300mm Probing Error Analysis

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**Background & Assumptions**

- Analysis of a prober system containing upward and downward looking camera
- Analysis does not assume any specific layout of prober or camera configuration
- It is possible to move a wafer under the probe card & grab images of the probe tips with an upward looking camera
- It is possible to grab images of wafer using the downward looking camera
Prober Geometry

- Point $O_a$ is position of optical center of alignment camera
- Point $O_p$ is position of optical center of upward looking camera
- Points $\{P_1, P_2, \ldots, P_n\}$ specify corners of various probe tips on probe card
- Point $P$ is the set of above points “probe reference point”

Figure 1: Prober geometry / critical tool points
Wafer Geometry

Figure 2: Important wafer geometry data

• Point A is location of optical reference on wafer at end of wafer alignment
• Points \{R_1, R_2, \ldots R_n\} specify locations of the pad within a die
• Point R is the set of the above points “pads reference point”
Two step process

- Determine probe card position (origin(X,Y) and angle $\eta$ of the probe card coordinate system (PcCS) w.r.t. RCS and the Z height of the plane in which the PcCS lies.

- Align the wafer (WCS and DCS) at the $\eta$ angle determined at the PcCS and move the wafer under the probe card such that the origin of the DCS and PcCS are aligned.

- Probe card position is determined by measuring points $\{P_1, P_2, \ldots, P_n\}$ and then computing (x,y) position of probe reference point P and the $\eta$ of the probe card so that the probes can be optimally contacted with a die(dice) on the wafer.

- Once P and $\eta$ are known, wafer aligned at $\eta$ can be moved A-O$_a$+P to achieve optimal probe to pad alignment.
Probing Procedure

• Setup wafer data training
  • Setup the known product data
    • Wafer diameter, load angle, die size, thermal expansion coefficient
  • Load above product data, load wafer, allow wafer to reach desired temp.
  • Align target is selected by user and wafer is aligned at 0 degree wrt RCS
  • WSSC (Wafer Scaling & Stepping Calibration) is run to determine the die size seen by the prober at current temperature.
  • User trains the die boundaries, the reference die and pad locations within a die
• Wafer Data stored after training
  • Alignment target, its position in WCS ie. A_{WcCS} & A_{WCS} vectors and pad positions \{R_1, R_2, \ldots R_n\}, and updated data (die size, expansion coefficient)

• On subsequent wafers, the above data provides ability to fairly approximate the alignment target based on wafer center (A_{WcCS}), and then establish WCS.

• Once WCS is established the prober can identify the position of reference die and all other dice on the wafer, locations of various pads/other features trained within a die.
Probing Procedure (contd)

• Determining Probe Card Position
  • Z height of the plane containing the probe tips is determined
  • Using upward looking camera (ULC), is moved under the probe tips and
    the its position is recorded in RCS where it detects a probe tip.
  • Knowing the transform between the ULC and the RCS, the probe tip
    positions can be expressed in RCS as $P_n = M + O_p + p_n$
Probing Procedure (contd)

\[ M = \text{RCS position of the motion system moving the ULC} \]

- The set of detected probe tip positions \( \{P_1, P_2, \ldots, P_n\} \) and the set of pad positions \( \{R_1, R_2, \ldots, R_n\} \) through a probe to pad alignment algorithm yield a position \( P \) and angle \( \eta \)

*Figure 3:* Probe tips as seen by the upward looking camera
Probing Procedure (contd)

$\theta$

$P_{ccs} = \text{Probe card coordinate system}$

Figure 4: Probe card coordinate system w.r.t. RCS

• Relationship between vector P and angle $\eta$ is shown above

• For optimal touchdown wafer is aligned to angle $\eta$ and moved under probe card so that point P and R coincide
Probing Procedure (contd)

• Production steps

• Thermal Stabilization: Prober waits until loaded wafer reaches desired temperature (steady state)

• Profiling: Wafer surface is profiled, to measure thickness at various points and to determine the offset between the wafer center and the chuck center (null the wafer placement error)

• Alignment: Wafer is aligned to the probe card angle $\eta$, final step of alignment will move wafer optical reference point $A$ under the alignment camera optical reference $O_a$

• Touchdown !!: Prober computes touchdown point $T'$ on reference die
  
  $T' = A' - O_{a'} + P'$

• $T'$, $A'$, $O_{a'}$ and $P'$ are ideal locations for touchdown at run time, however we only know $A$, $O_a$ and $P$ from calibration, so we use these.
Error Analysis

\[ T = A - O_a + P \]

• Each component of above equation contributes to total system error.

• Errors include
  • Machine Vision errors
  • Motion errors
  • Thermal errors
  • Calibration errors
Error Analysis

• Alignment errors
  • Vector A is part of the product data trained by the user
  • Subsequent wafers use this vector to establish WCS
  • Errors during training, aligning and nulling phases will be introduced in overall system accuracy.

\[ A = A' + E_{\text{ran}} + E_{\text{ran}} + E_{\text{rtw}} \]

\( A' \) is the correct location of the point and vector
\( E_{\text{ran}} \) is the run time alignment theta error \( \text{---------Eq a.1} \)
\( E_{\text{ran}} \) is the run time alignment nulling error \( \text{---------Eq a.2} \)
\( E_{\text{rtw}} \) is the run time thermal expansion error \( \text{---------Eq a.3} \)
Error Analysis

• Alignment camera position errors
  • Prober uses position of alignment camera $O_a$ in computing $T$
  • Error in $O_a$ will reflect in touch down errors
    \[ O_a = O_{ac}' - \delta EO_{racn} + E_{oac} \]

$O_{ac}'$ is the correct location of the alignment camera optical reference point at the end of the nulling process.

$\delta EO_{racn}$ is the delta offset between real location of $O_a$ at the end of calibration and the real $O_a$ at the end of nulling (this error is present because of difference in temperature and other stresses between calibration and nulling).

$E_{oac}$ is the error in calibration process that establishes the position of the alignment camera in the RCS (this error is primarily a combination of vision and motion system errors).
Error Analysis

• Probe card position errors
  • Probe card position, P is calculated based on probe tips seen by the ULC and the pads data trained by the user.
  • Any error in any of these components will be reflected in P

\[ P = f(\{P_1, P_2, \ldots P_n\}, \{R_1, R_2, \ldots R_n\}) \]

since \( P_j = p_j + M_j + O_p \)  \--------Fig 3

\[ P = f(\{p_1 + M_1, p_2 + M_2, \ldots p_n + M_n\}, \{R_1, R_2, \ldots R_n\}) + O_p \]

every \( p_j, M_j, \) and \( R_i \) have some vision, motion and calibration errors \( E_{pf(p,M,R)} \)
**Error Analysis**

- Probe card position errors (continued)

  \( O_p \) also contributes to error because of two reasons

  \( E_{O_{pc}} \) is the error in calibration process that establishes \( O_p \) in RCS

  \( \delta E_{O_{pcp}} \) is the delta offset error between true \( O_p \) at time of calibration and the true \( O_p \) at PTPA time. This error is present because of difference is temperature during calibration and nulling time.

  Thus

  \[
  P = P_{ptpa}' + E_{p(p,M,R)} + E_{O_{pc}} - \delta E_{O_{pcp}}
  \]

  where \( P_{ptpa}' \) is the true probe card position at PTPA time.
Error Analysis

• Probe card position errors (continued)

  • Probe card position in RCS is not static, probe card moves with time because of thermal and other stresses.

  • Probe card position at time of touchdown can be represented as

    \[ P' = P_{ptpa} + \delta EP \]

  \( P_{ptpa} \) is the real probe card position at PTPA time

  \( \delta EP \) is the delta offset between real probe card position at PTPA time and its real position at probe time

  \[ P = P' + E_{pf(p,M,R)} + E_{opc} - \delta E_{opcp} - \delta EP \]
**Error Analysis**

- **Total touchdown error**
  - Touchdown point T can be represented as combination of true touchdown pint T’ and the total system error ET at reference die touchdown.
  
  \[ T = T' + ET \]

\[ T = (A' - O_a' + P') + (optimal \ touchdown \ point) \]
\[ (EA_{ran} + EA_{ran} + E_{artw}) - (alignment \ error \ component) \]
\[ (E_{oac} - \delta E_{racn}) + (alignment \ camera \ position \ errors) \]
\[ (E_{pf(p,M,R)} + E_{opc} - \delta E_{opc} - \delta E_P) + (probe \ card \ position \ errors) \]
\[ EMT \] (motion error in reaching point T)
Error Analysis

• Total touchdown error (substituting terms)

\[ T = T' + ET \]

\[ = (A' - O_a' + P') + \]

\[ (A * E_{ran} + E_{Arvn} + E_{Mrn} + A * E_{tw} * T) - (E_{oa} - \delta E_{Oacn}) + \]

\[ (E_{p_{(p,M,R)}} + E_{opc} - \delta E_{opc} - \delta EP) + \]

\[ E_{MT} \]

Rearranging terms we get
**Error Analysis**

• Total touchdown error (substituting terms)

\[ T = T' + ET \]

\[ = (A' - O_a' + P') + \text{(optimal touchdown position)} \]

\[ EM_T + Em_rn + \text{(Motion errors)} \]

\[ Ea_{rvn} + \text{(Vision nulling errors)} \]

\[ A * E_{ra} + \text{(Theta Alignment errors)} \]

\[ A * E_{tw} * T + \text{(Wafer thermal comp errors)} \]

\[ EO_{pc} - EO_{ac} + \text{(Camera calib. errors)} \]

\[ \delta EO_{racn} - \delta EP - \delta EO_{pcp} + \text{(Tool thermal stress errors)} \]

\[ EP_{f(p,M,R)} + \text{(PTPA error)} \]
Practical Uses

• Analysis of prober accuracy and effects of error sources can be performed.
• Effects of improvement of each subsystem of prober on the total accuracy of the system can be readily evaluated.
• Model can be used to determine “Biggest Bang for the Buck” solutions.
Example