CLAIMS

What is claimed is:

1. A computer-program product tangibly embodied in a non-transitory machine-readable storage medium, the computer-program product including instructions operable to cause a computing system (2002, 2060) to:

access a machine learning model (2050) trained on training data (2032) of first bonding operations (1308, 2040A), wherein the first bonding operations comprise operations to bond a first set of multiple wires (1504) to a first set of surfaces (1506, 1508), and wherein the machine learning model is trained by supervised learning comprising:

receiving the training data (2032), wherein the training data comprises:

process data (2034) generated from measurements of the first bonding operations (2040A); and

statuses (2036) of the multiple wires after bonding to the first set of surfaces, each status of the statuses comprising one or more candidate outcomes for an objective related to detecting one or more anomalies in the first bonding operations; and

generating one or more weights for the process data such that the process data input to the machine learning model predicts the one or more candidate outcomes for the objective;

receive input data (2070) indicating process data (2074) generated from measurements of second bonding operations (2040B), wherein the second bonding operations comprise operations to bond a second set of multiple wires to a second set of surfaces, wherein the second set of multiple wires are different than the first set of multiple wires, and wherein the second set of surfaces are different than the first set of surfaces;

weight the input data according to the machine learning model;

generate an anomaly predictor (2052) indicating a risk for an anomaly occurrence in the second bonding operations based on weighting the input data according to the machine learning model; and

output the anomaly predictor to control the second bonding operations.

2. The computer-program product of claim 1,

wherein the one or more candidate outcomes comprise one or more destructive quality assurance tests (1800, 1900) for individual wires (1504) or bonds (1510, 1512) in the first bonding operations; and

wherein the anomaly predictor (2052) is a predictor of an anomaly in an individual wire or bond in the second bonding operations without performing a destructive quality assurance test on the individual wire or bond.

3. The computer-program product of claim 2, wherein the first bonding operations comprises one of:

ball bonding operations, and wherein the destructive quality assurance tests comprise a ball shear test (1800) for testing a ball bond (1510); and

stitch bonding operations, and wherein the destructive quality assurance tests comprise a stitch pull test (1900) for testing a stitch bond (1512).

4. The computer-program product of claim 1,

wherein the first bonding operations bond wires (1504) of the first set of multiple wires to corresponding surfaces of the first set of surfaces to form integrated circuit chips (1700);

wherein the one or more candidate outcomes comprise one or more defective chip outcomes for the integrated circuit chips in the first bonding operations; and

wherein the instructions are operable to cause the computing system to generate the anomaly predictor for risk of the anomaly in an integrated circuit chip manufacturing process in the second bonding operations.

5. The computer-program product of claim 1, wherein the one or more anomalies are associated with one or more of:

floating condition;

lead frame contamination; and

die tilt.

6. The computer-program product of claim 1,

wherein the second bonding operations bond wires of the second set of multiple wires to form integrated circuit chips (1700); and

wherein the process data generated from the measurements of the second bonding operations pertains holistically to a particular chip of the integrated circuit chips and is derived from measurement data for wires associated with the particular chip and bonded in the second bonding operations.

7. The computer-program product of claim 1,

wherein the input data comprises real-time sensor measurements (2200) received during the second bonding operations; and

wherein for a given wire of the second set of multiple wires, the real-time sensor measurements comprise one or more of:

heat measurements;

power measurements;

force measurements;

electric flame-off (EFO) measurements; and

ultrasonic measurements.

8. The computer-program product of claim 1,

wherein the input data comprises real-time sensor measurements (2200) received during the second bonding operations;

wherein the sensor measurements comprise measurements of a bonding system involved in the second bonding operations; and

wherein the anomaly predictor controls the second bonding operations to correct the one or more anomalies or reduce the occurrence of the one or more anomalies in the bonding system involved in the second bonding operations.

9. The computer-program product of claim 1,

wherein the input data comprises received sensor measurements tagged with origin information indicating one or more of an identity or location for a particular wire, die, or chip involved in the second bonding operations; and

wherein the anomaly predictor identifies the anomaly that occurred in the second bonding operations and is correlated with the origin information to indicate the location of the anomaly.

10. The computer-program product of claim 1, wherein the instructions are operable to cause the computing system to:

receive feedback indicating that the anomaly predictor correctly or incorrectly predicted the anomaly in a particular chip manufactured in the second bonding operations; and

update the machine learning model based on the feedback.

11. The computer-program product of claim 1,

wherein the second bonding operations are performed by a chip manufacturing system; and

wherein the instructions are operable to cause the computing system to adjust bonding operations subsequent to the second bonding operations by the chip manufacturing system based on one or more of:

the anomaly predictor indicating the risk for the anomaly occurrence in the second bonding operations; and

feedback indicating that the anomaly predictor correctly or incorrectly predicted the anomaly occurrence in a particular chip manufactured in the second bonding operations.

12. The computer-program product of claim 1, wherein the input data includes derived data comprising one or more of:

a generated value indicating a median (2353) or average value for measurements pertaining to multiple wires bonded in a particular chip (1700) in the second bonding operations;

a generated set of deviations (2354) comprising a deviation from the value for each of the multiple wires; and

a generated metric for the chip accounting for the set of deviations.

13. The computer-program product of claim 1,

wherein the training data comprises the process data generated from derived data comprising a generated singular data value correlated with multiple different types of measurements and pertaining to a same wire in the first bonding operations; and

wherein the input data indicating the process data generated from measurements of the second bonding operations comprises a generated singular data value, wherein the generated singular data value is correlated with the multiple different types of measurements and pertains to a same wire in the second bonding operations.

14. The computer-program product of claim 1,

wherein the training data comprises the process data generated by deriving information from multiple different measurement types accounting for a relationship between measurement types in the first bonding operations; and

wherein the instructions are operable to cause the computing system to receive the input data indicating the process data generated from measurements of the second bonding operations by deriving information from multiple measurement types accounting for a relationship between measurement types in the second bonding operations.

15. The computer-program product of claim 1,

Wherein the instructions are operable to cause the computing system to receive the training data by selectively choosing a subset of parameter types observed while performing a process of bonding the first set of multiple wires to the first set of surfaces in the first bonding operations; and

wherein the measurements of the first bonding operations are measurements for the subset of parameter types.

16. The computer-program product of claim 1, wherein the one or more weights for the process data are generated for a gradient boosting model of the training data.

17. The computer-program product of claim 1, wherein the machine learning model is further trained by multiple generated machine learning models and is selected based on k-fold cross-validation.

18. The computer-program product of claim 1, wherein the measurements of the first and second bonding operations comprise measurements captured while performing a process of forming ball bonds (1510).

19. The computer-program product of claim 1, wherein the measurements of the first and second bonding operations comprise measurements captured while performing a process of forming stitch bonds (1512).

20. The computer-program product of claim 1, wherein the anomaly predictor is a predictor of a defective bond between a wire of the second set of multiple wires and a lead frame or die of the second set of surfaces.

21. A computer-implemented method (2130) comprising:

accessing (2131) a machine learning model (2050) trained on training data of first bonding operations (1308, 2040A), wherein the first bonding operations comprise operations to bond a first set of multiple wires (1504) to a first set of surfaces (1506, 1508), and wherein the machine learning model is trained by supervised learning comprising:

receiving (2101) the training data (2032), wherein the training data comprises:

process data (2034) generated from measurements of the first bonding operations (2040A); and

statuses (2036) of the multiple wires after bonding to the first set of surfaces, each status of the statuses comprising one or more candidate outcomes for an objective related to detecting one or more anomalies in the first bonding operations; and

generating (2102) one or more weights for the process data such that the process data input to the machine learning model predicts the one or more candidate outcomes for the objective;

receiving (2132) input data (2070) indicating process data (2074) generated from measurements of second bonding operations (2040B), wherein the second bonding operations comprise operations to bond a second set of multiple wires to a second set of surfaces, wherein the second set of multiple wires are different than the first set of multiple wires, and wherein the second set of surfaces are different than the first set of surfaces;

weighting (2133) the input data according to the machine learning model;

generating (2134) an anomaly predictor (2052) indicating a risk for an anomaly occurrence in the second bonding operations based on weighting the input data according to the machine learning model; and

outputting (2135) the anomaly predictor to control the second bonding operations.

22. The computer-implemented method of claim 21,

wherein the one or more candidate outcomes comprise one or more destructive quality assurance tests (1800, 1900) for individual wires (1504) or bonds (1510, 1512) in the first bonding operations; and

wherein the anomaly predictor (2052) is a predictor of an anomaly in an individual wire or bond in the second bonding operations without performing a destructive quality assurance test on the individual wire or bond.

23. The computer-implemented method of claim 21,

wherein the first bonding operations bonds wires (1504) of the first set of multiple wires to form integrated circuit chips (1700);

wherein the one or more candidate outcomes comprise one or more defective chip outcomes for the integrated circuit chips in the first bonding operations; and

wherein generating the anomaly predictor comprises generating the anomaly predictor for risk of the anomaly in an integrated circuit chip manufactured in the second bonding operations.

24. The computer-implemented method of claim 21,

wherein the second bonding operations bonds wires of the second set of multiple wires to form integrated circuit chips (1700); and

wherein the process data generated from the measurements of the second bonding operations pertains holistically to a particular chip of the integrated circuit chips, and is derived from measurement data for wires associated with the particular chip and that are bonded in the second bonding operations.

25. The computer-implemented method of claim 21,

further comprising receiving real-time sensor measurements (2200) during the second bonding operations; and

wherein for a given wire (1504) of the second set of multiple wires, the real-time sensor measurements comprise one or more of:

heat measurements;

power measurements;

force measurements;

electric flame-off (EFO) measurements; and

ultrasonic measurements.

~~26. The computer-implemented method of claim 21,~~

~~wherein the receiving input data comprises receiving real-time sensor measurements (2200) during the second bonding operations, and wherein the sensor measurements comprise measurements of a bonding system involved in the second bonding operations; and~~

~~wherein the anomaly predictor controls the second bonding operations to correct the one or more anomalies or reduce the occurrence of the one or more anomalies in the bonding system involved in the second bonding operations.~~

~~27. The computer-implemented method of claim 21,~~

~~wherein the input data comprises received sensor measurements tagged with origin information indicating one or more of an identity or location for a particular wire, die, or chip involved in the second bonding operations; and~~

~~wherein the anomaly predictor identifies the anomaly that occurred in the second bonding operations and is correlated with the origin information to indicate the location of the anomaly.~~

~~28~~26. The computer-implemented method of claim 21, further comprising:

receiving (2161) feedback indicating that the anomaly predictor correctly or incorrectly predicted the anomaly in a particular chip manufactured in the second bonding operations; and

updating (2162) the machine learning model based on the feedback.

~~29. The computer-implemented method of claim 21, wherein the input data includes derived data comprising one or more of:~~

~~a generated value indicating a median (2353) or average value for measurements pertaining to multiple wires bonded in a particular chip in the second bonding operations;~~

~~a generated set of deviations (2354) comprising a deviation from the value for each of the multiple wires; and~~

~~a generated metric for the particular chip (1700) accounting for the set of deviations.~~

~~30~~27. A computing device (2002) comprising processor (2008) and memory (2010), the memory containing instructions executable by the processor wherein the computing device is configured to:

access a machine learning model (2050) trained on training data of first bonding operations (1308, 2040A), wherein the first bonding operations comprise operations to bond a first

set of multiple wires (1504) to a first set of surfaces (1506, 1508), and wherein the machine learning model is trained by supervised learning comprising:

receiving the training data (2032), wherein the training data comprises:

process data (2034) generated from measurements of the first bonding operations (2040A); and

statuses (2036) of the multiple wires after bonding to the first set of surfaces, each status of the statuses comprising one or more candidate outcomes for an objective related to detecting one or more anomalies in the first bonding operations; and

generating one or more weights for the process data such that the process data input to the machine learning model predicts the one or more candidate outcomes for the objective;

receive input data (2070) indicating process data (2074) generated from measurements of second bonding operations (2040B), wherein the second bonding operations comprise operations to bond a second set of multiple wires to a second set of surfaces, wherein the second set of multiple wires are different than the first set of multiple wires, and wherein the second set of surfaces are different than the first set of surfaces;

weight the input data according to the machine learning model;

generate an anomaly predictor (2052) indicating a risk for an anomaly occurrence in the second bonding operations based on weighting the input data according to the machine learning model; and

output the anomaly predictor to control the second bonding operations.

~~31~~28. The computer-program product of claim 1,

wherein the measurements of the first bonding operations comprise measurements captured while performing a process of bonding the first set of multiple wires to the first set of surfaces;

wherein the statuses comprise multiple candidate outcomes for the objective; and

wherein the measurements of the second bonding operations comprise measurements captured while performing a process of bonding the second set of multiple wires to the second set of surfaces.

~~32~~29. The computer-implemented method of claim 21,

wherein the measurements of the first bonding operations comprise measurements captured while performing a process of bonding the first set of multiple wires to the first set of surfaces;

wherein the statuses comprise multiple candidate outcomes for the objective; and

wherein the measurements of the second bonding operations comprise measurements

captured while performing a process of bonding the second set of multiple wires to the second set of surfaces.

~~33~~30. The computing device of claim ~~30~~27,

wherein the measurements of the first bonding operations comprise measurements captured while performing a process of bonding the first set of multiple wires to the first set of surfaces;

wherein the statuses comprise multiple candidate outcomes for the objective; and

wherein the measurements of the second bonding operations comprise measurements captured while performing a process of bonding the second set of multiple wires to the second set of surfaces.