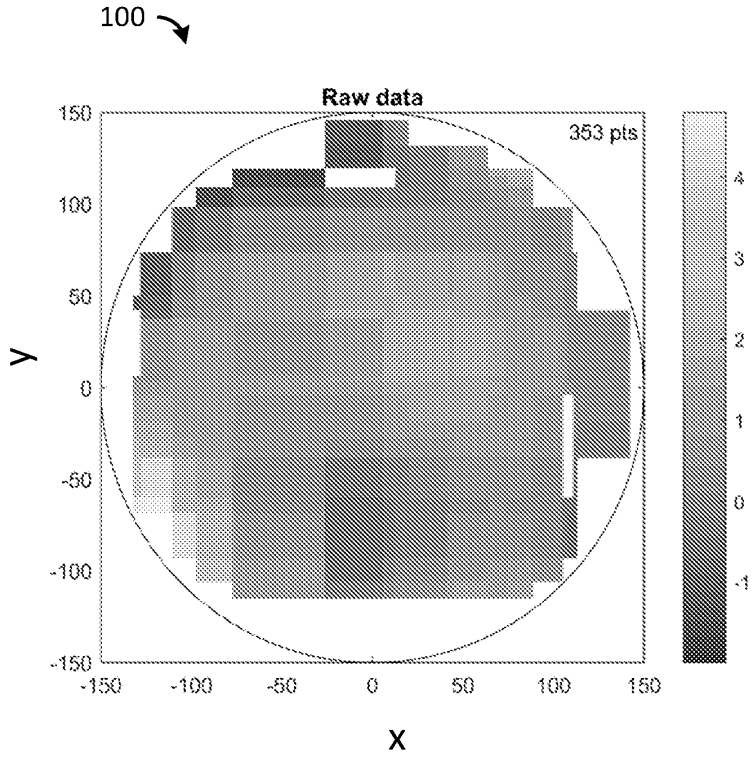

100
Raw data
353 pts
150
100
50
0
-50
-100
-150
y
-150
-100
-50
0
50
100
150
x
4
3
2
1
0
-1

Figure 1A

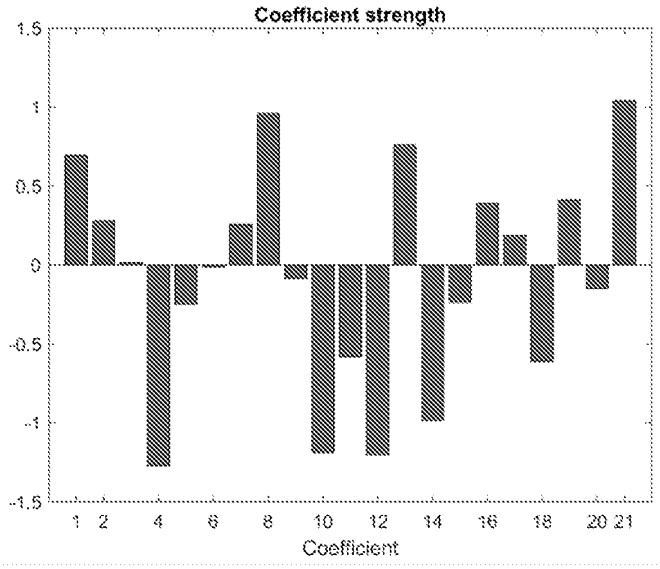


Figure 1B

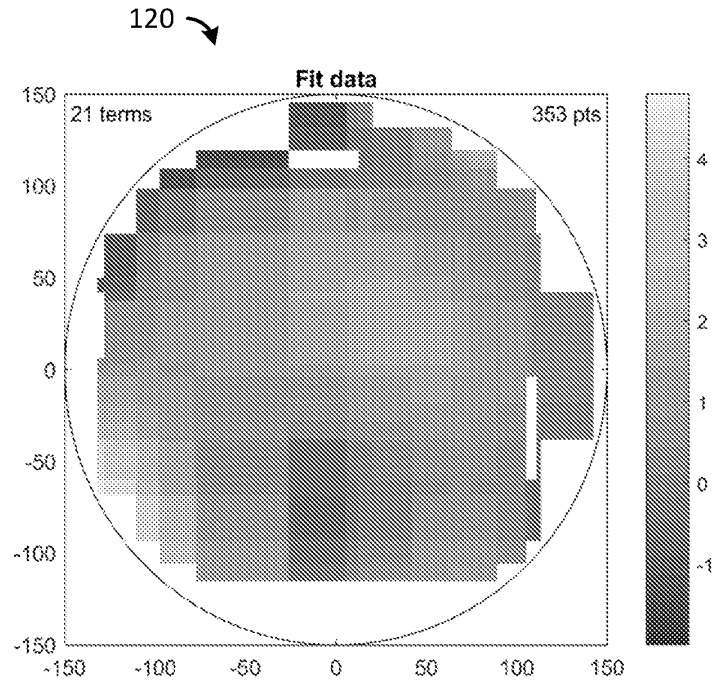


Figure 1C

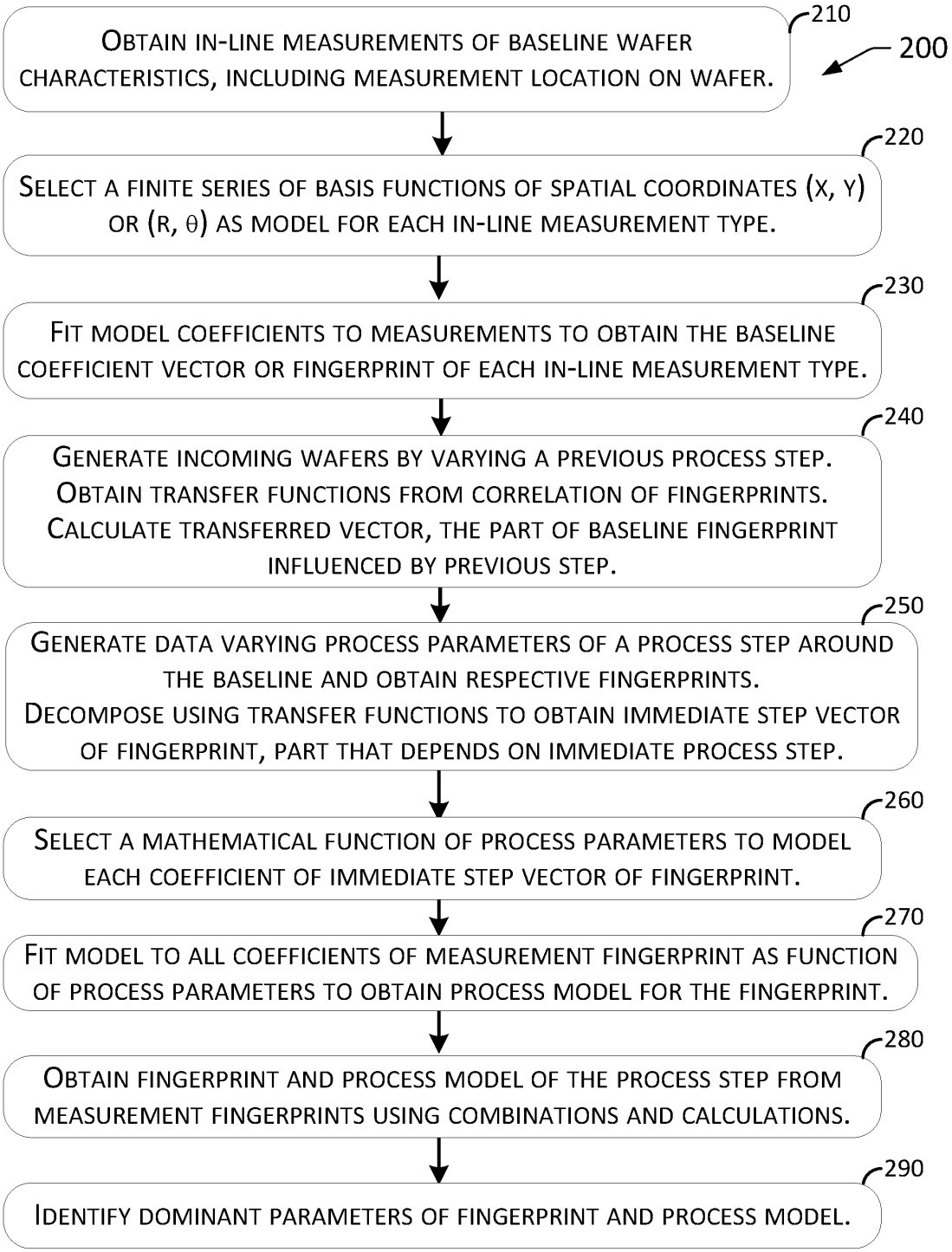

200
210
OBTAIN IN-LINE MEASUREMENTS OF BASELINE WAFER CHARACTERISTICS, INCLUDING MEASUREMENT LOCATION ON WAFER.
220
SELECT A FINITE SERIES OF BASIS FUNCTIONS OF SPATIAL COORDINATES (X, Y) OR (R, θ) AS MODEL FOR EACH IN-LINE MEASUREMENT TYPE.
230
FIT MODEL COEFFICIENTS TO MEASUREMENTS TO OBTAIN THE BASELINE COEFFICIENT VECTOR OR FINGERPRINT OF EACH IN-LINE MEASUREMENT TYPE.
240
GENERATE INCOMING WAFERS BY VARYING A PREVIOUS PROCESS STEP. OBTAIN TRANSFER FUNCTIONS FROM CORRELATION OF FINGERPRINTS. CALCULATE TRANSFERRED VECTOR, THE PART OF BASELINE FINGERPRINT INFLUENCED BY PREVIOUS STEP.
250
GENERATE DATA VARYING PROCESS PARAMETERS OF A PROCESS STEP AROUND THE BASELINE AND OBTAIN RESPECTIVE FINGERPRINTS. DECOMPOSE USING TRANSFER FUNCTIONS TO OBTAIN IMMEDIATE STEP VECTOR OF FINGERPRINT, PART THAT DEPENDS ON IMMEDIATE PROCESS STEP.
260
SELECT A MATHEMATICAL FUNCTION OF PROCESS PARAMETERS TO MODEL EACH COEFFICIENT OF IMMEDIATE STEP VECTOR OF FINGERPRINT.
270
FIT MODEL TO ALL COEFFICIENTS OF MEASUREMENT FINGERPRINT AS FUNCTION OF PROCESS PARAMETERS TO OBTAIN PROCESS MODEL FOR THE FINGERPRINT.
280
OBTAIN FINGERPRINT AND PROCESS MODEL OF THE PROCESS STEP FROM MEASUREMENT FINGERPRINTS USING COMBINATIONS AND CALCULATIONS.
290
IDENTIFY DOMINANT PARAMETERS OF FINGERPRINT AND PROCESS MODEL.

Figure 2

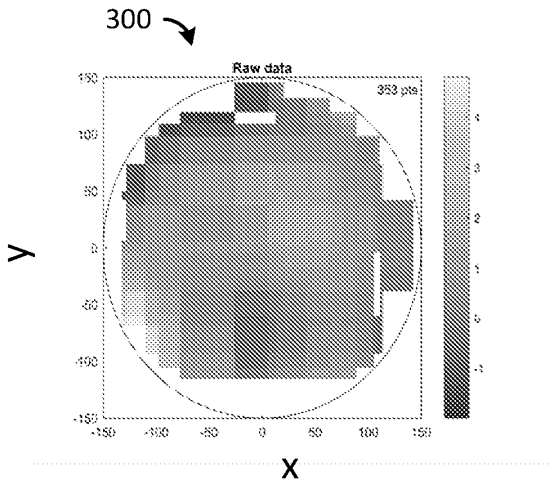


Figure 3A

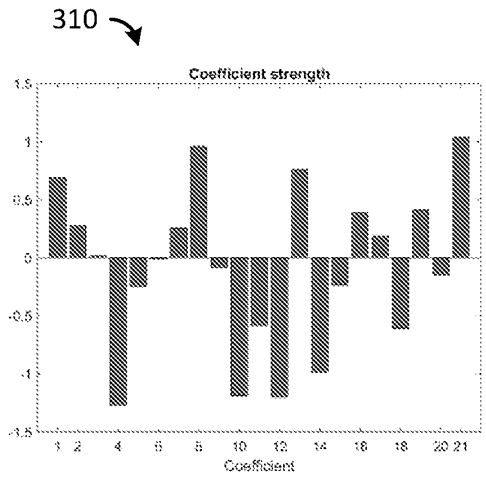


Figure 3B

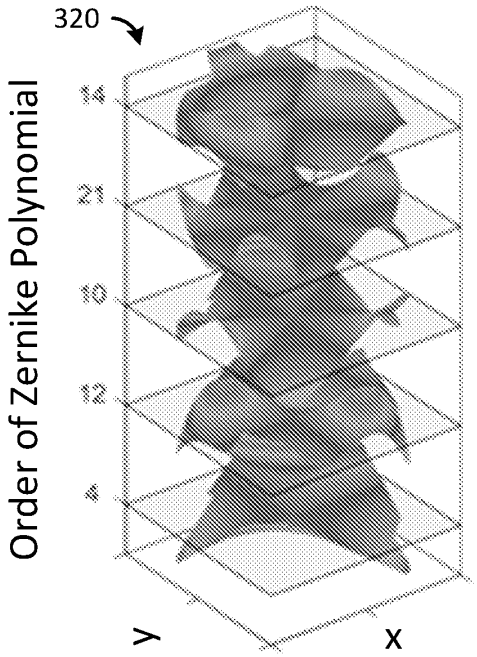


Figure 3C

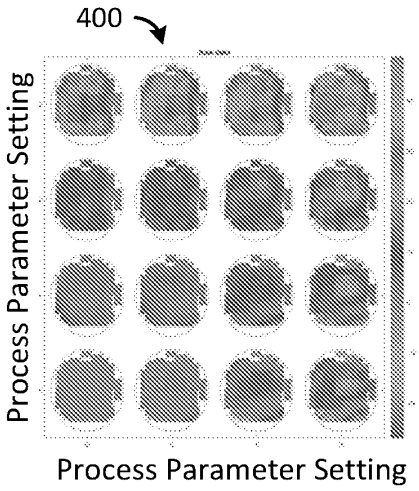


Figure 4A

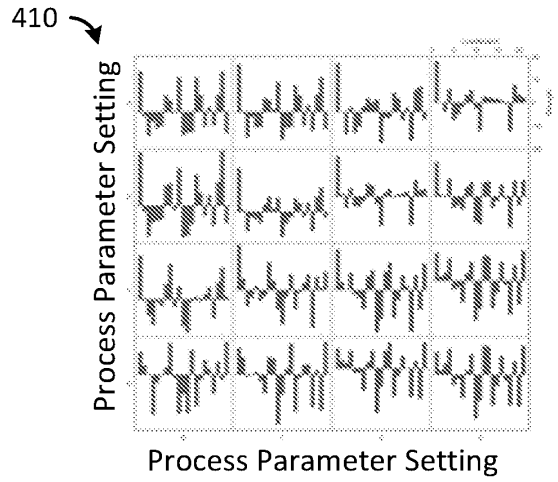
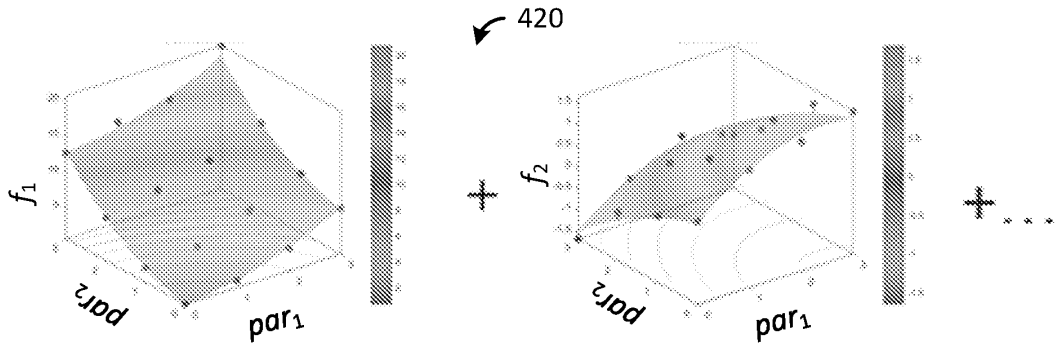


Figure 4B



$$a_i = f_i(\mathrm{par}_1, \mathrm{par}_2, \ldots)$$

Figure 4C

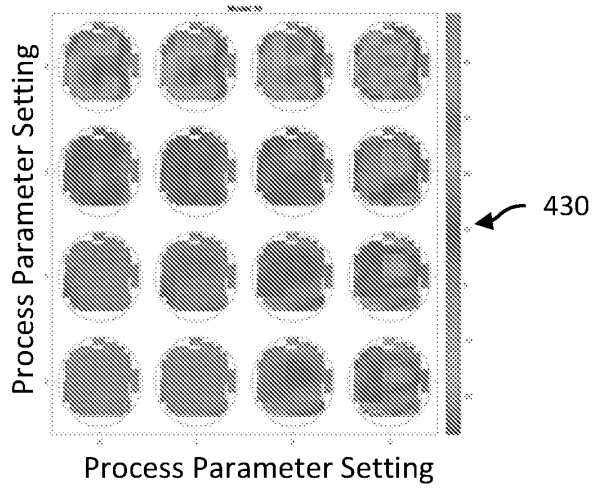


Figure 4D

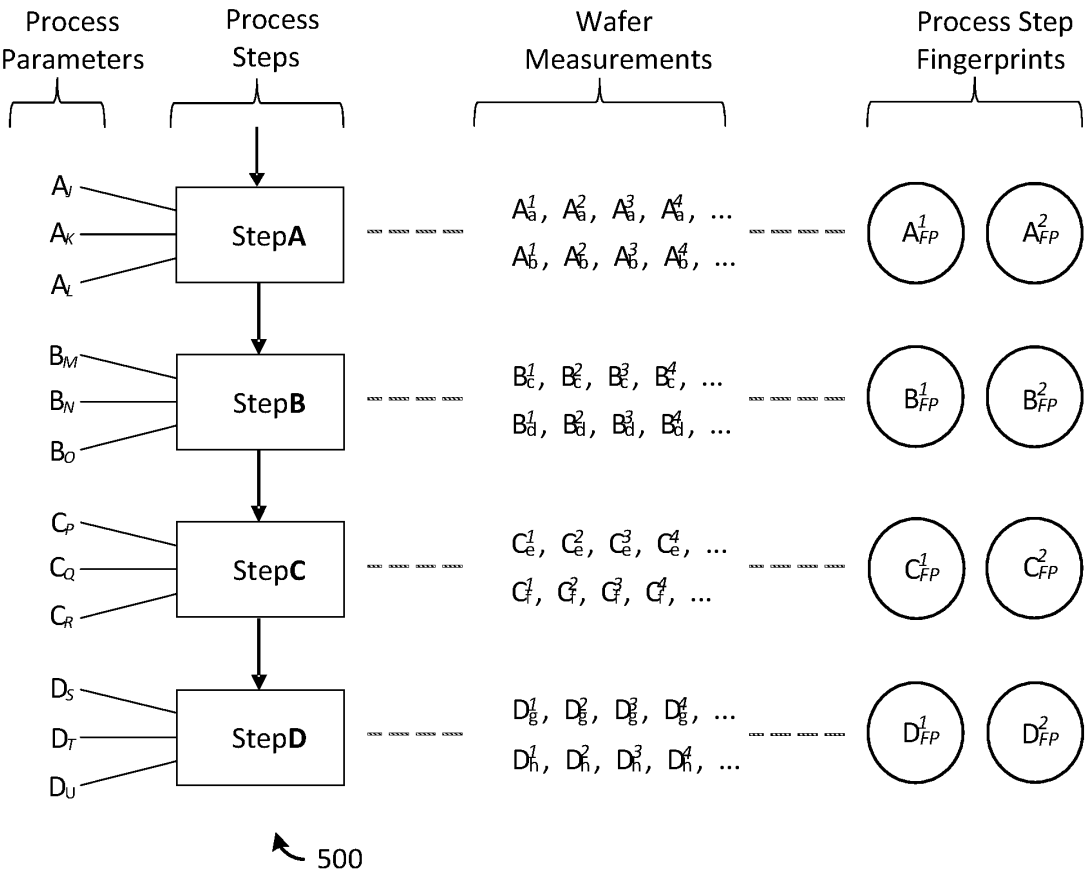

Process Parameters
Process Steps
Wafer Measurements
Process Step Fingerprints
StepA
StepB
StepC
StepD
500

Figure 5

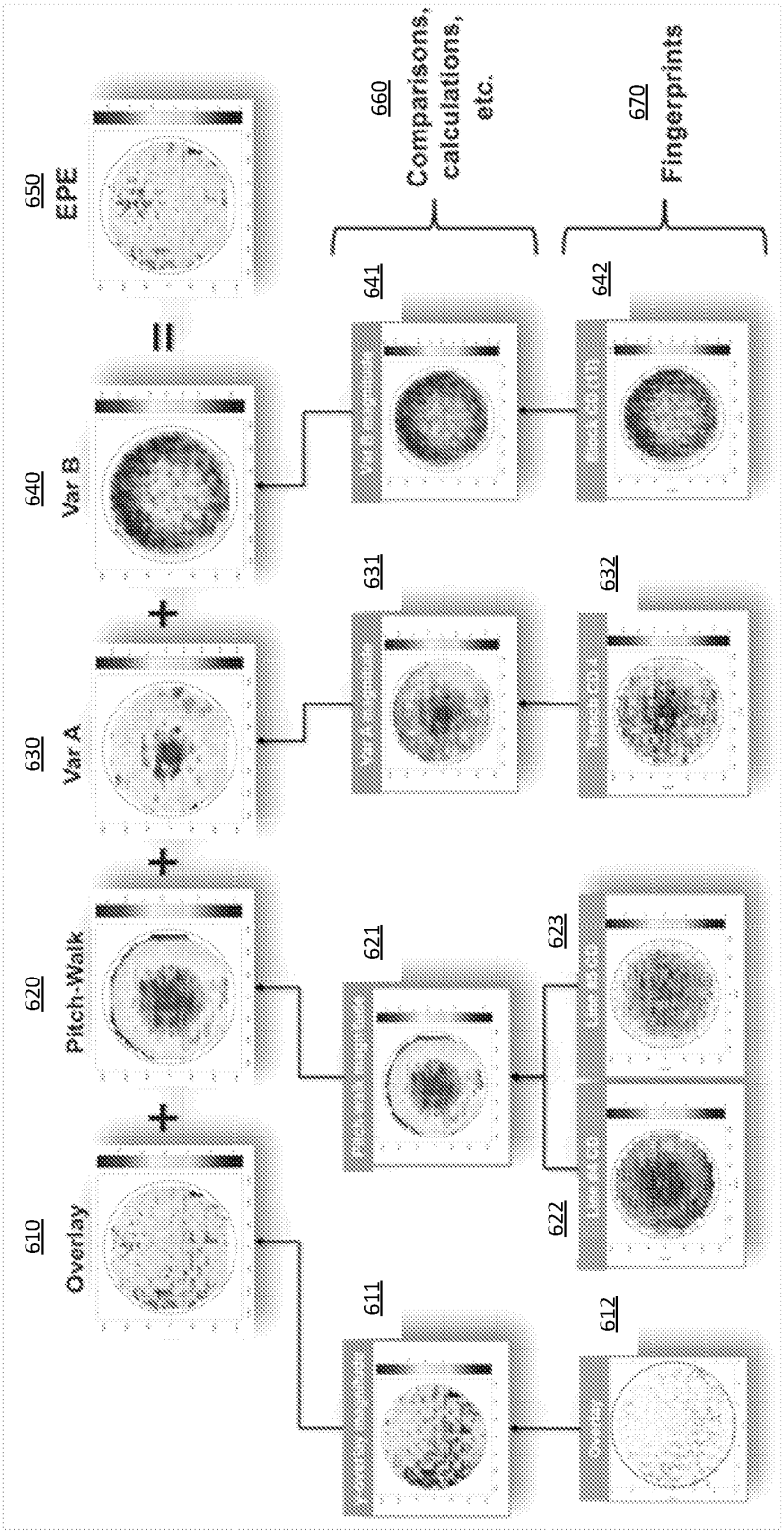

610
Overlay
620
Pitch-Walk
630
Var A
640
Var B
650
EPE
660
Comparisons, calculations, etc.
670
Fingerprints
611
612
621
622
623
631
632
641
642

Figure 6A

680

$$(EPE)_A = [((Var_B - Var_A) \times (MP)_A - Preg_A) - Lspec_A] - (OL)_{AB} + Pwalk_A$$

Figure 6B

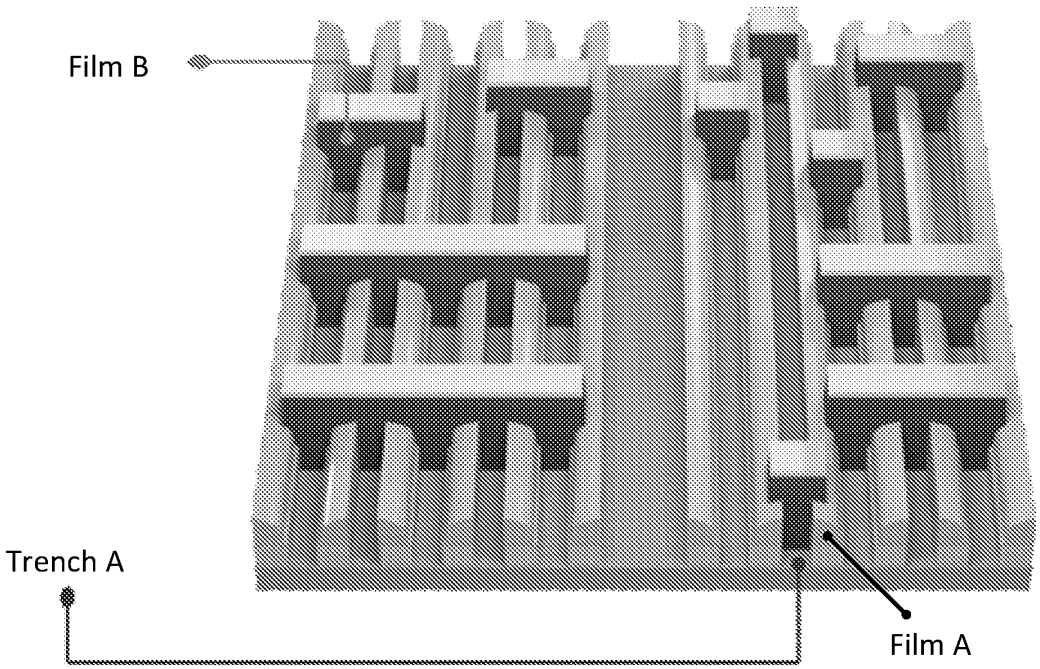


Figure 6C

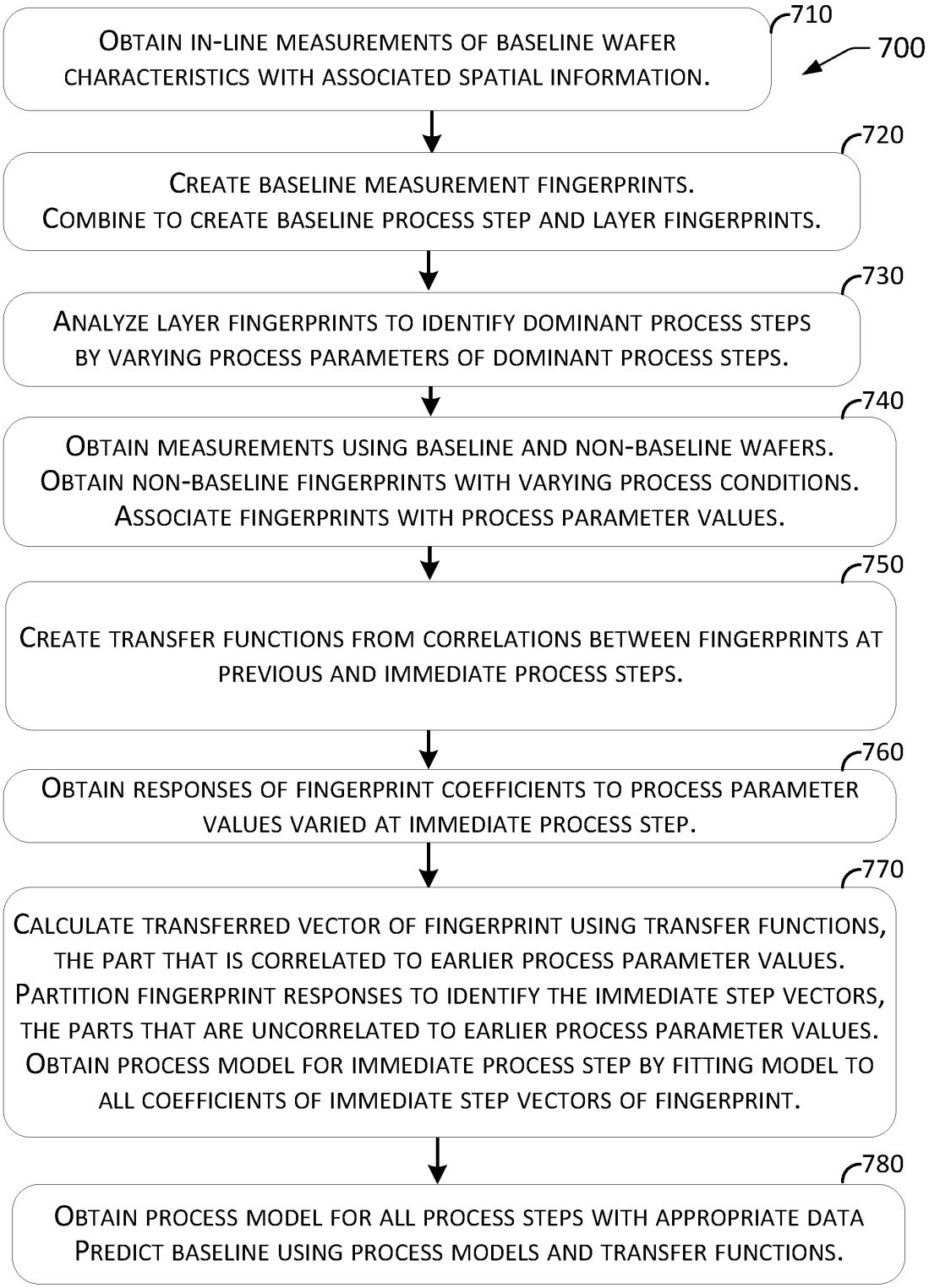

700
710
OBTAIN IN-LINE MEASUREMENTS OF BASELINE WAFER CHARACTERISTICS WITH ASSOCIATED SPATIAL INFORMATION.
720
CREATE BASELINE MEASUREMENT FINGERPRINTS.
COMBINE TO CREATE BASELINE PROCESS STEP AND LAYER FINGERPRINTS.
730
ANALYZE LAYER FINGERPRINTS TO IDENTIFY DOMINANT PROCESS STEPS BY VARYING PROCESS PARAMETERS OF DOMINANT PROCESS STEPS.
740
OBTAIN MEASUREMENTS USING BASELINE AND NON-BASELINE WAFERS.
OBTAIN NON-BASELINE FINGERPRINTS WITH VARYING PROCESS CONDITIONS.
ASSOCIATE FINGERPRINTS WITH PROCESS PARAMETER VALUES.
750
CREATE TRANSFER FUNCTIONS FROM CORRELATIONS BETWEEN FINGERPRINTS AT PREVIOUS AND IMMEDIATE PROCESS STEPS.
760
OBTAIN RESPONSES OF FINGERPRINT COEFFICIENTS TO PROCESS PARAMETER VALUES VARIED AT IMMEDIATE PROCESS STEP.
770
CALCULATE TRANSFERRED VECTOR OF FINGERPRINT USING TRANSFER FUNCTIONS, THE PART THAT IS CORRELATED TO EARLIER PROCESS PARAMETER VALUES.
PARTITION FINGERPRINT RESPONSES TO IDENTIFY THE IMMEDIATE STEP VECTORS, THE PARTS THAT ARE UNCORRELATED TO EARLIER PROCESS PARAMETER VALUES.
OBTAIN PROCESS MODEL FOR IMMEDIATE PROCESS STEP BY FITTING MODEL TO ALL COEFFICIENTS OF IMMEDIATE STEP VECTORS OF FINGERPRINT.
780
OBTAIN PROCESS MODEL FOR ALL PROCESS STEPS WITH APPROPRIATE DATA
PREDICT BASELINE USING PROCESS MODELS AND TRANSFER FUNCTIONS.

Figure 7

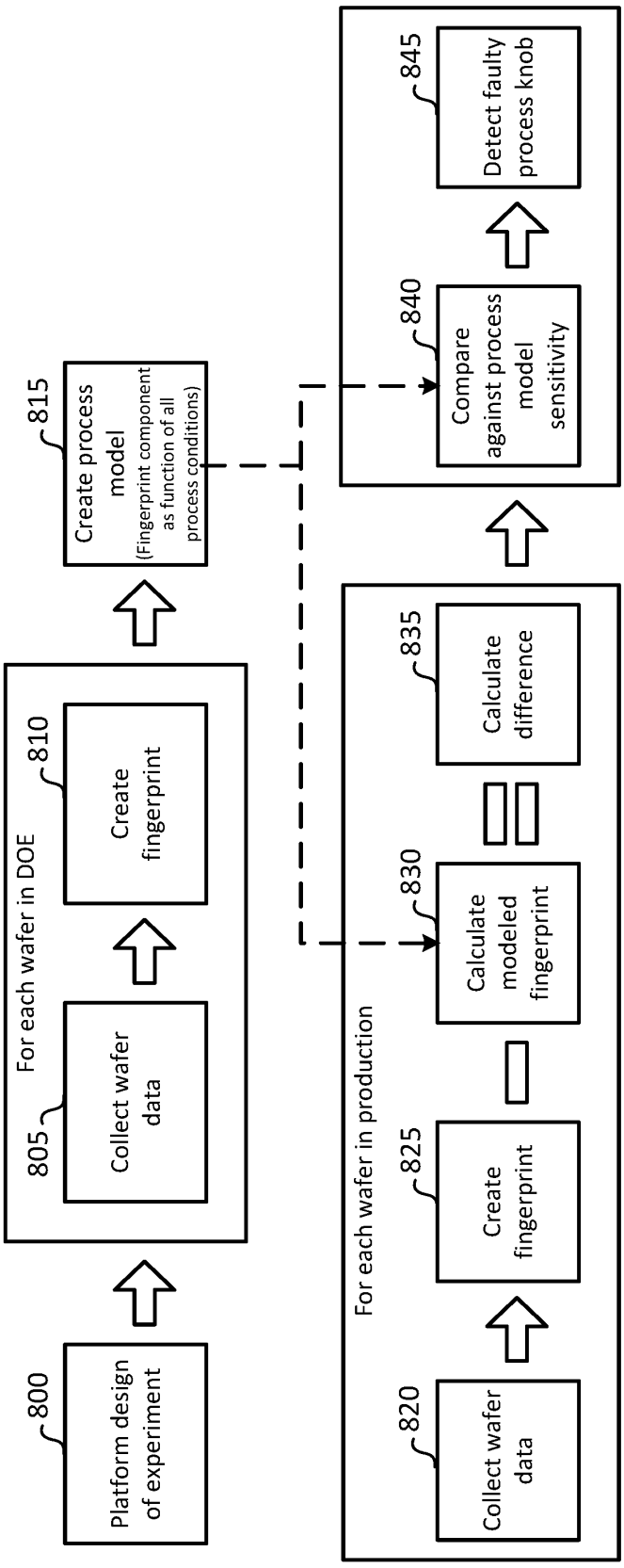

800
Platform design of experiment
For each wafer in DOE
805
Collect wafer data
810
Create fingerprint
815
Create process model
(Fingerprint component as function of all process conditions)
For each wafer in production
820
Collect wafer data
825
Create fingerprint
830
Calculate modeled fingerprint
835
Calculate difference
840
Compare against process model sensitivity
845
Detect faulty process knob

Figure 8

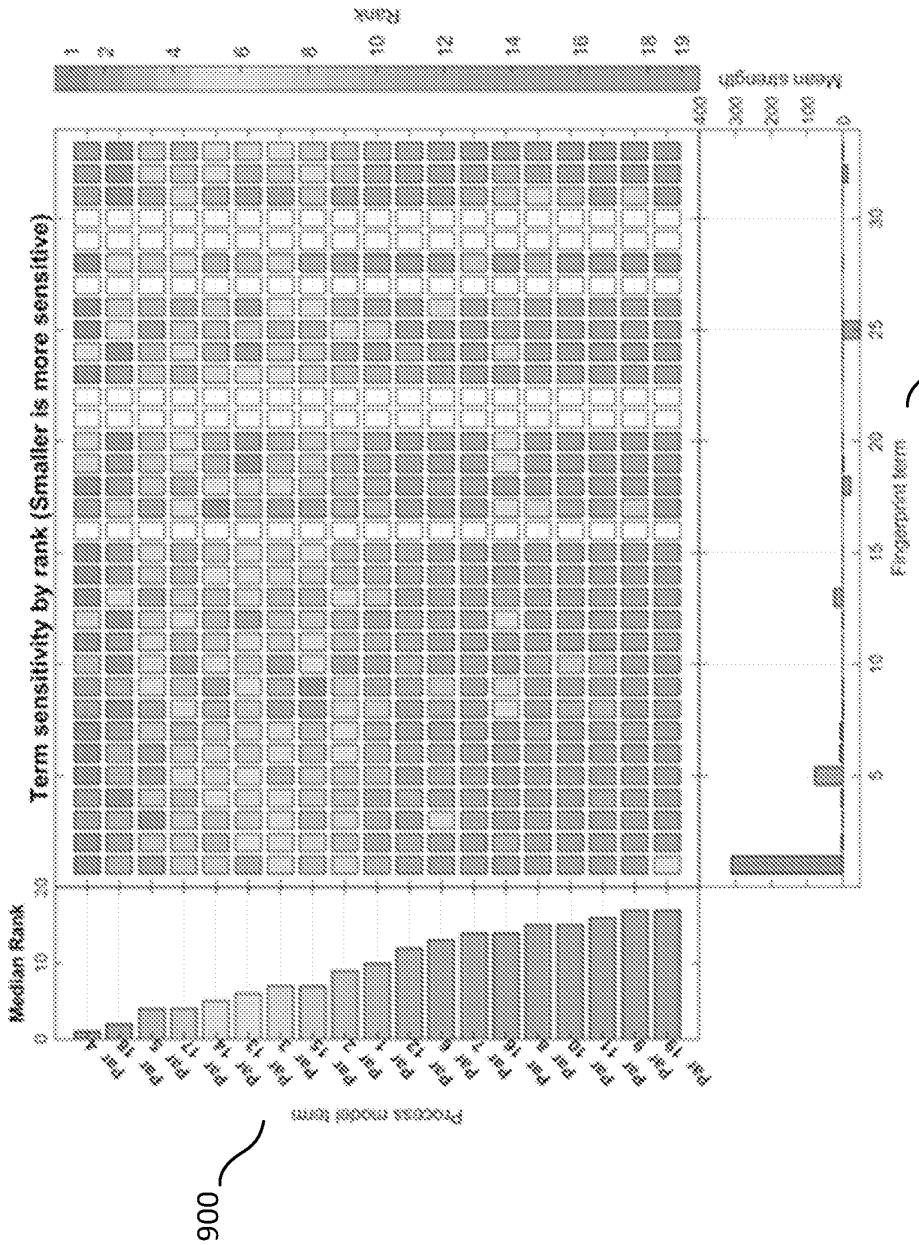

Term sensitivity by rank (Smaller is more sensitive)
Median Rank
Rank
Term length
Fingerprint term
Fingerprint length
900
905

Figure 9

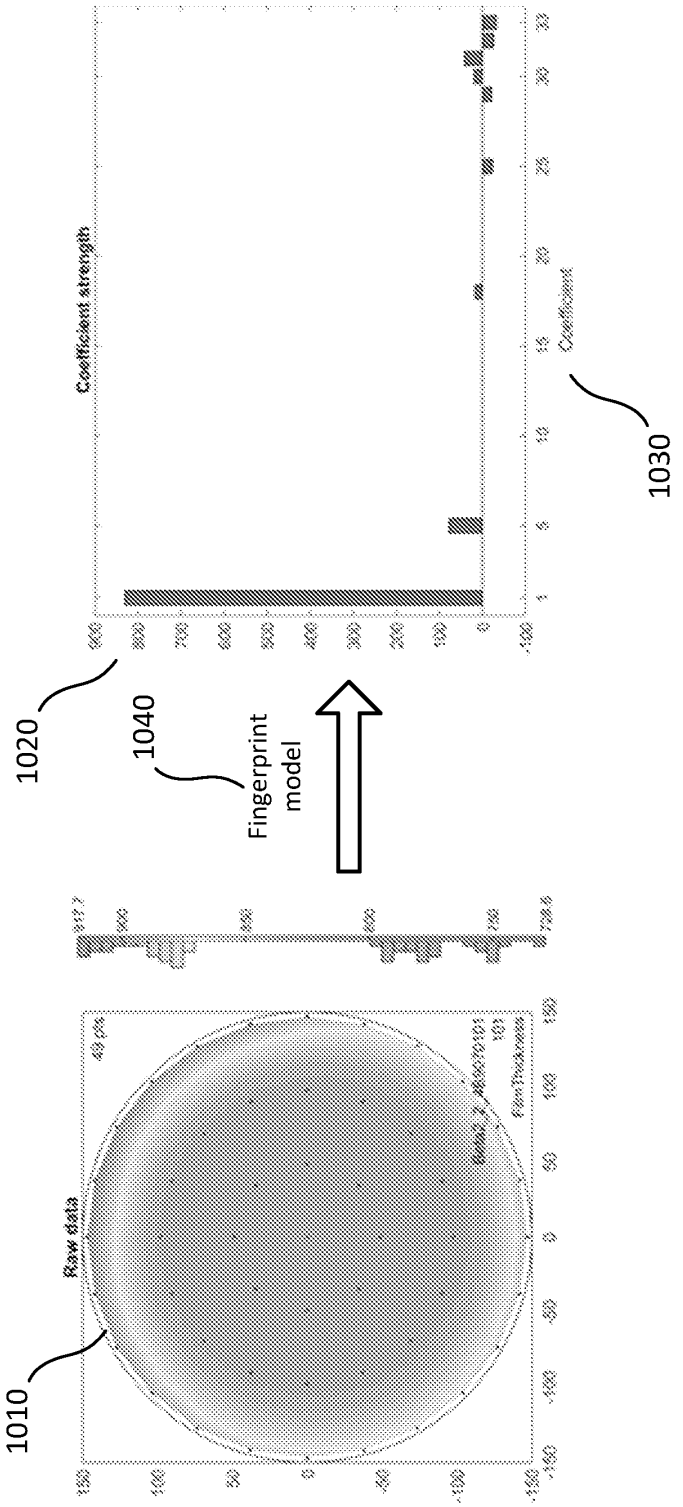

Raw data
Coefficient strength
Coefficient
1010
1020
1030
1040
Fingerprint model

Figure 10

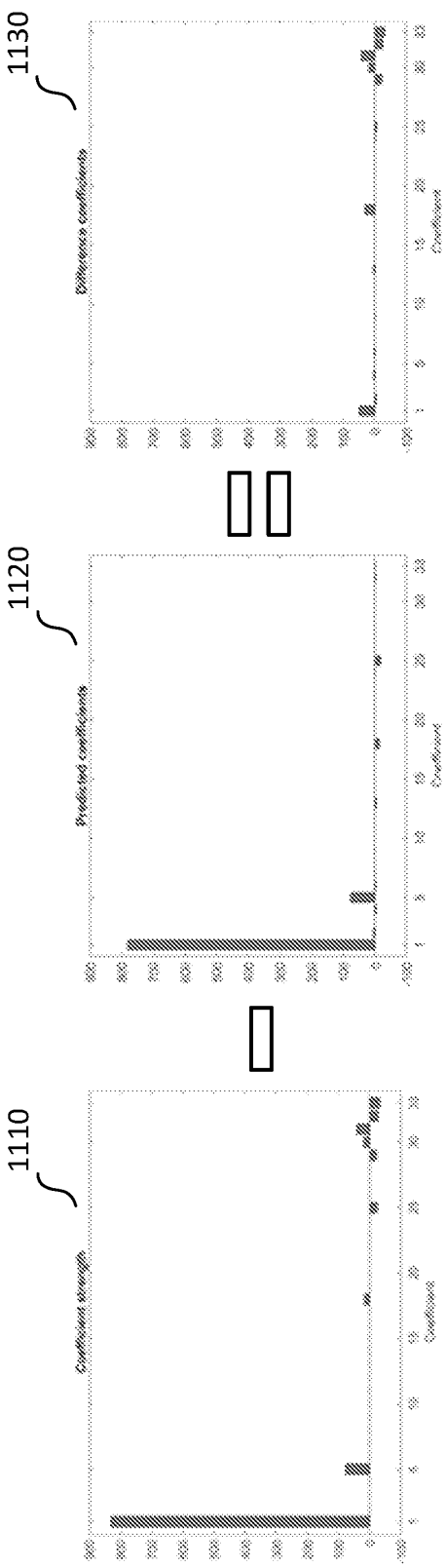


Figure 11A

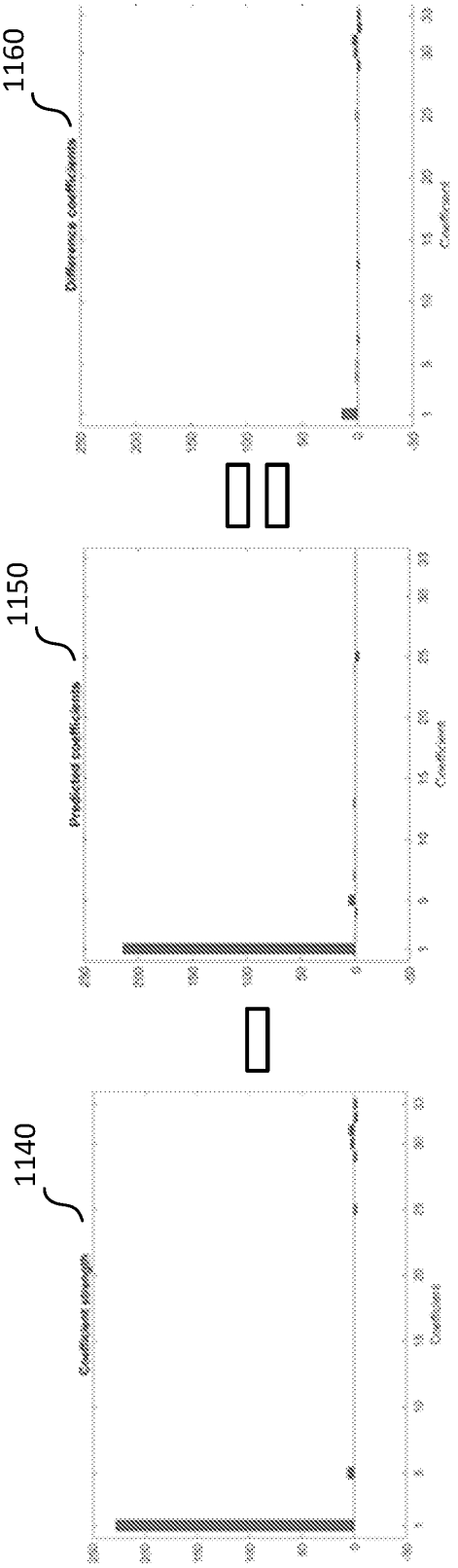


Figure 11B

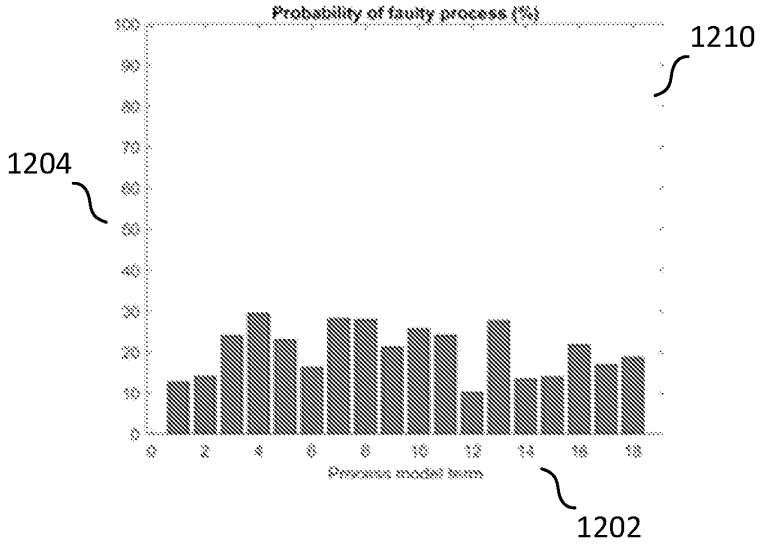


Figure 12A

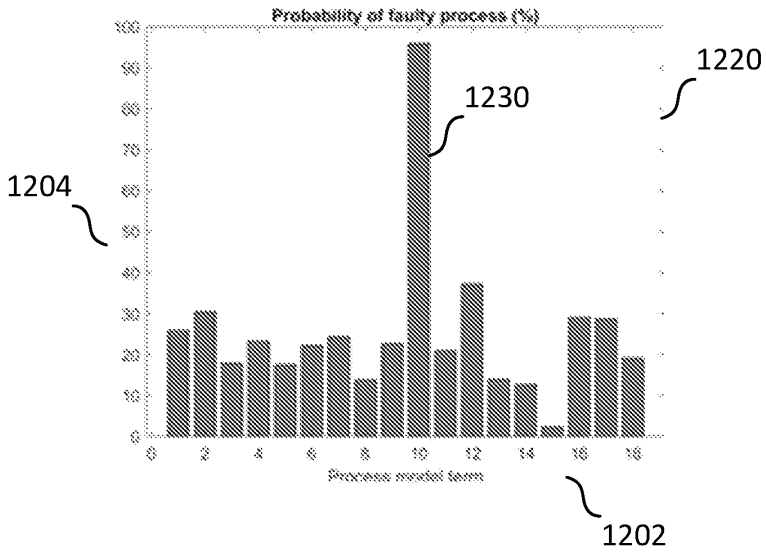


Figure 12B

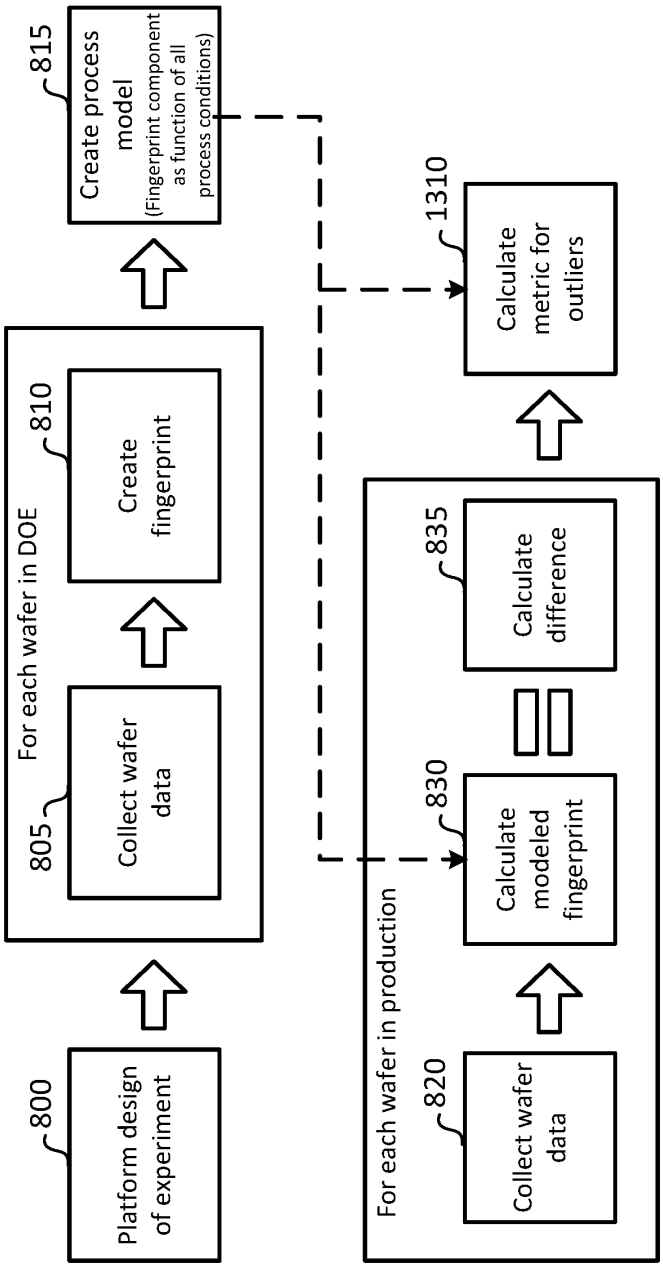

800
Platform design of experiment
For each wafer in DOE
805
Collect wafer data
810
Create fingerprint
815
Create process model
(Fingerprint component as function of all process conditions)
For each wafer in production
820
Collect wafer data
830
Calculate modeled fingerprint
835
Calculate difference
1310
Calculate metric for outliers

Figure 13

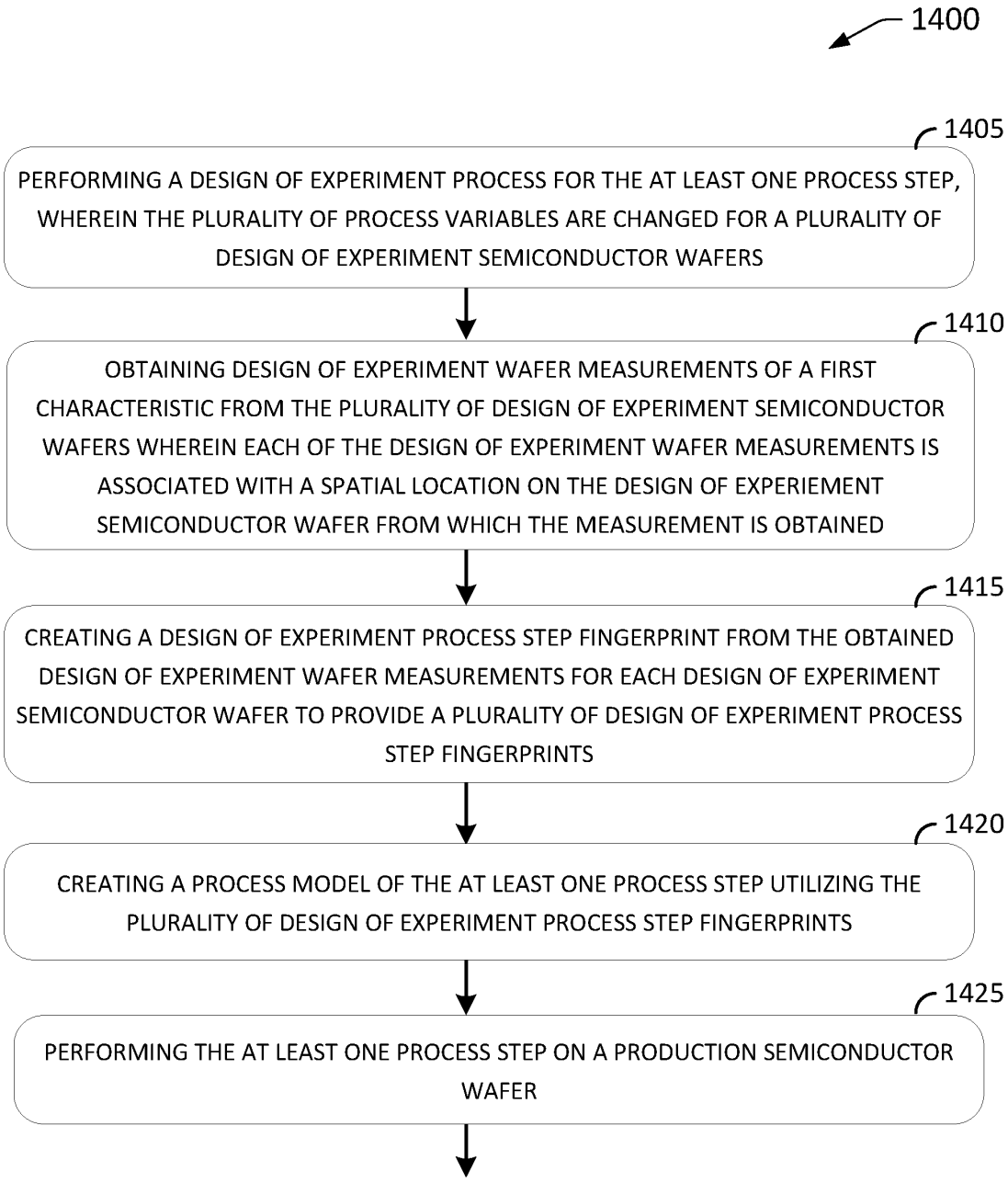

1400
1405
PERFORMING A DESIGN OF EXPERIMENT PROCESS FOR THE AT LEAST ONE PROCESS STEP, WHEREIN THE PLURALITY OF PROCESS VARIABLES ARE CHANGED FOR A PLURALITY OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS
1410
OBTAINING DESIGN OF EXPERIMENT WAFER MEASUREMENTS OF A FIRST CHARACTERISTIC FROM THE PLURALITY OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS WHEREIN EACH OF THE DESIGN OF EXPERIMENT WAFER MEASUREMENTS IS ASSOCIATED WITH A SPATIAL LOCATION ON THE DESIGN OF EXPERIEMENT SEMICONDUCTOR WAFER FROM WHICH THE MEASUREMENT IS OBTAINED
1415
CREATING A DESIGN OF EXPERIMENT PROCESS STEP FINGERPRINT FROM THE OBTAINED DESIGN OF EXPERIMENT WAFER MEASUREMENTS FOR EACH DESIGN OF EXPERIMENT SEMICONDUCTOR WAFER TO PROVIDE A PLURALITY OF DESIGN OF EXPERIMENT PROCESS STEP FINGERPRINTS
1420
CREATING A PROCESS MODEL OF THE AT LEAST ONE PROCESS STEP UTILIZING THE PLURALITY OF DESIGN OF EXPERIMENT PROCESS STEP FINGERPRINTS
1425
PERFORMING THE AT LEAST ONE PROCESS STEP ON A PRODUCTION SEMICONDUCTOR WAFER

Figure 14

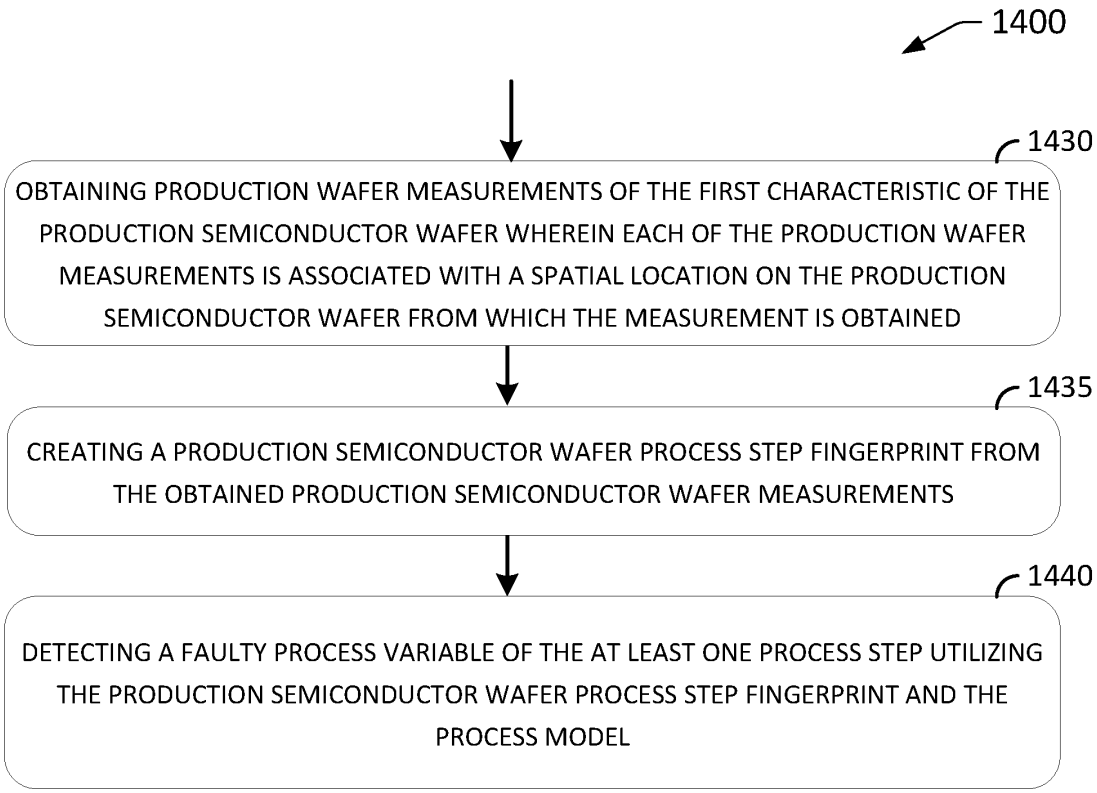


Figure 14 (*cont.*)

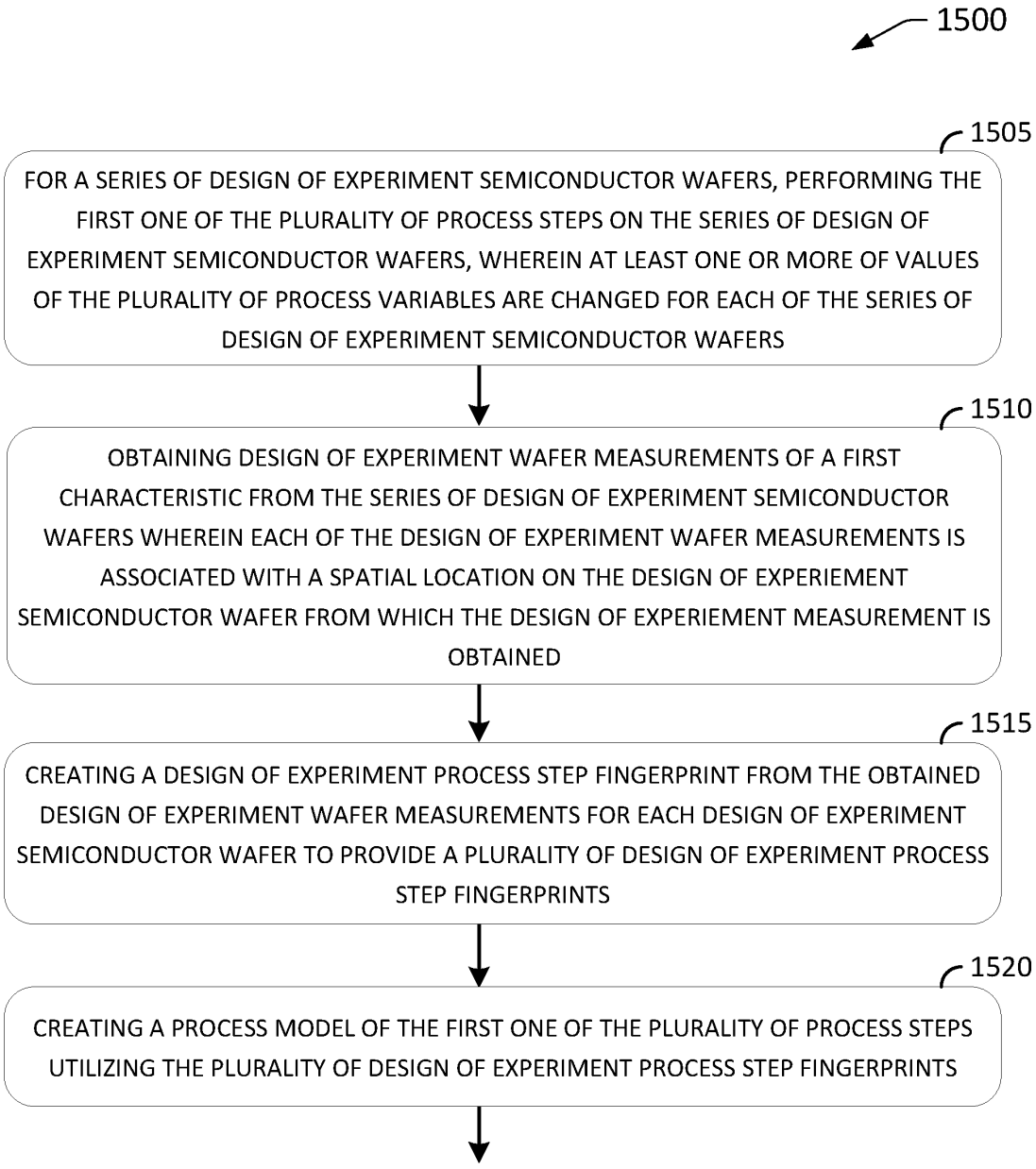

1500
1505
FOR A SERIES OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS, PERFORMING THE FIRST ONE OF THE PLURALITY OF PROCESS STEPS ON THE SERIES OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS, WHEREIN AT LEAST ONE OR MORE OF VALUES OF THE PLURALITY OF PROCESS VARIABLES ARE CHANGED FOR EACH OF THE SERIES OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS
1510
OBTAINING DESIGN OF EXPERIMENT WAFER MEASUREMENTS OF A FIRST CHARACTERISTIC FROM THE SERIES OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS WHEREIN EACH OF THE DESIGN OF EXPERIMENT WAFER MEASUREMENTS IS ASSOCIATED WITH A SPATIAL LOCATION ON THE DESIGN OF EXPERIEMENT SEMICONDUCTOR WAFER FROM WHICH THE DESIGN OF EXPERIEMENT MEASUREMENT IS OBTAINED
1515
CREATING A DESIGN OF EXPERIMENT PROCESS STEP FINGERPRINT FROM THE OBTAINED DESIGN OF EXPERIMENT WAFER MEASUREMENTS FOR EACH DESIGN OF EXPERIMENT SEMICONDUCTOR WAFER TO PROVIDE A PLURALITY OF DESIGN OF EXPERIMENT PROCESS STEP FINGERPRINTS
1520
CREATING A PROCESS MODEL OF THE FIRST ONE OF THE PLURALITY OF PROCESS STEPS UTILIZING THE PLURALITY OF DESIGN OF EXPERIMENT PROCESS STEP FINGERPRINTS

Figure 15

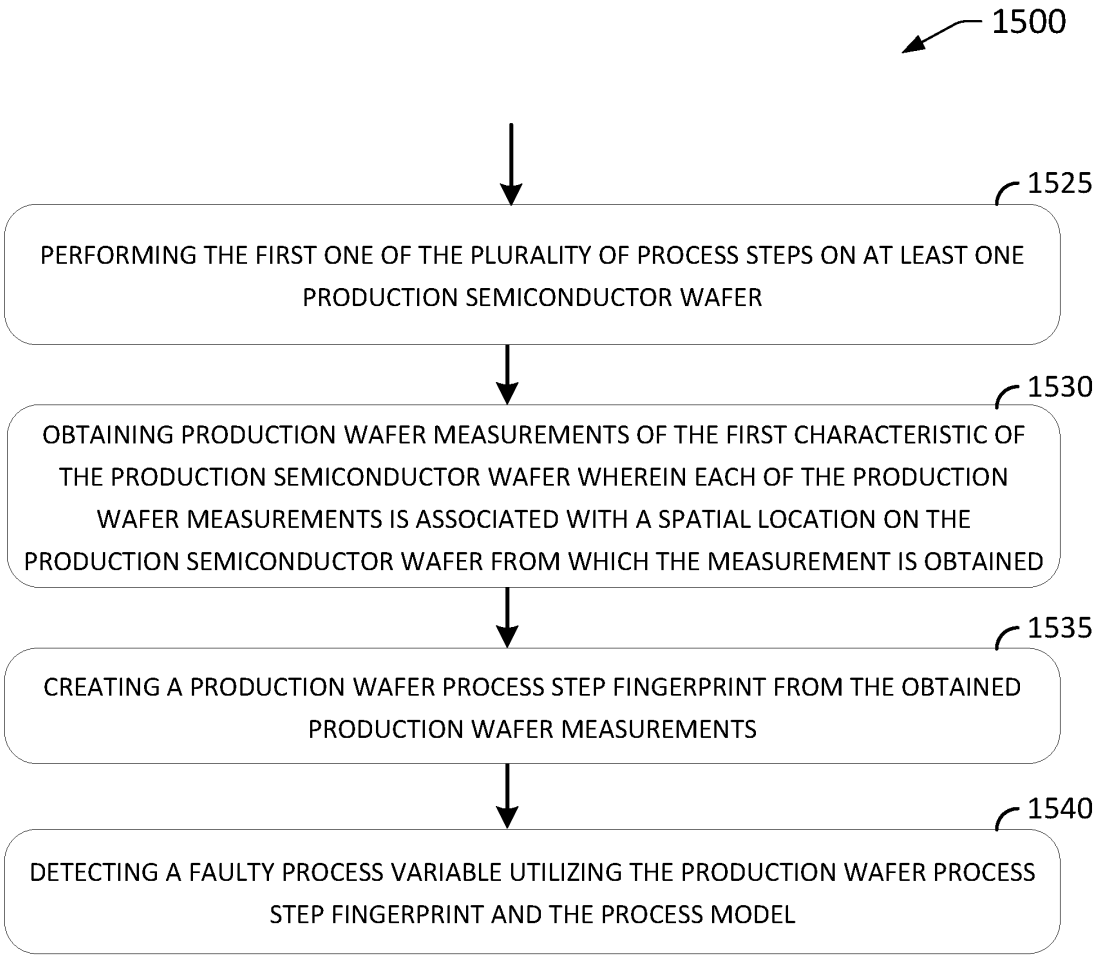


Figure 15 (*cont.*)

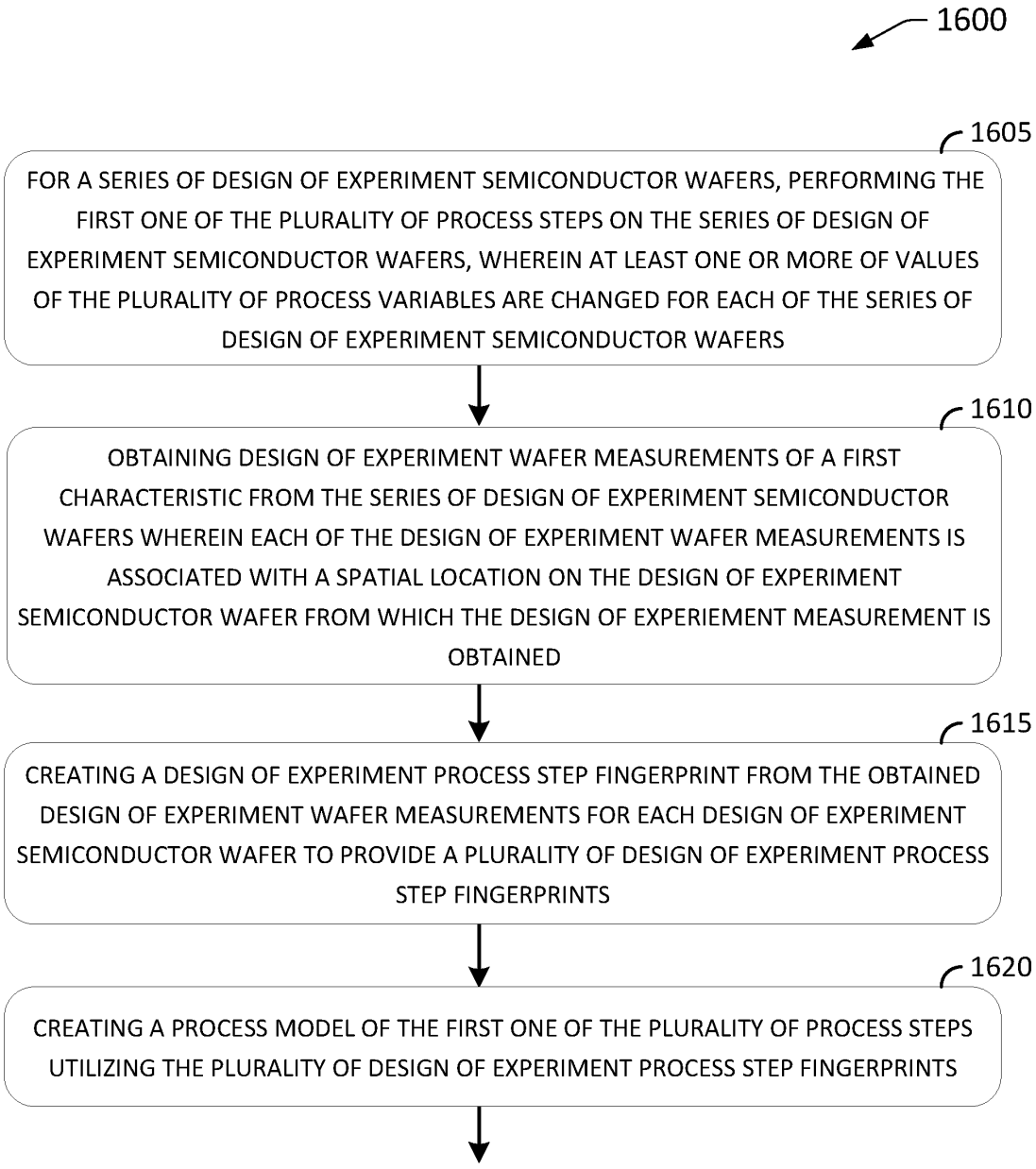

1600
1605
FOR A SERIES OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS, PERFORMING THE FIRST ONE OF THE PLURALITY OF PROCESS STEPS ON THE SERIES OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS, WHEREIN AT LEAST ONE OR MORE OF VALUES OF THE PLURALITY OF PROCESS VARIABLES ARE CHANGED FOR EACH OF THE SERIES OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS
1610
OBTAINING DESIGN OF EXPERIMENT WAFER MEASUREMENTS OF A FIRST CHARACTERISTIC FROM THE SERIES OF DESIGN OF EXPERIMENT SEMICONDUCTOR WAFERS WHEREIN EACH OF THE DESIGN OF EXPERIMENT WAFER MEASUREMENTS IS ASSOCIATED WITH A SPATIAL LOCATION ON THE DESIGN OF EXPERIMENT SEMICONDUCTOR WAFER FROM WHICH THE DESIGN OF EXPERIEMENT MEASUREMENT IS OBTAINED
1615
CREATING A DESIGN OF EXPERIMENT PROCESS STEP FINGERPRINT FROM THE OBTAINED DESIGN OF EXPERIMENT WAFER MEASUREMENTS FOR EACH DESIGN OF EXPERIMENT SEMICONDUCTOR WAFER TO PROVIDE A PLURALITY OF DESIGN OF EXPERIMENT PROCESS STEP FINGERPRINTS
1620
CREATING A PROCESS MODEL OF THE FIRST ONE OF THE PLURALITY OF PROCESS STEPS UTILIZING THE PLURALITY OF DESIGN OF EXPERIMENT PROCESS STEP FINGERPRINTS

Figure 16

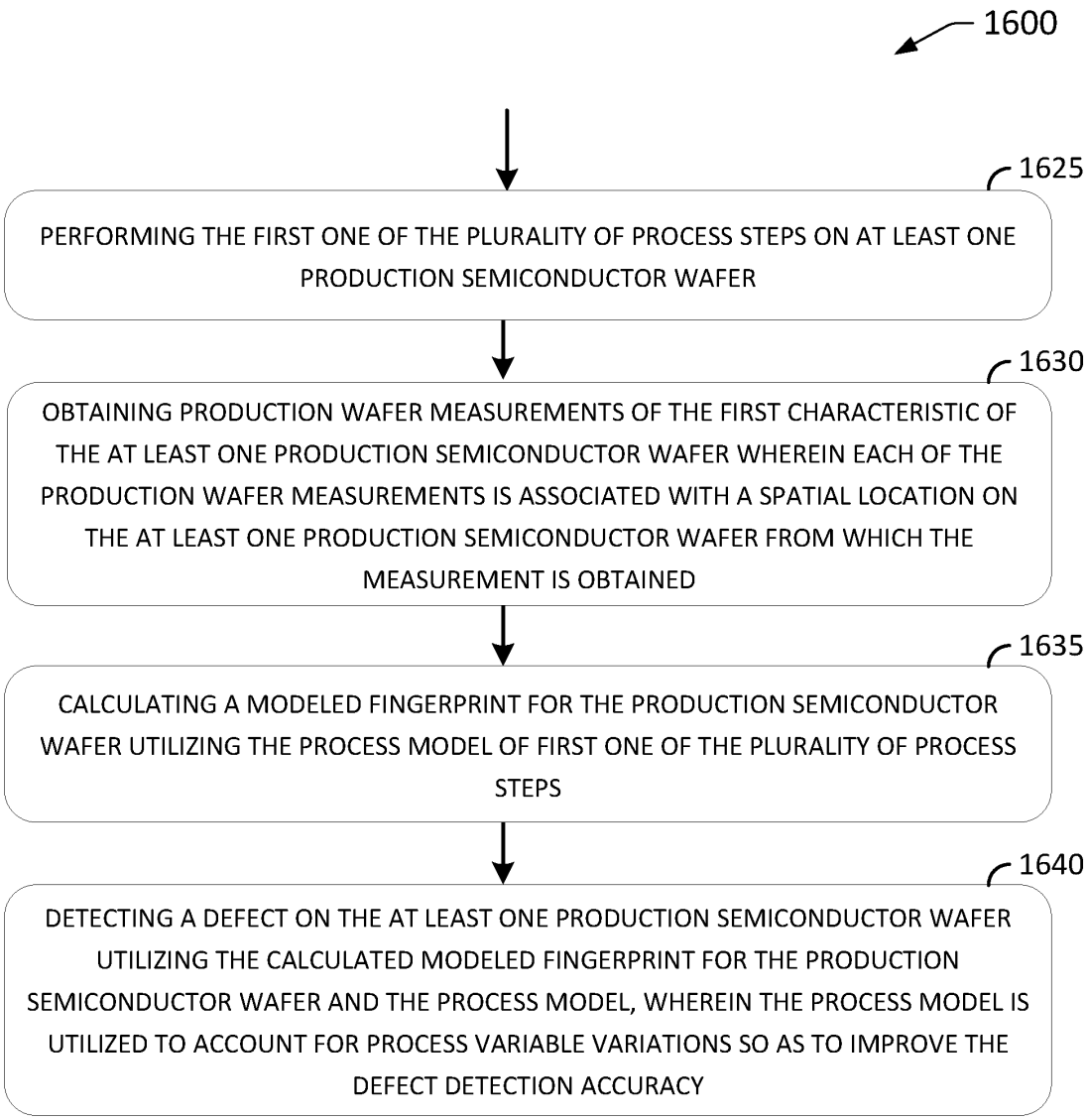


Figure 16 (*cont.*)