper and (b) lower wafer

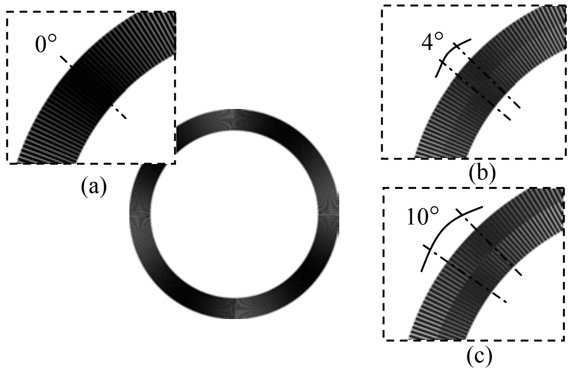

Fig.4 Computer generated moiré fringes produced by superimposing duplex radial gratings in the circumference of two wafers with different misalignments of θ–axis; (a) no rotation (b) Δθ =0.02° (c) Δθ =0.05°

3. Conclusions

Moiré patterns combined centro-symmetric square gratings in center with vernier-like duplex radial gratings in circumference were developed to evaluate alignment accuracy of bonded wafers. Results of computer simulation show that a measuring accuracy is 0.5μm of X-Y axis as well as 0.01° of θ-axis could be achieved in wafer-scale simultaneously considering fabricating error within ± 0.2μm. And the limitation of this method was also estimated besides fabrication errors. We expect that this moiré pattern would be fabricated on 4-inch or 8-inch wafers to evaluate the alignment accuracy of wafer bonding apparatus.

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