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

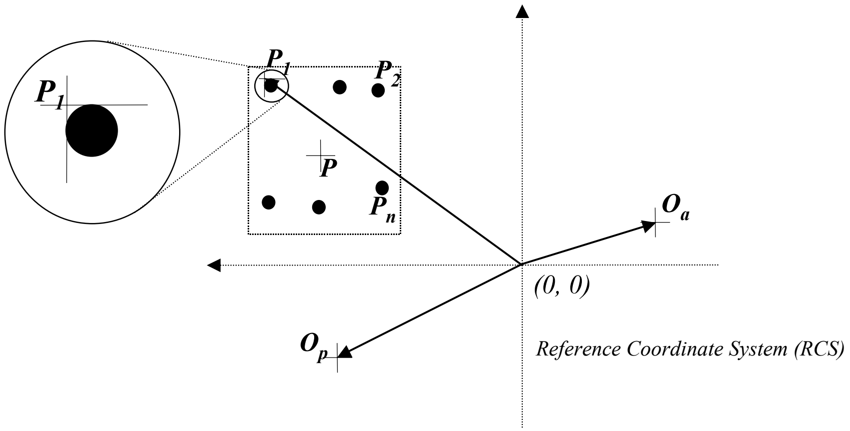


Figure 1 : Prober geometry / critical tool points

- •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”

Wafer Geometry

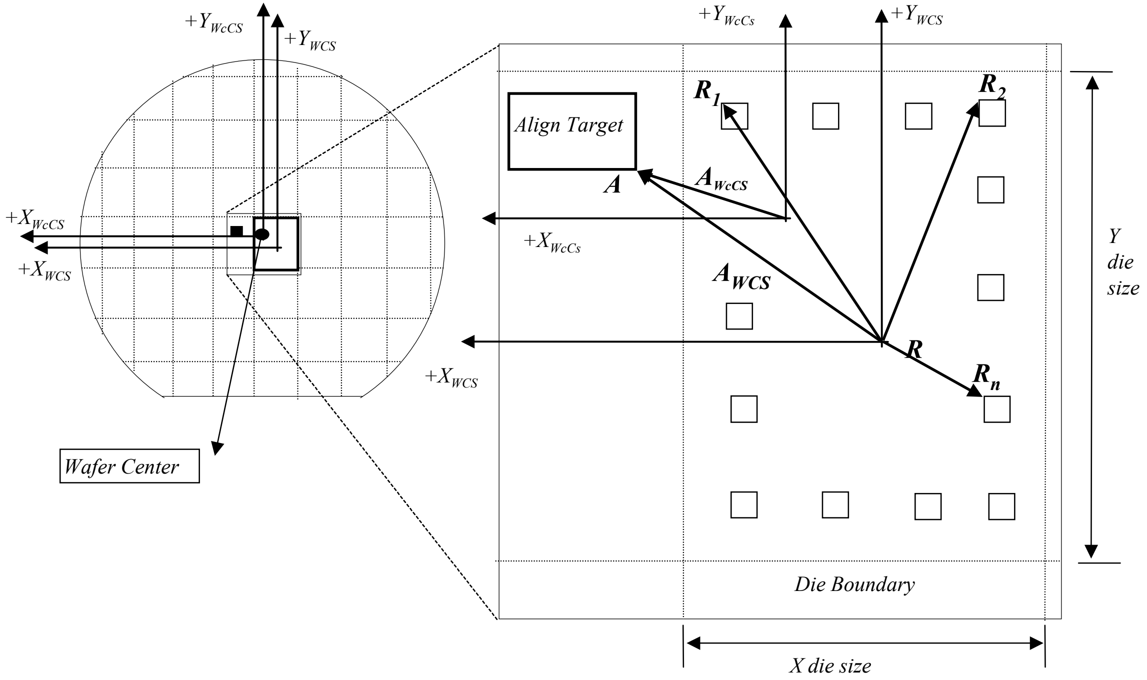


Figure 2 : Important wafer geometry data

- •Point A is loction 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”

Probe to Pad Alignment

- Two step process
  - Determine probe card position (origin(X,Y) and angle η 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 η 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 η of the probe card so that the probes can be optimally contacted with a die(dice) on the wafer.
- Once P and η are known, wafer aligned at η 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

Probing Procedure (contd)

- 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)

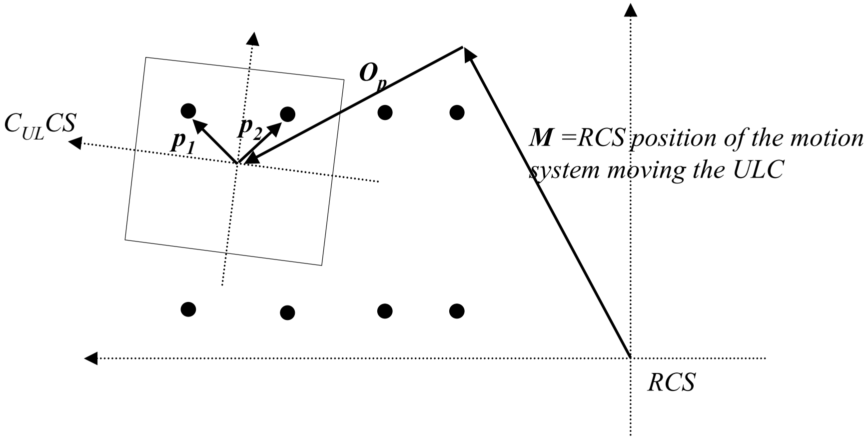


Figure 3 : Probe tips as seen by the upward looking camera

- 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 η

Probing Procedure (contd)

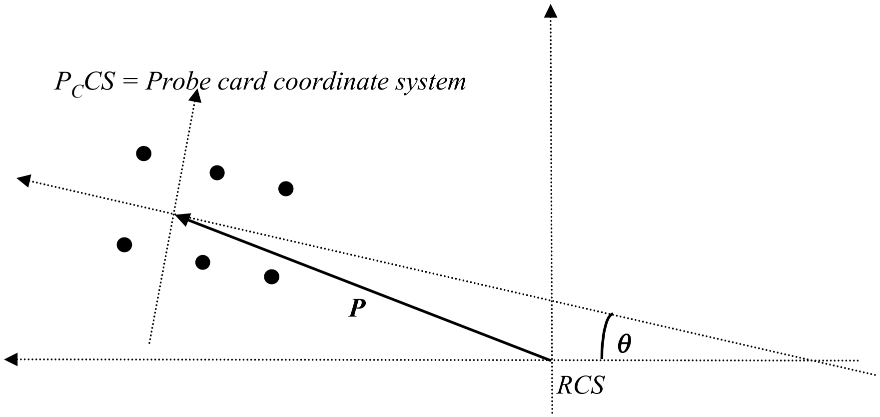


Figure 4 : Probe card coordinate system w.r.t. RCS

- Relationship between vector P and angle η is shown above
- For optimal touchdown wafer is aligned to angle η 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 η, 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.

$$A = A' + EA_{ra\eta} + EA_{ran} + Ea_{rtw}$$

A’ is the correct location of the point and vector

$Ea_{ra\eta}$ is the run time alignment theta error ---------Eq a.1

Ea_{ran} is the run time alignment nulling error-------Eq a.2

Ea_{rtw} is the run time thermal expansion error------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

$$O_a = O_{ac}' - \delta EO_{racn} + Eo_{ac}$$

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

δEO_{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).

Eo_{ac} 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 $Ep_{f(p,M,R)}$

Error Analysis

- Probe card position errors (continued)

O_p also contributes to error because of two reasons

EO_{pc} is the error in calibration process that establishes O_p in RCS

$\delta\, Eo_{pcp}$ 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

$$P = P_{ptpa}' + Ep_{f(p,M,R)} + Eo_{pc} - \delta\, Eo_{pcp}$$

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

δEP is the delta offset between real probe card position at PTPA time and its real position at probe time

$$P = P' + Ep_{f(p,M,R)} + Eo_{pc} - \delta\ Eo_{pcp} - \delta EP$$

Error Analysis

- Total touchdown error
  - Touchdown point T can represented as combination of true touchdown pint T’ and the total system error ET at reference die touchdown.

$T = T' + ET$

$= (A' - O_a' + P') +$	(optimal touchdown point)
$(EA_{ra\eta} + EA_{ran} + Ea_{rtw}) -$	(alignment error component)
$(Eo_{ac} - \delta EO_{racn}) +$	(alignment camera position errors)
$(Ep_{f(p,M,R)} + Eo_{pc} - \delta\, Eo_{pcp} - \delta EP) +$	(probe card position errors)
EM_T	(motion error in reaching point T)

Error Analysis

- Total touchdown error (substituting terms)

$$
\begin{aligned}
T &= T' + ET \\
&= (A' - O_a' + P') + \\
&\quad (\underline{A * E_{ra\eta}} + \underline{EA_{rvn}} + \underline{EM_{rn}} + \underline{A * E_{tw} * T}) - \\
&\quad (Eo_{ac} - \delta EO_{racn}) + \\
&\quad (Ep_{f(p,M,R)} + Eo_{pc} - \delta\, Eo_{pcp} - \delta EP) + \\
&\quad EM_T
\end{aligned}
$$

Rearranging terms we get

Error Analysis

- Total touchdown error (substituting terms)

$T = T' + ET$

$= (A' - O_a' + P') +$ (optimal touchdown position)

$EM_T + Em_{rn} +$ (Motion errors)

$Ea_{rvn} +$ (Vision nulling errors)

$A * E_{ra\eta} +$ (Theta Alignment errors)

$A * E_{tw} * T +$ (Wafer thermal comp errors)

$EO_{pc} - EO_{ac} +$ (Camera calib. errors)

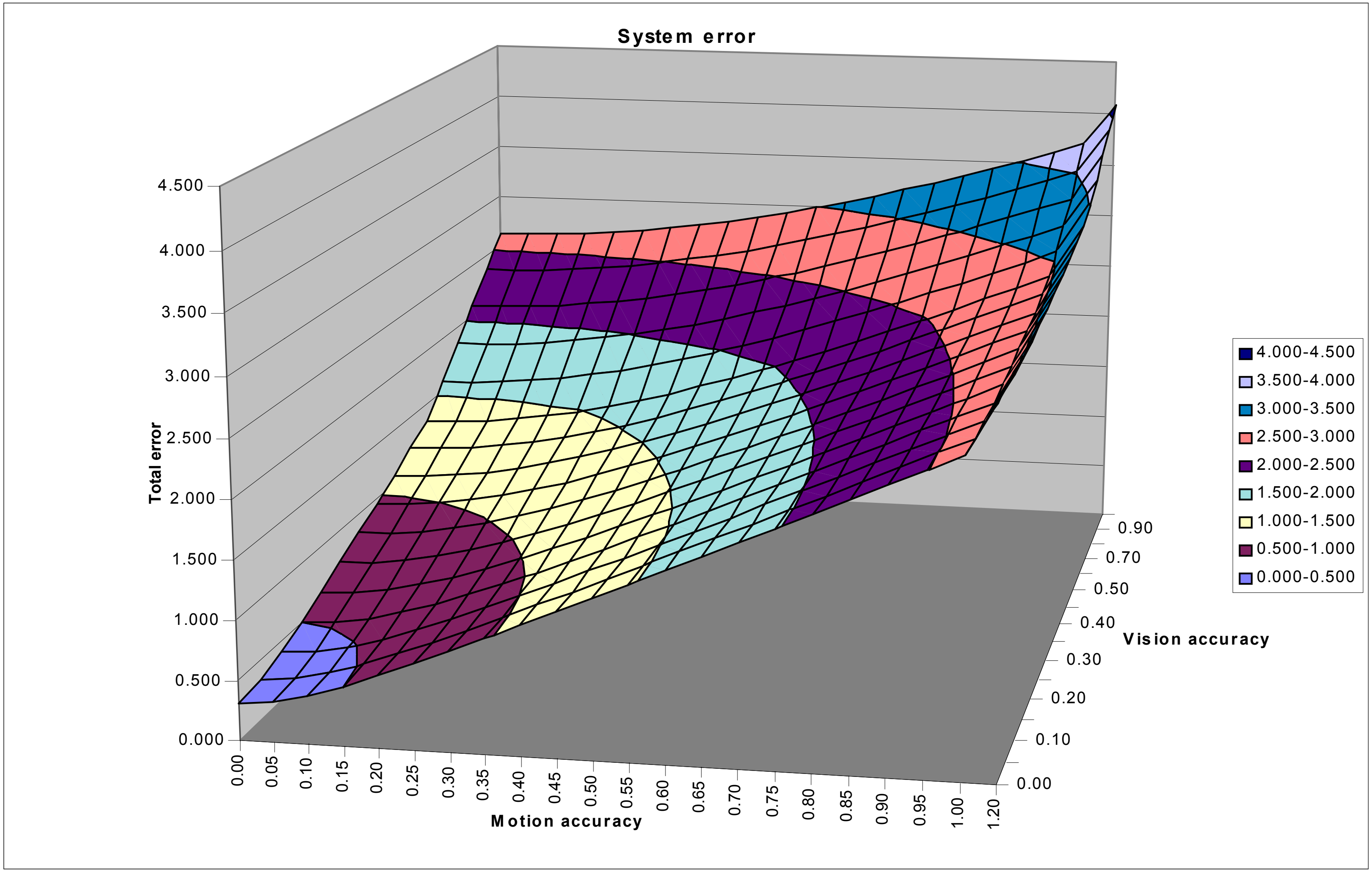
$\delta EO_{racn} - \delta EP - \delta EO_{pcp} +$ (Tool thermal stress errors)

$EP_{f(p,M,R)}$ (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


System error
Total error
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
Motion accuracy
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.20
Vision accuracy
0.90
0.70
0.50
0.40
0.30
0.20
0.10
0.00
4.000-4.500
3.500-4.000
3.000-3.500
2.500-3.000
2.000-2.500
1.500-2.000
1.000-1.500
0.500-1.000
0.000-0.500