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# Research on Contact Characteristics between Bump End Effector and Wafer

Jiang Cheng[1],Fang Song[1,2],Yigang Hu[1],Tao Chen[2]

*1(Laboratory of Intelligent Control and Robotics, Shanghai University of Engineering Science, Shanghai , China)*

*2(Research Center of Robot and Micro system, Soochow University, SuZhou, China,*
*Corresponding author: songfang2005@163.com)*

**Abstract***: In the IC industry, commonly used methods are wafer clamping friction transmission type and vacuum suction. Combining science and theological contact theory,the contact friction transmission characteristics when using the bump and transmission actuator wafer, the wafer and the end actuators. Starting from the material properties of the wafer by ANSYS simulation analysis in contact with the wafer bump deformation due to its own gravity, and verify that it meets the requirements of small deformation wafer transfer. Compute and solve the friction contact with the wafer bump bristles between.*

**Keywords-** *end effector, Contact characteristics, Solder bump, friction*

## I. Introduction

Semiconductor wafer transfer robot is a key component in the manufacture of equipment. Its main role is to achieve rapid transfer between wafers each station with precise positioning. Where in the end effector is a wafer transfer robot important transmission section, efficient and reliable transmission of a large degree of influence of the wafer[1].

In the wafer transport system, the wafer transfer mode is considered one of the key technical studies[2]. Currently, on the end-effector design mainly in two ways: Vacuum adsorption using vacuum adsorption wafer to complete the transfer.Friction transmission type, use friction to complete the transfer, bump into contact and contactless edge of end two kinds.

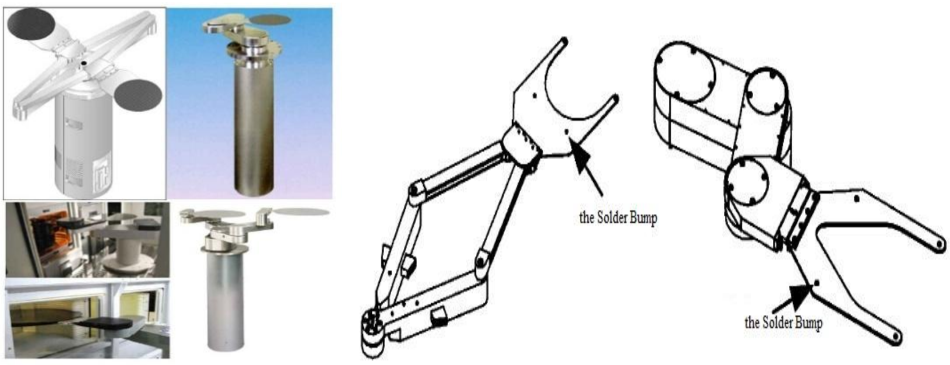


Fig.1 Wafer transfer robot and the solder bump end effector

High friction and small deformation are basic requirements for transferring large size of the wafer. In this paper, bump -contact end as the research object, analyzes the characteristics of the wafer anisotropic materials, due to the weight of the wafer deformation produced under Ansys simulation bump contact. Focus on under bump contact friction calculation, influence of transmission microarray bumps friction. Finally, analysis of the impact of changes in end-effector poses transmission acceleration.

## II. Material characteristics of wafer Bump contact

The main purpose of the end effector is designed to reduce the amount of deformation of the wafer, the wafer transfer process to prevent damage; while increasing the frictional force to prevent wafer slippage in the transmission process. In order to determine the feasibility of a bump -contact end effector wafer transfer, we must first determine the material properties of the wafer, in order to calculate the yield stress ; simultaneous analysis of wafer deformation properties under its own weight , and verify that meet the requirements of small deformation .

### 2.1 Analysis of the wafer material parameters determined

Components of the integrated circuit industry in general for monocrystalline silicon wafers, are anisotropic materials, the initial thickness of the wafer according to changes in the diameter varies. Because the semiconductor industry to use more Czochralski (CZ) silicon rods production, so this analysis is used in CZ monocrystalline material parameters of the legal system[3,4].

In terms of the bulk crystal silicon, polycrystalline silicon due to the symmetry of the body structure, the elastic stiffness matrix formula:

$$C = \begin{bmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ 0 & C_{22} & C_{23} & 0 & 0 & 0 \\ 0 & 0 & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ sym & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix}$$

In monocrystalline material parameters, CZ material stiffness matrix model is known, stiffness matrix corresponds with monocrystalline silicon, the result is:

$$C_{11} = C_{22} = C_{33} = 165.64GPa; C_{44} = C_{55} = C_{66} = 79.51GPa; \mathrm{C}_{12} = C_{13} = C_{23} = 63.94GPa$$

Stiffness coefficient matrix inversion, can get the material compliance coefficient matrix as follows:

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & 0 & 0 & 0 \\ & S_{22} & S_{23} & 0 & 0 & 0 \\ & & S_{33} & 0 & 0 & 0 \\ & & & S_{44} & 0 & 0 \\ & & & & S_{55} & 0 \\ sym & & & & & S_{66} \end{bmatrix}$$

By linear elastic constants of anisotropic materials and engineering flexibility matrix constant relationship formula: $(l_1,l_2,l_3)$.Available single-crystal silicon in an arbitrary direction of Young's modulus:

$$\tfrac{1}{E} = S_{11} - 2\left(S_{11} - S_{12} - \tfrac{1}{2} S_{44}\right)\left(l_1^2 l_2^2 + l_2^2 l_3^2 + l_1^2 l_3^2\right) \qquad (1)$$

Wherein, $(l_1,l_2,l_3)$ is the crystal orientation of the major axis of the coordinate system direction cosines.

Monocrystalline in any direction Poisson ratio:

$$v = -E\left[S_{12} + \left(S_{11} - S_{12} - \tfrac{1}{2}S_{44}\right)\left(l_1^2 m_1^2 + l_2^2 m_2^2 + l_3^2 m_3^2\right)\right] \qquad (2)$$

Wherein $(l_1,l_2,l_3)$ and $(m_1,m_2,m_3)$ are orthogonal to the cosine of the crystal axis of the coordinate system of the main crystal direction. Calculated according to the formula (1), the wafer can be obtained in the X, Y, Z three directions of the Young's modulus. According to the wafer in coordinate system: $x = [1 \quad 0 \quad 0]$ $y = [0 \quad 1 \quad 0]$ $z = [0 \quad 0 \quad 1]$. Three different crystal orientations were into the formula ( 1) can be obtained:

$$E_x = E_y = E_z = 128.87GPa$$

According to equation(2), the wafer can be obtained in the X, Y, Z three directions Poisson ratio:

$$v_x = v_y = v_z = 0.274$$

Meanwhile, wafer calculated shear modulus: $G_{xy} = G_{yz} = G_{xz} = 79.51GPa$.

In consideration of the wafer is plastically deformed, the water will need to determine whether the occurrence of plastic deformation. According to the guidelines calculation von.Misses wafer equivalent force of gravity by the formula (3).

$$\sigma_m = \sqrt{\left\{0.5\left[\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2\right] + 3\left[\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2\right]\right\}} \qquad (3)$$

In type:

$\sigma_x, \sigma_y, \sigma_z$ −−*normal stress* X, Y, Z −*axis direction*;

$\tau_{xy}$ −−*XoY plane shear stress*;

$\tau_{yz}$ −−*YoZ plane shear stress*;

$\tau_{zx}$ −−*ZoX plane shear stress*;

Calculated by the formula (4) wafer yield stress:

$$\sigma_s = \left(4.27 \pm 0.2\right) \times 10^{-3} MPa \times \exp\frac{0.7 \pm 0.01eV}{kT} \qquad (4)$$

Where $k$ is Boltzmann's constant, $T$ is the wafer where the processing temperature. Into the corresponding data calculated $\sigma_s = 43.7GPa$, you can determine the nature of the wafer deformation under its own weight.

### 2.2 Deformation Analysis wafer bump contact

When the contact bump transmitted wafer, wafer deformation analysis of different numbers bump contact, Here are three points of contact, and when the four-point contact, deformation analysis of different thickness due to the weight of the water to produce results.

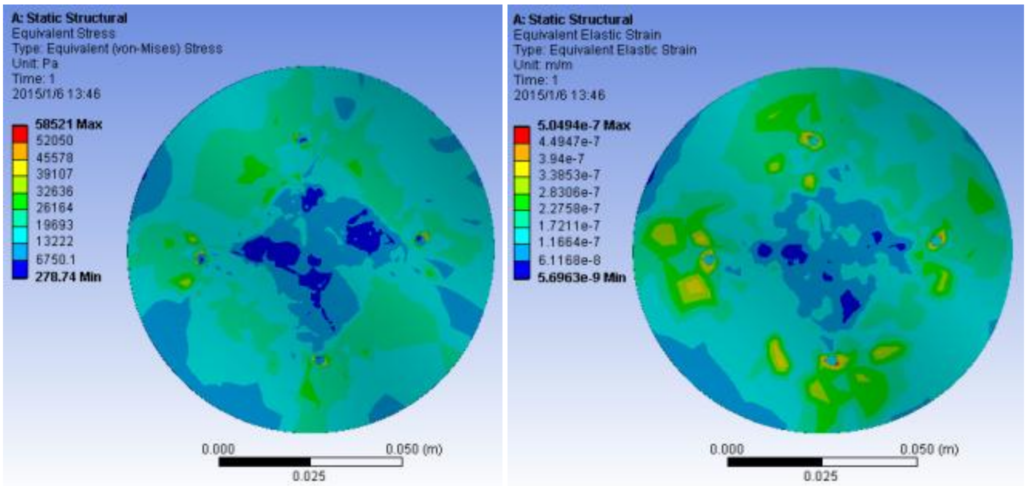


Fig.2 Stress and strain contour of wafer under bump contact

Based on the above analysis we can see the end of the actuator bump contact wafer transport to meet the requirements of small deformation. At the same time the bump structure can reduce the weight of the end effector. The wafer is conducive to steady and rapid delivery.

## III. Frictional contact analysis of wafer and solder bump

In the friction transmission process of the wafer, the forces of the wafer as showed in Fig.3.

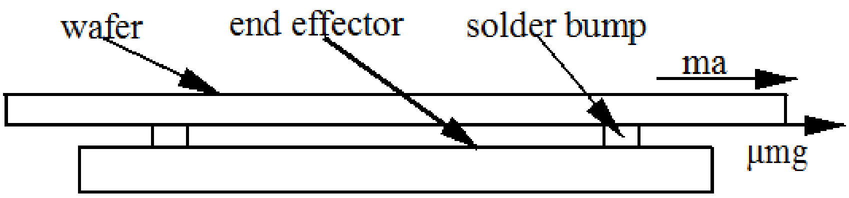


Fig.3 The force model of wafer transfer process

In order to achieve efficient and reliable transmission of the wafer, on the one hand to consider the design of the end effector when the stress state of the wafer, the wafer to prevent deformation , breakage ;on the other hand to improve the wafer transfer friction , effectively increase the transmission acceleration and improve efficiency . Therefore, when using contactless transmission wafer bump, to in-depth study of the frictional contact between the wafer bump characteristics analyzed under different frictional contact state changes.

In bionics, bristle array gecko feet are one of the hotspots of current research. Currently, there is corresponding gecko setae material such as a polymer, silicone rubber used in scientific research[5,6]. Experimental studies have shown that, according to the microscopic structure and function of the adhesive can be made of artificial gecko feet bonding system[7]. Contact the microarray approach bristles can effectively improve the friction between the contact surfaces. Below to bump arrays bristles example frictional contact wafer characterization[8].

Firstly, the mechanical model of a single bristles.

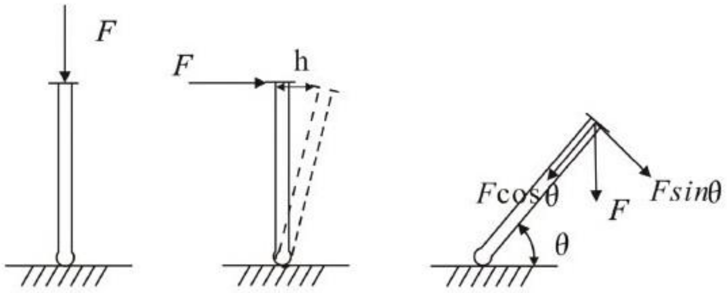


Fig.4 Mechanical model of single bristle

When the contact surface perpendicular to the bristles, the bristles being vertically downward pressure, while the bristles of the contact surface pressure is generated. According to the material mechanics bar stable knowledge struts softness:

$$\lambda = \frac{\alpha l}{i} = \frac{\alpha l}{\sqrt{I/A}} \qquad (5)$$

In type:

$\alpha$ −−*Bar length factor*;

$I$ −−*Strut moment of inertia*;

$A$ −−*Cross−sectional area*;

Euler critical buckling strut formula is:

$$F_{cr} = \frac{\pi^2 EI}{(\alpha l)^3} \qquad (6)$$

At the end of the fixed end of the free bar, $\alpha=2$. When the external force is greater than this value, the bristles will occur big deflection. When the applied force $F<F_{cr}$, will not bar instability. Bar axial deformation occurs. According to the classical formula of friction, single bump down the friction generated for $f$:

$$f = \hat{\mu} F = (\mu + \tau A_f / F_{cr})F \qquad (7)$$

In type:

$\hat{\mu}$ −−*Microsorium equivalent friction coefficient between the bump and wafer* ;

$\mu$ −−*Coefficient of dynamic friction between the wafer and the bump material* ;

$\tau$ −−*Shear strength between the bump and wafer* $(Pa)$;

$A_f$ −−*A single cross−sectional area of the cylinder* $(m^2)$;

$F_{cr}$ −−*The critical buckling pressure single cylinder* $(N)$;

$F$ −−*The contact pressures between the wafer and the bump* $(N)$;

According to the above analysis, the known diameter of *300mm*, thickness of *775* $\mu m$, wafer gravity 1.28*N*. When using four contact bumps, the wafer gravity on the distribution of the pressure on each bump $F=0.32N$, the number of bristles per bump required for $n$, calculated $n$ = 43243. Due to its flexible bristles will deform and thus an appropriate increase in the number of bristles. Take $n = 43500$. According to JKR theory, the actual contact area $A_{JKR}$ can be approximately equal to $\pi r^2$.Wherein, $\tau$ is the shear strength between the two contact surfaces, $\tau \approx 10MPa$, into equation (7) is calculated to produce the frictional force $f = 2N$.

## IV. Conclusions

The end-effector is an important part of the wafer transfer robot, frictional contact between the wafer characteristics it is the focus of this study. Analysis of characteristics of the wafer anisotropic materials, and based on the relationship of anisotropic material stiffness matrix material constants of constants and engineering analyzes to determine the model parameters wafer materials for wafer frictional contact analysis of the foundation. Wafer bumping against contact transmission mode. The paper analyzed and calculated bristling array of bumps and friction characteristics between wafers.By elastic contact model theory, derived formulas friction. Simulation and calculation results show that bump -type contact way to meet the requirements of small deformation wafer transfer, while using bristles array consisting of friction bump -and transmission actuator can effectively increase the friction between two contacting surfaces. The application in this way, the transmission can be increased acceleration, improve the efficiency of the water transfer.

## V. Acknowledgements

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