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Huang et al.

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(54) **DATA CAPTURE AND TRANSFORMATION TO SUPPORT DATA ANALYSIS AND MACHINE LEARNING FOR SUBSTRATE MANUFACTURING SYSTEMS**

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G06F 16/11 (2019.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G06N 20/00*** (2019.01); ***G06F 16/122*** (2019.01); ***G06F 16/176*** (2019.01); ***H01L 21/00*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G06N 20/00
(Continued)

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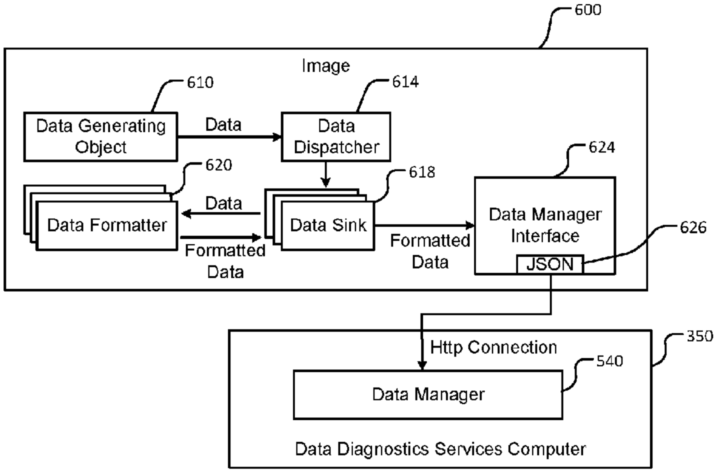
Primary Examiner — Ruay Ho

(57) **ABSTRACT**

A data collection system for semiconductor manufacturing includes: T substrate processing tools, where each of the T substrate processing tools includes: N processing chambers, where each of the N processing chambers includes a processing chamber controller configured to receive a plurality of different types of data during operating of the corresponding one of the N processing chambers, where the plurality of different types of data have different formats, where the
(Continued)



processing chamber controller is further configured to format the plurality of different types of data into formatted data, and where T and N are integers; and a data diagnostic services computer configured to: receive and store the formatted data as categories in a common file having a table-like data structure including rows with contextual data; and in response to a request, generate an output file including a subset of the data from the common file.

20 Claims, 10 Drawing Sheets

(51) **Int. Cl.**

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H01L 21/67	(2006.01)
H04L 67/06	(2022.01)

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See application file for complete search history.

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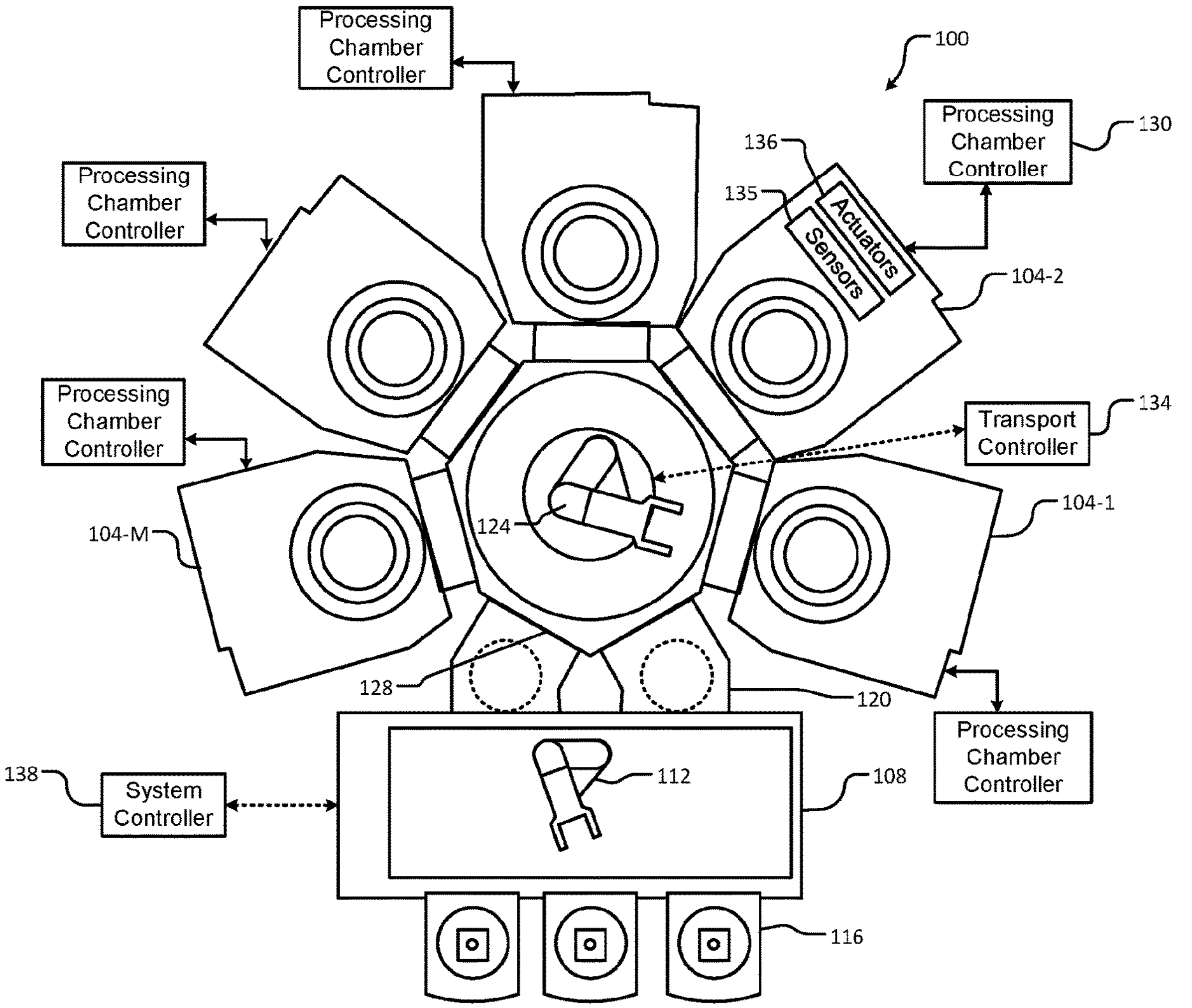
Processing Chamber Controller
100
Processing Chamber Controller
130
136
135
Actuators
Sensors
Processing Chamber Controller
104-2
Processing Chamber Controller
Transport Controller
134
104-1
124
104-M
128
120
Processing Chamber Controller
138
System Controller
112
108
116

FIG. 1

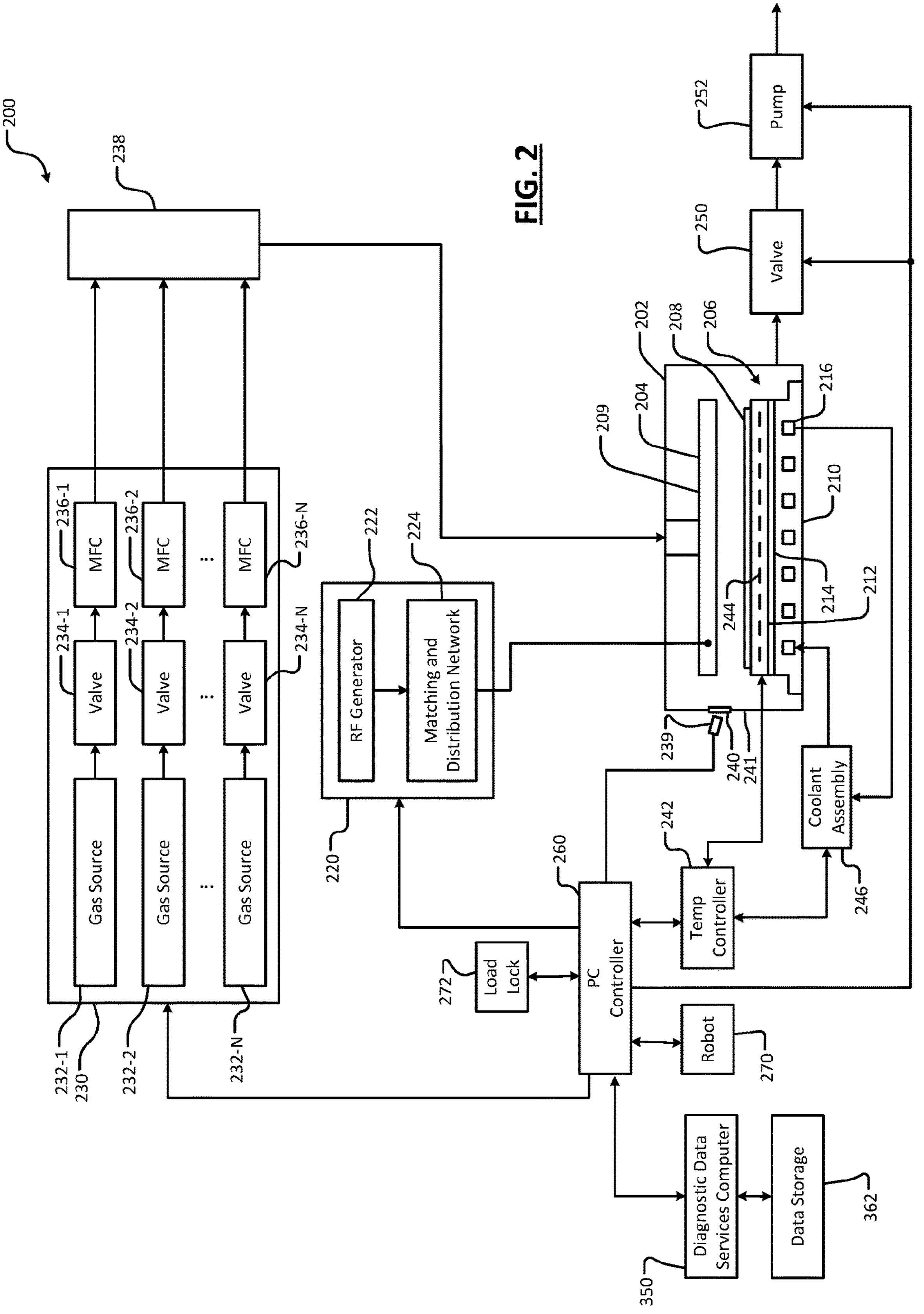
200
238
Gas Source
Gas Source
Gas Source
Valve
Valve
Valve
MFC
MFC
MFC
232-1
230
232-2
232-N
234-1
234-2
234-N
236-1
236-2
236-N
RF Generator
Matching and Distribution Network
222
224
220
209
204
202
208
206
244
214
212
210
216
239
240
241
Coolant Assembly
246
Temp Controller
242
PC Controller
260
Load Lock
272
Robot
270
Diagnostic Data Services Computer
350
Data Storage
362
Valve
250
Pump
252

FIG. 2

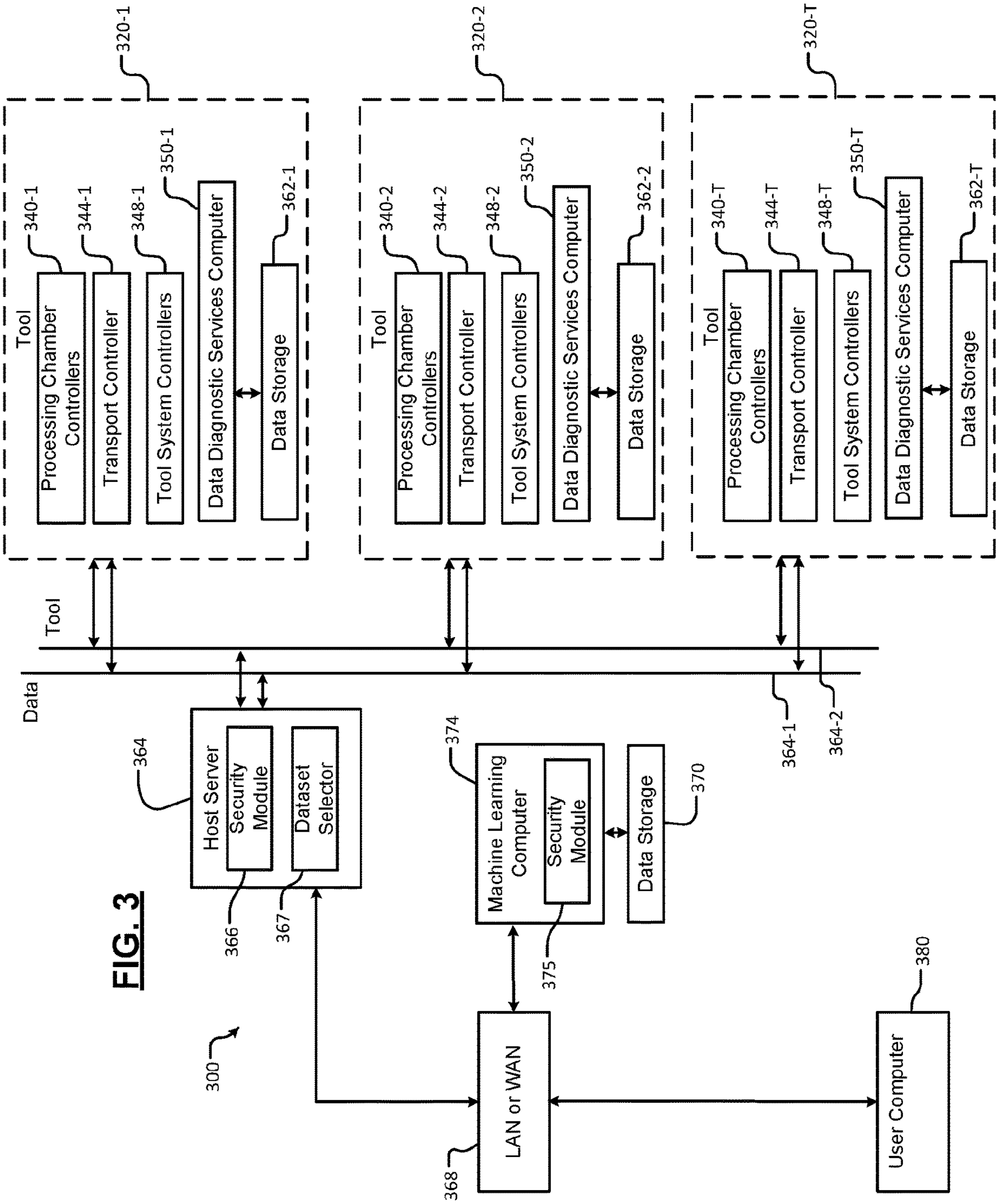

FIG. 3

300
320-1
Tool
Processing Chamber Controllers
340-1
Transport Controller
344-1
Tool System Controllers
348-1
Data Diagnostic Services Computer
350-1
Data Storage
362-1
320-2
Tool
Processing Chamber Controllers
340-2
Transport Controller
344-2
Tool System Controllers
348-2
Data Diagnostic Services Computer
350-2
Data Storage
362-2
320-T
Tool
Processing Chamber Controllers
340-T
Transport Controller
344-T
Tool System Controllers
348-T
Data Diagnostic Services Computer
350-T
Data Storage
362-T
Tool
Data
364-1
364-2
Host Server
364
Security Module
366
Dataset Selector
367
Machine Learning Computer
374
Security Module
375
Data Storage
370
LAN or WAN
368
User Computer
380

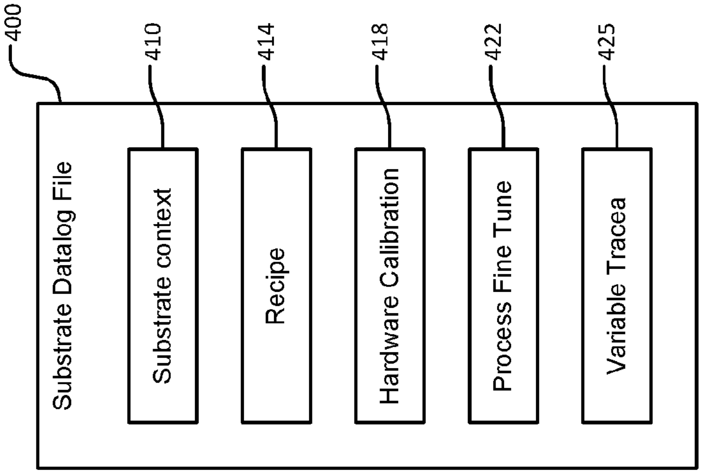
400
Substrate Datalog File
410
Substrate context
414
Recipe
418
Hardware Calibration
422
Process Fine Tune
425
Variable Tracea

FIG. 4A

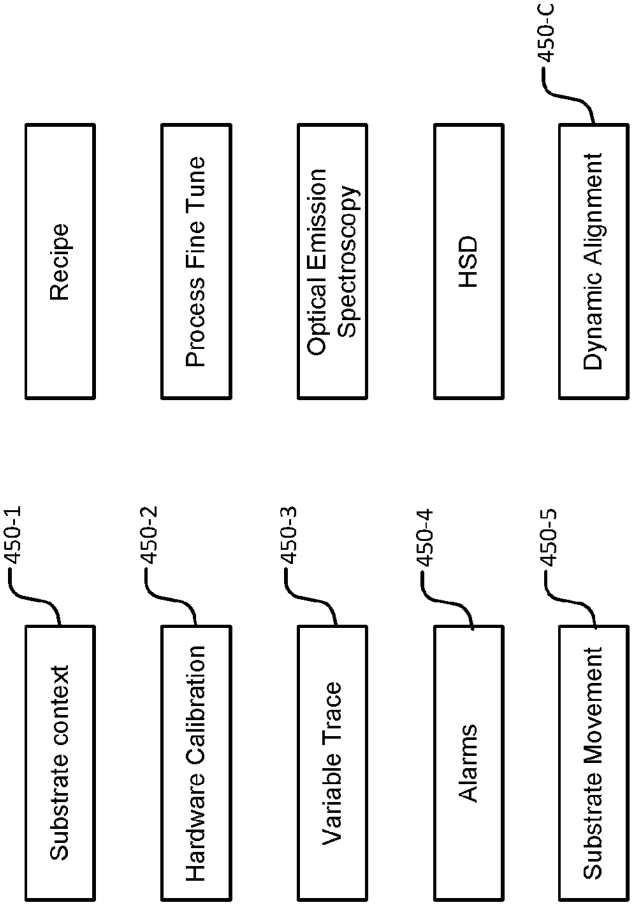
450-1
Substrate context
450-2
Hardware Calibration
450-3
Variable Trace
450-4
Alarms
450-5
Substrate Movement
Recipe
Process Fine Tune
Optical Emission Spectroscopy
HSD
450-C
Dynamic Alignment

FIG. 4B

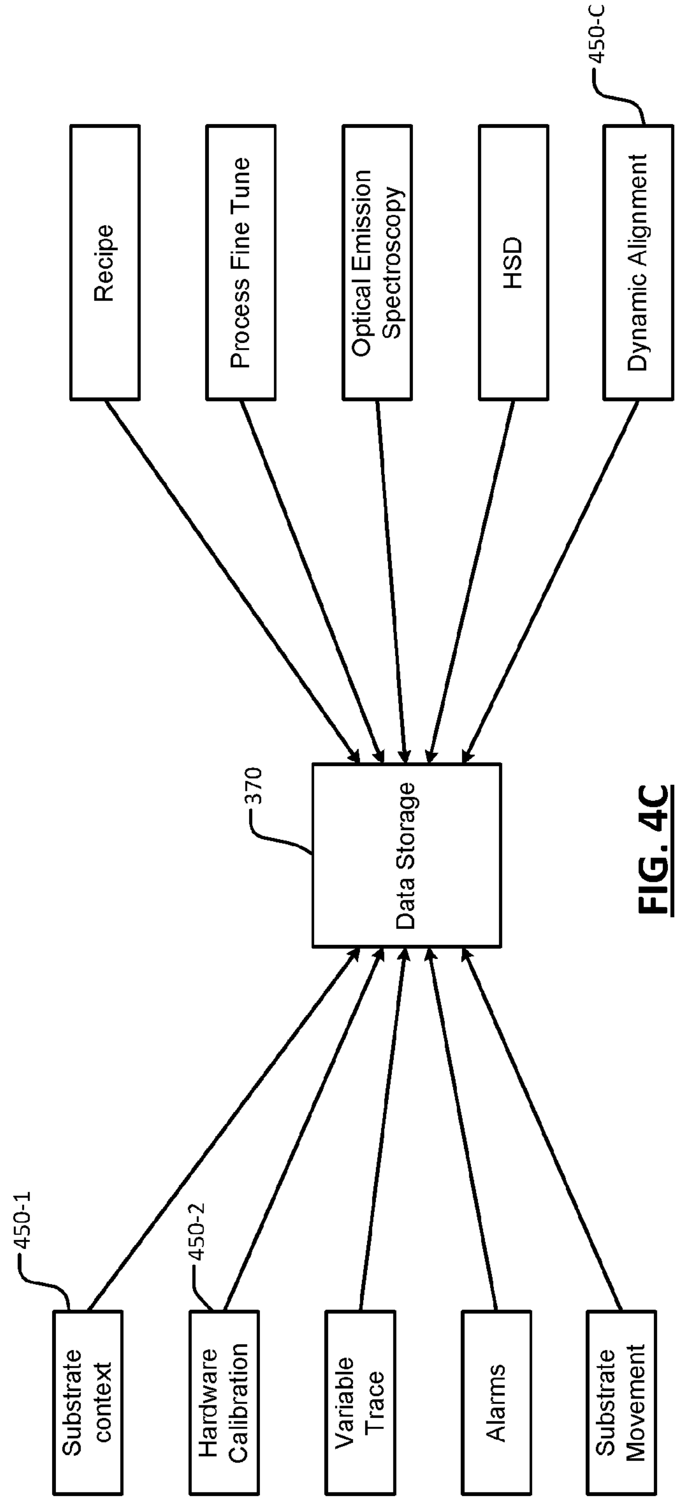
Recipe
Process Fine Tune
Optical Emission Spectroscopy
HSD
Dynamic Alignment
450-C
370
Data Storage
450-1
Substrate context
450-2
Hardware Calibration
Variable Trace
Alarms
Substrate Movement

FIG. 4C

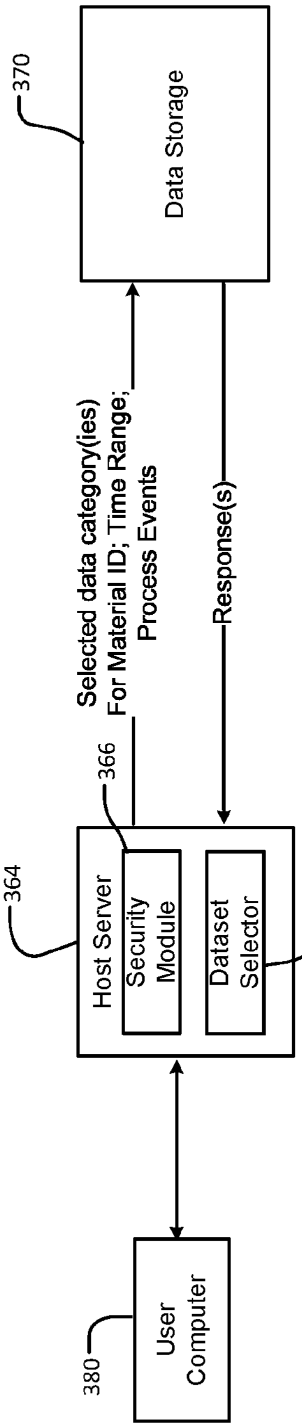
370
Data Storage
Selected data category(ies) For Material ID; Time Range; Process Events
Response(s)
366
364
Host Server
Security Module
Dataset Selector
367
380
User Computer

FIG. 4D

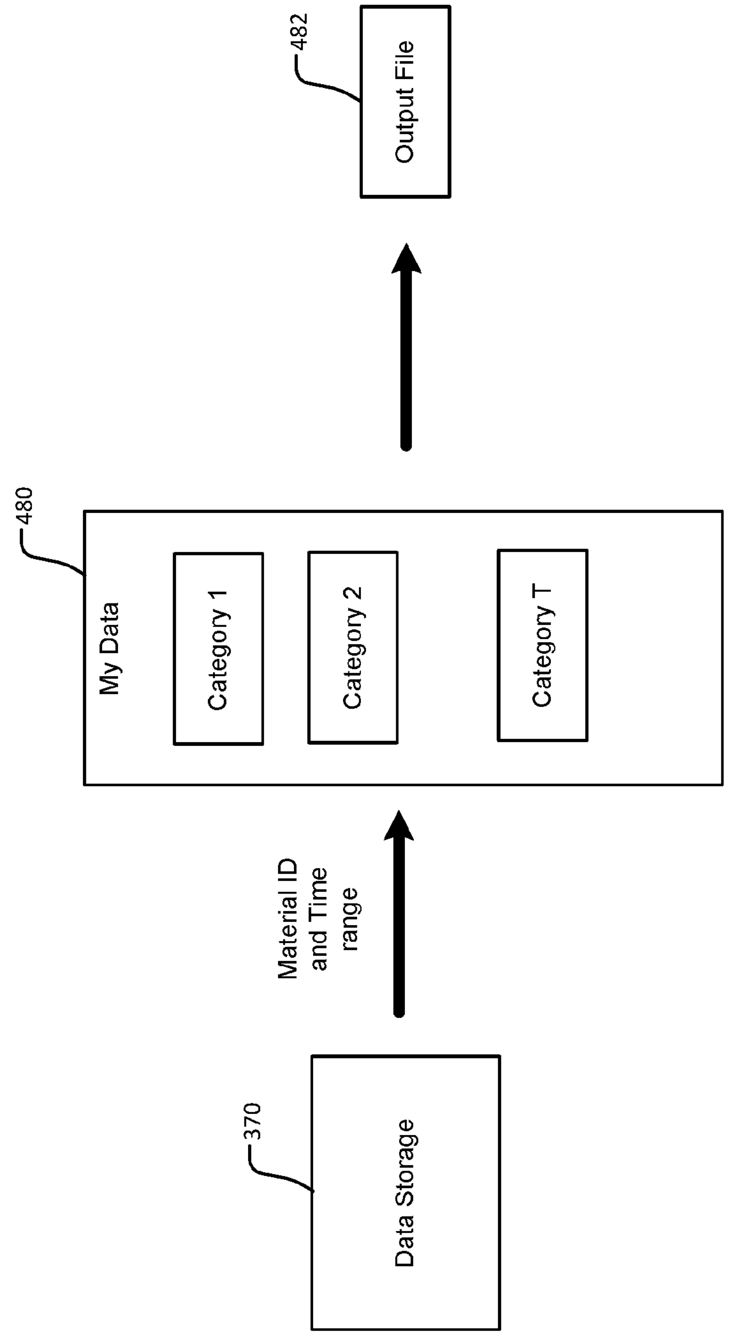
482
Output File
480
My Data
Category 1
Category 2
Category T
Material ID and Time range
370
Data Storage

FIG. 4E

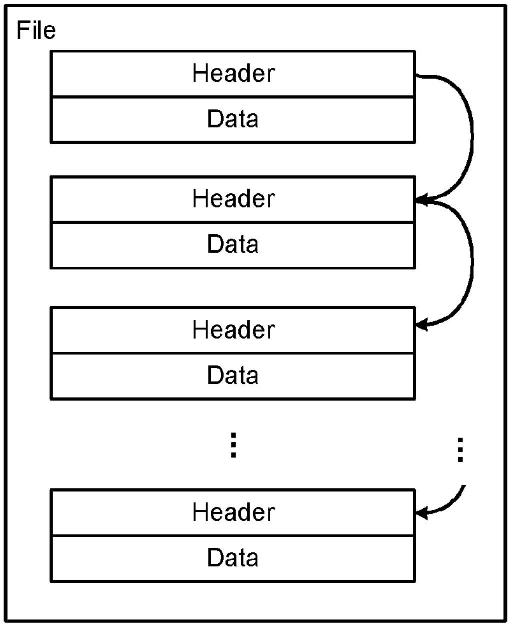
File
Header
Data
Header
Data
Header
Data
Header
Data

FIG. 4F

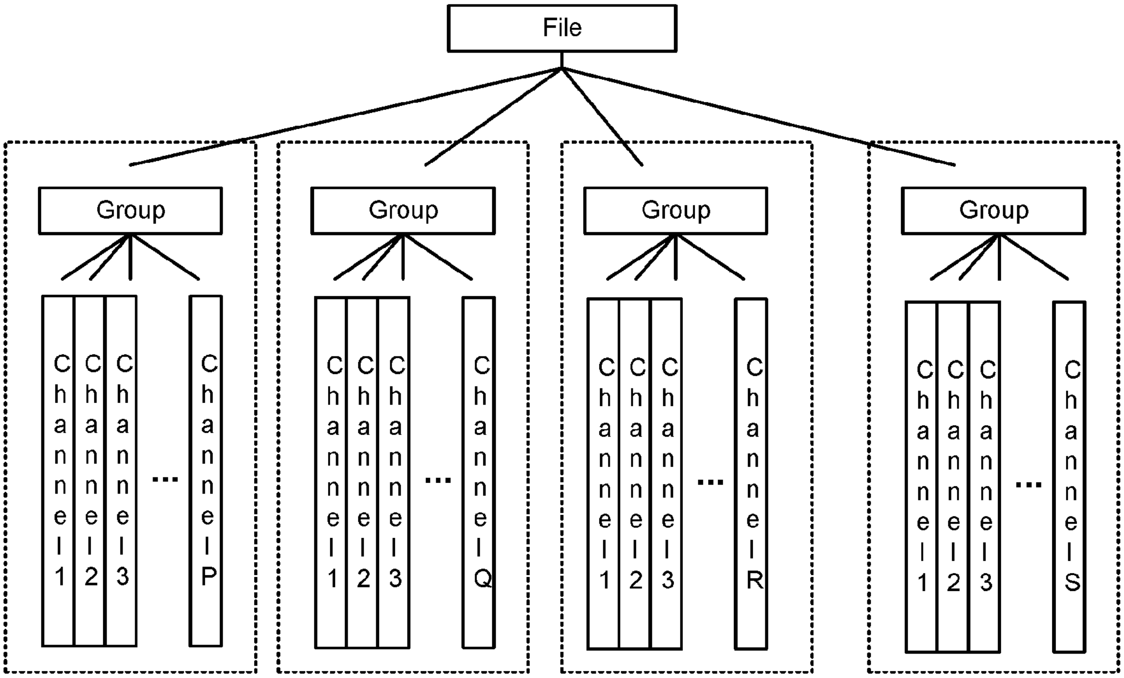
File
Group
Channel 1
Channel 2
Channel 3
...
Channel P
Group
Channel 1
Channel 2
Channel 3
...
Channel Q
Group
Channel 1
Channel 2
Channel 3
...
Channel R
Group
Channel 1
Channel 2
Channel 3
...
Channel S

FIG. 4G

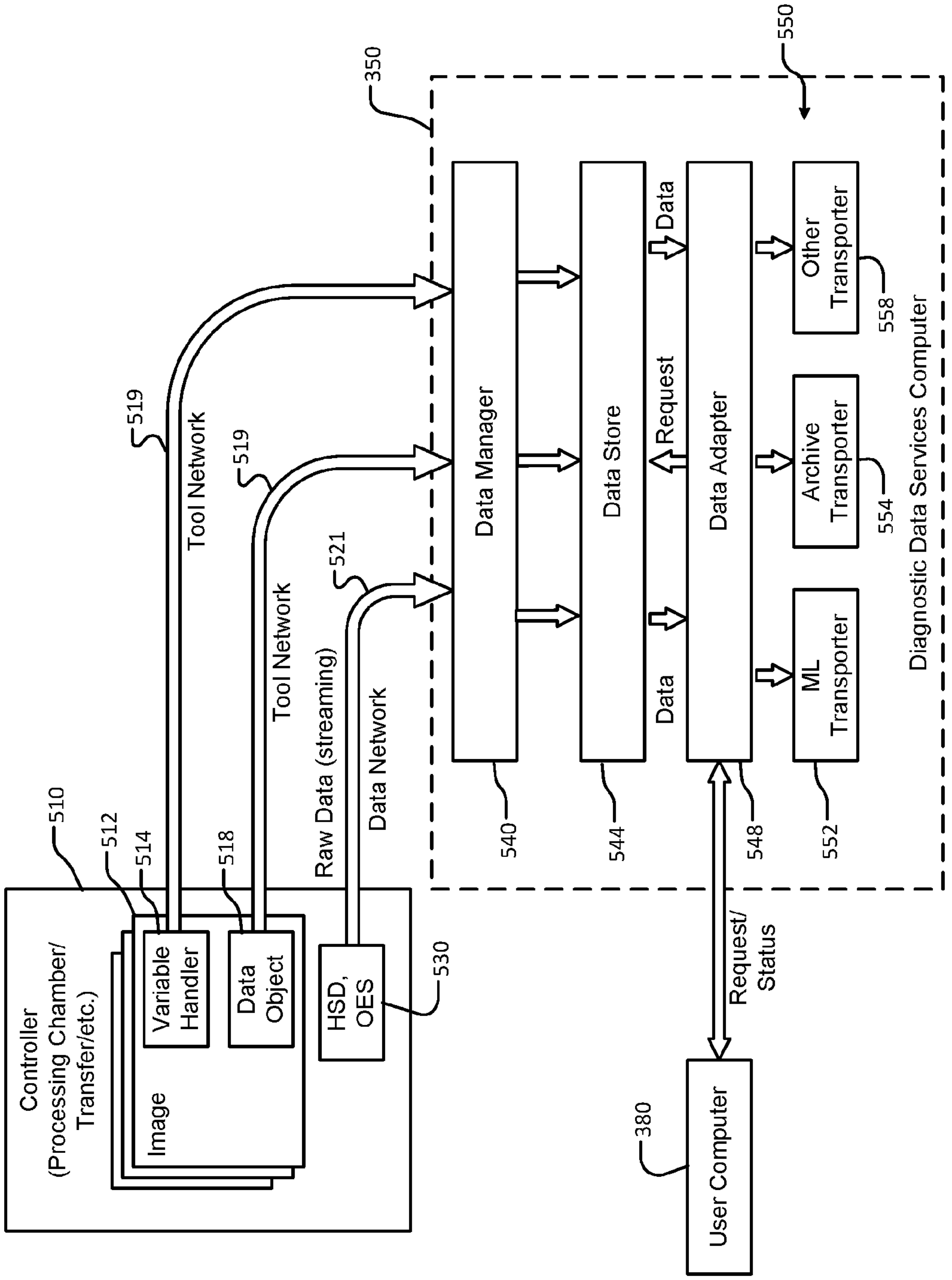
510
Controller
(Processing Chamber/
Transfer/etc.)
Image
512
514
Variable
Handler
518
Data
Object
HSD,
OES
530
519
Tool Network
519
Tool Network
521
Raw Data (streaming)
Data Network
350
Data Manager
540
Data Store
544
Data
Request
Data
Data Adapter
548
550
Other
Transporter
558
Archive
Transporter
554
ML
Transporter
552
Diagnostic Data Services Computer
Request/
Status
User Computer
380

FIG. 5

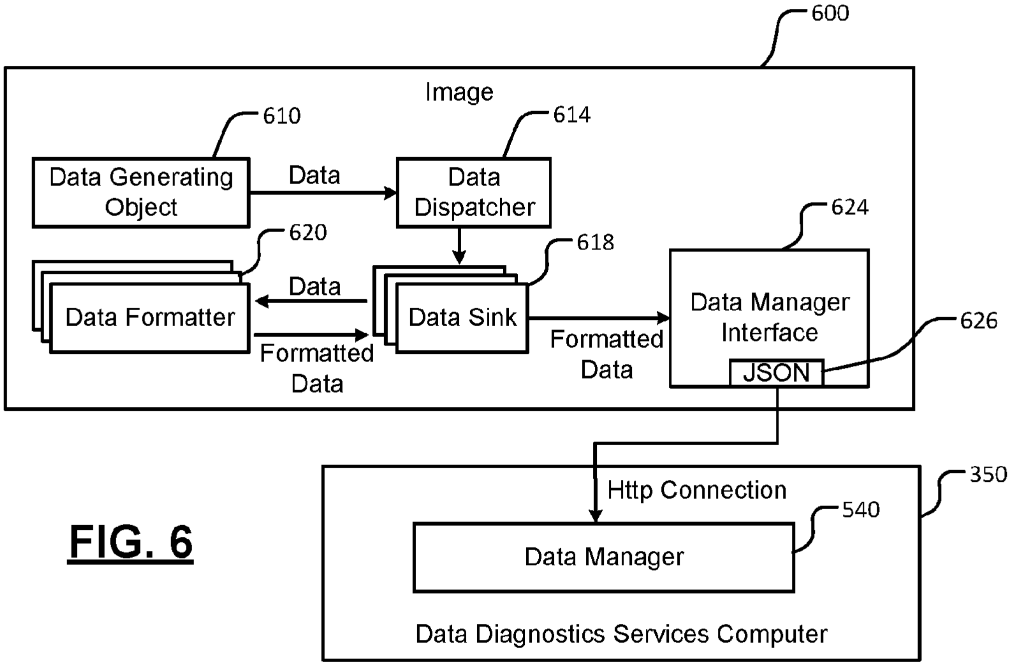
600
Image
610
Data Generating Object
Data
614
Data Dispatcher
620
Data
Data Formatter
Formatted Data
618
Data Sink
624
Data Manager Interface
Formatted Data
626
JSON
Http Connection
350
540
Data Manager
Data Diagnostics Services Computer

FIG. 6

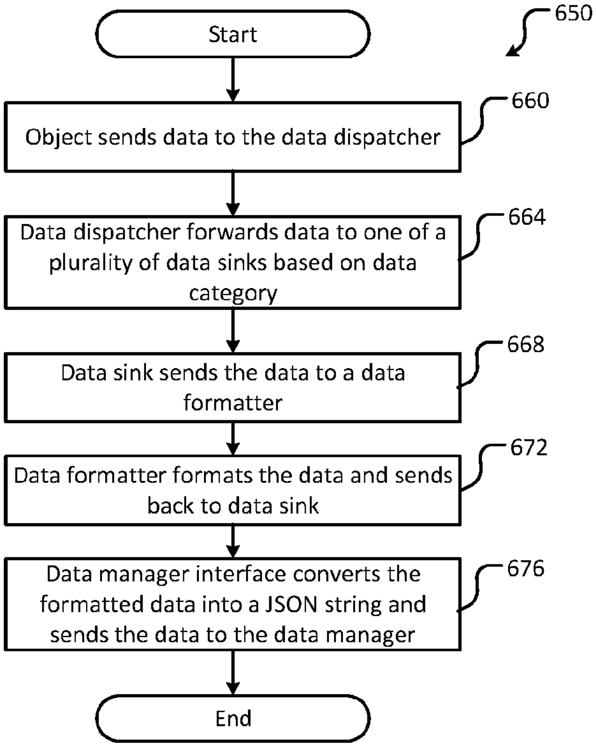
650
Start
Object sends data to the data dispatcher
660
Data dispatcher forwards data to one of a plurality of data sinks based on data category
664
Data sink sends the data to a data formatter
668
Data formatter formats the data and sends back to data sink
672
Data manager interface converts the formatted data into a JSON string and sends the data to the data manager
676
End

FIG. 7

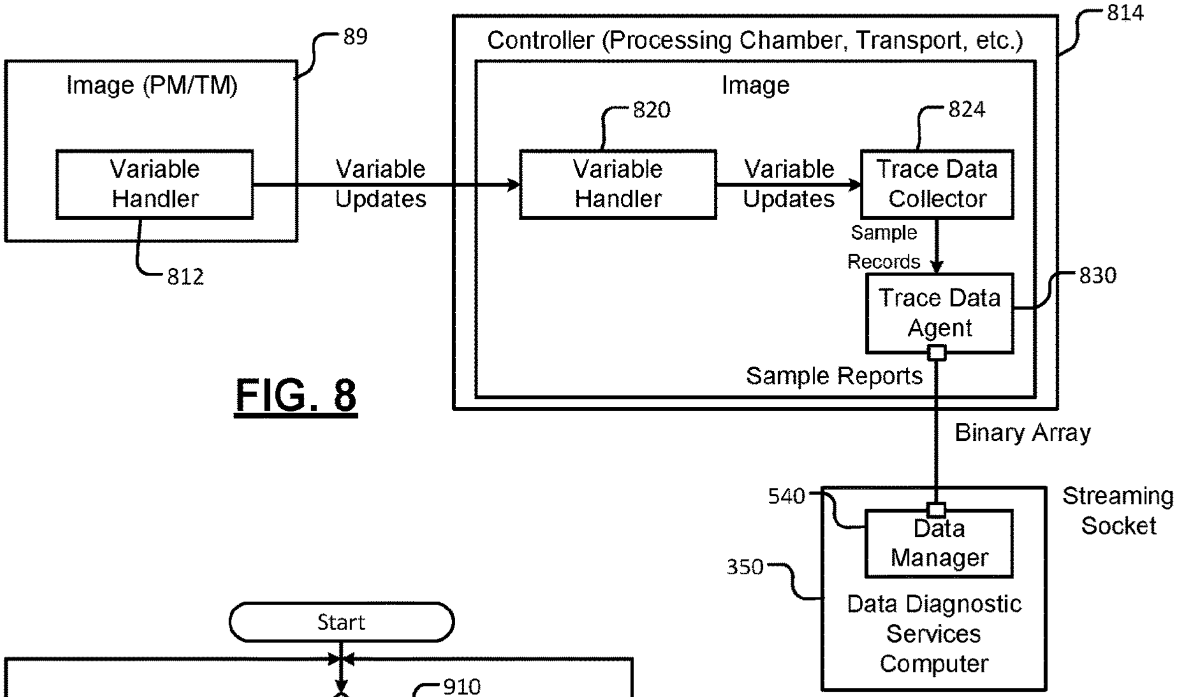
Image (PM/TM)
89
Variable Handler
812
Variable Updates
Controller (Processing Chamber, Transport, etc.)
814
Image
820
Variable Handler
Variable Updates
824
Trace Data Collector
Sample Records
Trace Data Agent
830
Sample Reports
Binary Array
Streaming Socket
540
Data Manager
350
Data Diagnostic Services Computer

FIG. 8

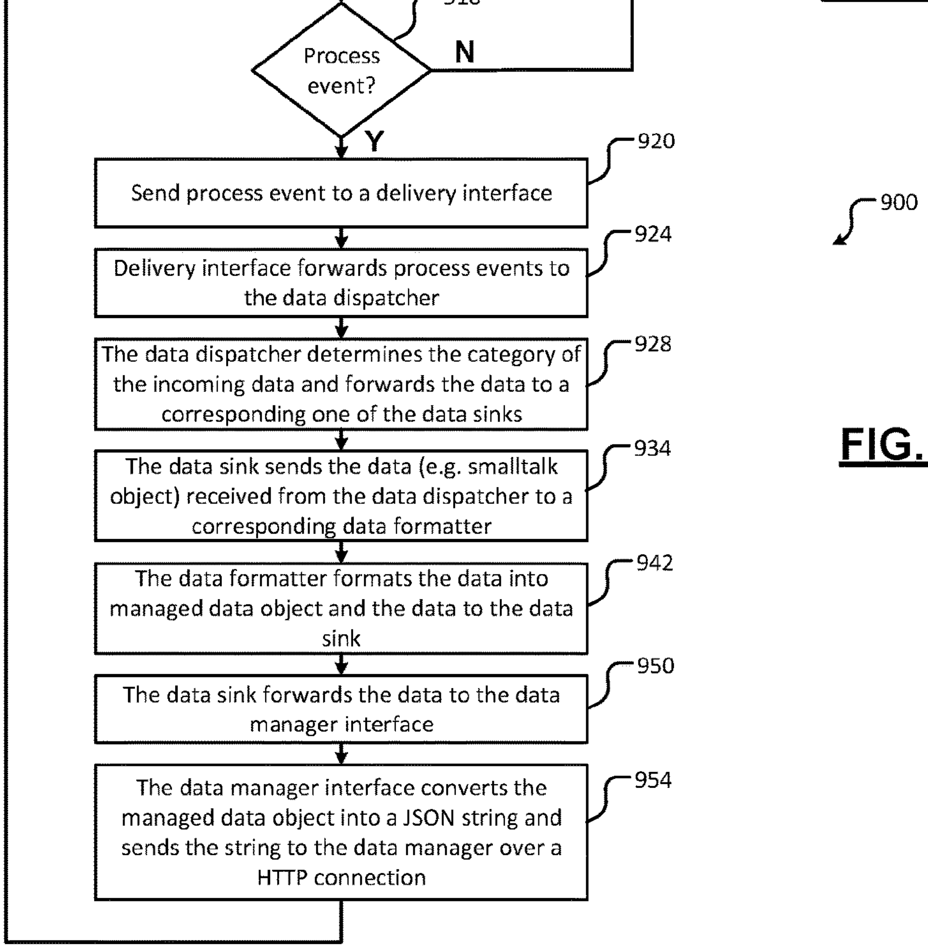
Start
910
Process event?
N
Y
920
Send process event to a delivery interface
924
Delivery interface forwards process events to the data dispatcher
928
The data dispatcher determines the category of the incoming data and forwards the data to a corresponding one of the data sinks
934
The data sink sends the data (e.g. smalltalk object) received from the data dispatcher to a corresponding data formatter
942
The data formatter formats the data into managed data object and the data to the data sink
950
The data sink forwards the data to the data manager interface
954
The data manager interface converts the managed data object into a JSON string and sends the string to the data manager over a HTTP connection
900

FIG. 9

DATA CAPTURE AND TRANSFORMATION TO SUPPORT DATA ANALYSIS AND MACHINE LEARNING FOR SUBSTRATE MANUFACTURING SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present disclosure is a U.S. National Phase Application under 35 U.S.C. 371 of International Application No. PCT/US2020/017606, filed on Feb. 11, 2020 which claims the benefit of U.S. Provisional Application No. 62/805,454 filed on Feb. 14, 2019. The entire disclosures of the applications referenced above are incorporated herein by reference.

FIELD

The present disclosure relates to substrate processing systems and more particularly to data capture and transformation to support data analysis and machine learning for substrate manufacturing systems.

BACKGROUND

The background description provided here is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

Semiconductor manufacturers use one or more substrate processing tools to perform deposition, etching, cleaning and/or other substrate treatments during fabrication of semiconductor wafers. Each of the substrate processing tools may include a plurality of processing chambers that perform the same type of treatment (such as deposition, etching or cleaning) or different treatments such as a series or sequence of treatments.

The processing chambers in the substrate processing tools usually repeat the same task on multiple substrates. The processing chambers operate based on a recipe that defines process parameters. For example, a recipe defines sequencing, operating temperatures, pressures, gas chemistry, plasma usage, periods for each operation or sub-operation, and/or other parameters. When manufacturing variations and/or defects occur, the semiconductor manufacturer needs to determine the root cause.

SUMMARY

In a feature, a data collection system for semiconductor manufacturing includes: T substrate processing tools, where each of the T substrate processing tools includes: N processing chambers, where each of the N processing chambers includes a processing chamber controller configured to receive a plurality of different types of data during operating of the corresponding one of the N processing chambers, where the plurality of different types of data have different formats, where the processing chamber controller is further configured to format the plurality of different types of data into formatted data, and where T and N are integers; and a data diagnostic services computer configured to: receive and store the formatted data as categories in a common file having a table-like data structure including rows with contextual data; and in response to a request, generate an output file including a subset of the data from the common file.

In further features: the contextual data includes a material identification field and a time field; and the plurality of different types of data include at least three or more data types selected from a group consisting of recipes, hardware calibration, process fine-tuning, optical emission spectroscopy, high speed data, and variable traces.

In further features, the data diagnostic services computer is configured to generate the output file based on at least one of: a subset of the categories; a subset of the material identification field; and a subset of the time field.

In further features, the common file has a three-level hierarchy including file, group and category.

In further features, the common file has a technical data management solution (TDMS) format.

In further features, data is stored in the common file in binary format.

In further features, a machine learning computer is configured to communicate with the diagnostics data services computer and to perform machine learning on data in the output file.

In further features, the processing chamber controller includes: a data generating object configured to transmit the plurality of different data types; a data dispatcher configured to receive the plurality of different data types from the data generating object; a plurality of data sinks, wherein each of the plurality of data sinks is configured to receive a corresponding one of the plurality of different data types from the from the data dispatcher; a plurality of data formatters, wherein each of the plurality of data formatters is configured to receive the corresponding one of the plurality of different data types from the data sink and to output the formatted data back to the corresponding one of plurality of data sinks; and a data interface manager configured to forward the formatted data from the plurality of data sinks to the data diagnostics services computer.

In further features, the data diagnostic services computer includes: a data manager configured to receive the formatted data from the processing chamber controller; and a data store configured to store and control access to the common file.

In further features, a data adapter is configured to receive the request and to generate the output file.

In further features, the data adapter is further configured to adapt the output file to one of a plurality of data transporters.

In further features, the plurality of data transporters include at least one of a file transfer protocol (FTP) transporter, a machine learning transporter, and an archive transporter.

In further features: a host server including a file selector is configured to select R portions of data from R output files of R of the T substrate processing tools, where R is an integer greater than one and less than or equal to T; and a machine learning computer is configured to combine and perform machine learning on data in the R output files.

In further features, a data collection method for semiconductor manufacturing includes: receiving a plurality of different types of data during operating of ones of N processing chambers of T substrate processing tools, where T and N are integers greater than zero, and where the plurality of different types of data have different formats; formatting the plurality of different types of data into formatted data; storing the formatted data as categories in a common file having a table-like data structure including rows with contextual data; and in response to a request, generating an output file including a subset of th from the common file.

In further features: the contextual data includes a material identification field and a time field; and the plurality of different types of data comprise at least three or more data types selected from a group consisting of recipes, hardware calibration, process fine-tuning, optical emission spectroscopy, high speed data, and variable traces.

In further features, generating the output file includes generating the output file based on at least one of: a subset of the categories; a subset of the material identification field; and a subset of the time field.

In further features, the common file has a three-level hierarchy including file, group and category.

In further features, the common file has a technical data management solution (TDMS) format.

In further features, the data is stored in the common file in binary format.

In further features, the data collection method further includes performing machine learning on data in the output file.

Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1** is a functional block diagram of an example of a substrate processing tool including one or more processing chambers;

FIG. **2** is a functional block diagram of an example of a substrate processing chamber connected to a data diagnostic services computer according to the present disclosure;

FIG. **3** is a functional block diagram of an example of a data collection architecture for a substrate manufacturer according to the present disclosure;

FIGS. **4**A to **4**G are diagrams illustrating examples of data handling;

FIG. **5** is a functional block diagram illustrating an example of flow of data from a source to the data diagnostic services computer according to the present disclosure;

FIG. **6** is a functional block diagram of an example of handling and formatting of the data;

FIG. **7** is a flowchart illustrating an example of a method for data handling and formatting;

FIG. **8** is a functional block diagram of an example of a system for updating variables and generating trace data; and

FIG. **9** is a flowchart of an example of a method for data handling.

In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

A significant amount of data such as structured data is generated during operation of the substrate processing tools. For example, to produce integrated circuits on a large scale, a semiconductor manufacturer may configure an array of substrate processing tools that are configured to fabricate semiconductor wafers. Since production uniformity is very important to reduce non-uniformity and/or defects, it is important to ensure that the same steps that are performed by

each of the processing chambers in each of the substrate processing tools are performed in the same way to produce the same results. Substrate manufacturing requires precise control of process parameters. One way to identify the root cause of defects or non-uniformities is to compare process conditions for different substrates produced in the same processing chamber and/or different processing chambers.

The processing chambers typically include sensors to sense chamber parameters such as temperature profiles of an electrostatic chuck, optical emission spectroscopy (OES) data, recipes, pressures, etc. The data that is generated typically has a variety of different file formats such as binary, binary MOSS, ASCII, XML, TDMS, etc. Furthermore, there is a large volume of data that is generated by each processing chamber. For example, each processing chamber can produce about 2 MB per second of data during operation. When problems such as defects or non-uniformities arise in current systems, it is very difficult to retrieve the data, re-format the data into a usable format and analyze the data due to the way that is collected and stored.

Systems and methods according to the present disclosure provide a data collection architecture for receiving, formatting and organizing data produced by one or more substrate processing tools. The architecture allows the data to be collected across multiple processing chambers, substrate processing tools, and/or locations such that it can be analyzed more readily. In the description that follows, an example of a substrate processing tool and a processing chamber are initially described to provide context for the description of the architecture that follows.

During processing, the substrate is typically delivered to the substrate processing tool in a cassette. A transfer robot loads the substrate through a load lock into a transfer station. A vacuum robot moves the substrate from the cassette to load lock. The vacuum robot moves the substrate from the load lock into one of the processing chambers for processing. After processing in the processing chamber, the vacuum robot moves the substrate to another one of the processing chambers or back to the cassette via the load lock.

While in the processing chamber, the substrate is treated. For example, a temperature of the substrate may be controlled by a temperature controlled electrostatic chuck (ESC). Pressure in the processing chamber may be controlled. One or more gas mixtures including one or more precursors, inert gases, etch gases or other gas mixtures are introduced into the processing chamber. In some processes, plasma may be struck in the processing chamber or supplied from a remote plasma source to initiate chemical reactions. Other processes may not involve the use of plasma. An RF bias may be supplied to the substrate support to control ion energy.

Referring now to FIG. **1**, an example substrate processing tool **100** is shown. The substrate processing tool **100** includes a plurality of processing chambers **104-1**, **104-2**, . . . and **104**-M (collectively processing chambers **104**) (where M is an integer greater than one). For example only, each of the processing chambers **104** may be configured to perform one or more types of substrate treatment. In other words, the substrates may be loaded into one of the processing chambers **104**, processed, and then moved to one or more other one of the processing chambers **104** (if at least one performs a different treatment) and/or removed from the substrate processing tool **100** (if all perform the same treatment).

Substrates to be processed are loaded into the substrate processing tool **100** via ports of a loading station of an atmosphere-to-vacuum (ATV) transfer module **108**. In some examples, the ATV transfer module **108** includes an equipment front end module (EFEM). The substrates are then transferred into one or more of the processing chambers **104**. For example, a transfer robot **112** is arranged to transfer substrates from loading stations **116** to airlocks, or load locks, **120**, and a vacuum transfer robot **124** of a vacuum transfer module **128** is arranged to transfer substrates from the load locks **120** to the various processing chambers **104**.

Processing chamber controllers **130**, a transport controller **134** and/or a system controller **138** may be provided. The transport controller **134** control robots **112** and **124**, actuators and sensors related to the transportation of substrates to and from the processing tool **100**. The processing chamber controllers **130** control operation of the processing chambers **104**. Generally, the processing chamber controllers **130** monitor sensors **135** such as temperature sensors, pressure sensors, position sensors, etc. and control actuators **136** such as robots, ports, heaters, gas delivery systems, the ESC, RF generators, etc. The processing chamber controllers **130** associated with the processing chambers **104** generally follow a recipe that specifies the timing of steps, process gases to be supplied, temperature, pressure, RF power, etc.

Referring now to FIG. **2**, an example substrate processing system **200** for treating a substrate is shown to illustrate examples of data types that are generated during operation of the processing chamber. While a specific type of processing chamber is shown, other types of processing chambers may be used. The substrate processing system **200** includes a processing chamber **202** that encloses other components of the substrate processing system **200** and contains the RF plasma. The substrate processing system **200** includes an upper electrode **204** and a substrate support, such as an electrostatic chuck (ESC) **206**. During operation, a substrate **208** is arranged on the ESC **206**.

For example only, the upper electrode **204** may include a showerhead **209** that introduces and distributes process gases such as deposition precursors, etch gases, carrier gases, etc. The ESC **206** includes a conductive baseplate **210** that acts as a lower electrode. The baseplate **210** supports a heating plate **212**, which may correspond to a ceramic multi-zone heating plate. A thermal resistance layer **214** may be arranged between the heating plate **212** and the baseplate **210**. The baseplate **210** may include one or more coolant channels **216** for flowing coolant through the baseplate **210**.

An RF generating system **220** generates and outputs an RF voltage to one of the upper electrode **204** and the lower electrode (e.g., the baseplate **210** of the ESC **206**). The other one of the upper electrode **204** and the baseplate **210** may be DC grounded, AC grounded or floating. For example only, the RF generating system **220** may include an RF voltage generator **222** that generates the RF voltage that is fed by a matching and distribution network **224** to the upper electrode **204** or the baseplate **210**. In other examples, the plasma may be generated inductively or remotely.

A gas delivery system **230** includes one or more gas sources **232-1**, **232-2**, . . . , and **232**-N (collectively gas sources **232**), where N is an integer greater than zero. The gas sources **232** supply one or more deposition precursors, etching gases, carrier gases, etc. Vaporized precursor may also be used. The gas sources **232** are connected by valves **234-1**, **234-2**, . . . , and **234**-N (collectively valves **234**) and mass flow controllers **236-1**, **236-2**, . . . , and **236**-N (collectively mass flow controllers **236**) to a manifold **238**. An output of the manifold **238** is fed to the processing chamber **202**. For example only, the output of the manifold **238** is fed to the showerhead **209**.

An optical emission spectroscopy (OES) sensor **239** may be arranged adjacent to a window **240** arranged on a chamber surface **241**. The OES sensor **239** selectively generates OES data. A temperature controller **242** may be connected to a plurality of thermal control elements (TCEs) **244** arranged in the heating plate **212**. For example, the TCEs **244** may include, but are not limited to, respective macro TCEs corresponding to each zone in a multi-zone heating plate and/or an array of micro TCEs disposed across multiple zones of a multi-zone heating plate. The temperature controller **242** may be used to control the plurality of TCEs **244** to control a temperature of the ESC **206** and the substrate **208**.

The temperature controller **242** may communicate with a coolant assembly **246** to control coolant flow through the channels **216**. For example, the coolant assembly **146** may include a coolant pump and reservoir. The temperature controller **242** operates the coolant assembly **246** to selectively flow the coolant through the channels **216** to cool the ESC **206**.

A valve **250** and pump **252** may be used to evacuate reactants from the processing chamber **202**. A controller **260** may be used to control components of the substrate processing system **200**. A robot **270** may be used to deliver substrates onto, and remove substrates from, the ESC **206**. For example, the robot **270** may transfer substrates between the ESC **206** and a load lock **272**. Although shown as separate controllers, the temperature controller **242** may be implemented within the controller **260**.

As can be appreciated, a significant amount of discrete data and streaming data is generated by the substrate processing tool during processing and transport of substrates. Event data can be used to determine the location and residence time in various components. For example, residence time in a module or FOUP may cause process differences between substrates. Systems logs record system level data. Additional data is recorded during substrate transport. Each of the processing chambers also records data during processing of the substrates. However, the data that is recorded includes different data types, sampling rates, and/or formats. Changing the data format will cause problems with respect to storage and retrieval of historical data. Furthermore, some of the data is only stored locally at the processing chamber while other data is stored at a fab level.

Data is usually streamed from the tool to a host in a message format at a fixed frequency. The data is generally not sent on a substrate basis. Rather the data is sent on a time basis. Data is typically collected in files based at a fixed frequency or file size. Data is usually collected continuously and has no bounds. In some systems, the data is collected during processing of an initial and final substrate at recipe start and recipe end, respectively, but not for intervening substrates.

The semiconductor manufacturer does not have easy access to all of the data in all its forms mentioned above using existing fab data collection methods. Therefore the semiconductor manufacturer is unable to extract a comprehensive holistic insight from the individual data segments to improve productivity, to diagnose problems and/or to make process improvements. In summary, the semiconductor manufacturer is unable to access fab data having a useable format and organization. Some of the data is not currently accessible to the semiconductor manufacturer. Many of data files are incomplete in its context information and/or lack consistency in timestamps or nomenclature used for the same subsystems.

To obtain insight, the semiconductor manufacturer may want to combine data from different files having different formats. Contextual data added to some data files is not consistent, which requires significant data wrangling to correct. Some of the data does not have sufficient quality to be relied upon.

Systems and methods according to the present disclosure capture, transport, store and/or transform data generated during substrate processing to allow subsequent analysis using big data tools and/or machine learning.

In some examples, the data has a common structured file format that supports encryption and forward/backward compatibility. In some examples, the data format is consistent with technical data management solution (TDMS) file format. In some examples, the data format is accessible and can be read by the customer using a key (e.g. an application protocol interface (API) key). The data context and collection are consistent across the different data types to allow usage without cleaning, reformatting and/or other work.

In some examples, the data is collected from the moment the substrate leaves the cassette until the substrate returns back to the cassette. In some examples, the data can be stored in a single file. In some examples, the file format is self-consistent. In some examples, the data is collected at different frequencies based on the type of data and context. In some examples, the data is formatted using TDMS with encryption. In some examples, a data adapter is used to support legacy data and backward compatibility, to incorporate new data types and to support host messaging/streaming data. Additional details will be described further below.

Referring now to FIG. **3**, a fab data collection system **300** for a semiconductor processing system is shown. The fab data collection system **300** includes N substrate processing tools **320-1**, **320-2**, . . . , and **320**-T (where T is an integer) (collectively substrate processing tools **320**). Each of the substrate processing tools **320-1**, **320-2**, . . . , and **320**-T includes one or more processing chamber controllers **340-1**, **340-2**, . . . , and **340**-T (collectively processing chamber controllers **340**) as described above to control operation of a processing chamber. Examples of data collected by the processing chambers include substrate or wafer data logs, auto preventive maintenance, high-speed data, optical emission spectroscopy (OES), trace data, OES snapshots, pedestal temperature maps and other data, calibration files, equipment constants, sensor data, and/or other data.

Each of the substrate processing tools **320-1**, **320-2**, . . . , and **320**-T may include a transport controller **344-1**, **344-2**, . . . , and **344**-N (collectively transport controllers **344**), to control dynamic alignment and to store calibration files, platform trace data logs, equipment constants, transfer module activity and/or other data. Dynamic alignment refers to the location of the substrate relative to other chamber components such as a center of the pedestal, edge ring or other object.

Each of the substrate processing tools **320-1**, **320-2**, . . . , and **320**-T may include a tool system controller **348-1**, **348-2**, . . . , and **348**-N (collectively the tool system controllers **348**), respectively. The tool system controllers **348** record lot history, detailed event logs, lot-based alarms, time-based alarms, tool controller health, parts tracking, component history, material scheduling, and other data.

Each of the substrate processing tools **320-1**, **320-2**, . . . , and **320**-T further includes a data diagnostic services computer **350-1**, **350-2**, . . . , and **350**-N (collectively data diagnostic services computers **350**) and data storage devices **362-1**, **362-2**, . . . , and **362**-N (collectively data storage devices **362**), respectively. In other examples, the data diagnostic services computers **350** may be shared by two or more tools or each tool may include more than one data diagnostic services computer **350**. The substrate processing tools **320** are connected by one or more buses such as a tool data bus or network **364-1** and a streaming data bus or network **364-2** to a host server **364**.

In some examples, the host server **364** includes a security module **366** and a data selector module **367**. The security module **366** provides security such as encryption or password protection. The security module **366** uses encryption or passwords to grant or deny access to data stored by the substrate processing tools **320** and/or to the data selector module **367**. The host server **364** further includes a data selector module **365** to allow a user computer **380** to select one or more categories of data from one or more substrate processing tools and filter the data using one or more of the data context fields. In other examples, the security module **366** and/or the data selector module **367** are implemented using separate servers.

The host server **364** is connected by a network **368** such as a WAN or LAN to a machine learning computer **374** and/or one or more user computers **380**. The data sets returned by the host server **364** can be made accessible to the machine learning computer **374** for further analysis. In some examples, the machine learning computer **374** includes a security module **375** to control access to the data. The machine learning computer **374** performs machine learning using one or more data files generated by the data collection system as selected by the user. Since the format of the files from the different substrate processing tools is the same, the data can be combined into a single file and analyzed. This allows the same process to be analyzed in multiple machines.

As can be appreciated, the number T of substrate processing tools **320** is not limited. Additionally, the substrate processing tools **320** need not be located at the same facility. In some examples, the equipment manufacturer can be granted access to the data stored by multiple semiconductor manufacturers.

In some examples, the sampling rates of some or all of the data generating devices (other than streaming or HSD devices) can be aligned to a common sampling period and the data is added to a common file (described below) based on the sampling period.

Referring now to FIGS. **4**A to **4**G, the data collection system according to the present disclosure implements changes to the way that the data is transported, stored and/or formatted. In FIG. **4**A, the data was previously stored in one or more large substrate datalog files **400** that store different types of data in various formats. For example, the substrate datalog files **400** may store data including substrate context **410**, recipes **414**, hardware calibration **418**, process fine-tuning **422** and one or more variable traces **425**.

In FIG. **4**B, rather than using large substrate datalog files **400** with disparate kinds of data and formats, the data collection system according to the present disclosure breaks the data down into data categories **450-1**, **450-2**, **450-3**, . . . , and **450**-C (where C is an integer) and adds contextual data such as material ID, lot ID, process job ID, time, module, etc. in some examples, the data is stored in a common file having a table-like data structure that is analogous to a sparsely populated table. The categories of data are stored in the data structure along with the contextual data.

In FIG. **4**C, data storage device **370** is used to store the data structure. In some examples, the data storage device **370** represents a distributed storage system including each of the data storage devices **362** associated with the substrate processing tools **320**. In other words, as each of the substrate processing tools **320** operates, it generates the categories of data and contextual data and populates the files in corresponding ones of the data storage devices **362**. Then, the data selector module **367** allows the user to pull data from one or more of the data storage devices **362**. The process can be repeated one or more times to create a new data set that can be used for further analysis or machine learning without requiring data wrangling or formatting changes.

In FIG. **4**D, as will be described further below, a semiconductor manufacturer can select a subset of the one or more categories of data and restrict the returned dataset by filtering one or more of the fields in the contextual data. In other words, a user computer **374** generates one or more requests for fab data by specifying one or more categories and filtering one or more contextual data fields. The process can be repeated one or more times to create a new data set for further analysis. In FIG. **4**E, an example is shown. In response to a request for data having a material ID, IDs or ID range, time range and/or categories, the data diagnostic services computer selects the categories for the user as limited by the material ID and time range (as shown at **480**) from the data storage device **370** and generates an output file **482** for further analysis.

Referring now to FIGS. **4**F and **4**G, an example of a suitable file format or data structure is shown. In FIG. **4**F, the data is appended to a file that includes a linked list. Once data is added to the file, it is not deleted or changed. New data is appended to the file. The appended data includes a header and data. The header of a last entry points to the next entry in the linked list. In FIG. **4**G, the file includes a 3-level hierarchy including file, group and channel properties. Each item at each level can include unique properties and there is no limit on the number of groups, channels or channel properties. The groups are similar to tables. Each row represents a point in time or an index. Each column represents data. In some examples, the file includes a TDMS file. TDMS files are binary and compress more efficiently than ASCII files. TDMS files are written and read faster than other formats. Since the files are stored in binary, sensitive data is protected. In some examples, streaming data such as HSD (high speed data up to 1 kHz) and/or OES (optical emission spectroscopy) data can be stored in the file or stored in a separate substrate datalog file.

Referring now to FIG. **5**, an example of data handling and processing by the data diagnostic services computer is shown. A controller **510** (such as one of the processing chamber controllers, tool system controllers or transfer module controllers described above) includes one or more images **512**. In some examples, the images **512** include Smalltalk images, although other types can be used. The images **512** include a variable data handler **514** and/or data object handler **518**. In some examples, the variable data handler **514** and/or a data object handler **518** output data via a tool network bus **519**. Other data such as HSD and/or OES (at **530**) is transported by a data network bus **521** and may include raw streaming data.

The data diagnostic services computer **350** includes a data manager **540** that receives data flows from the controllers **510**. The data manager **540** outputs the data flows to the data store **544**. A data adapter **548** receives requests from a user computer **380**. The data adapter **548** outputs the request to the data store **544** and receives the data back from the data store **544**. The data adapter **548** adapts the data as needed for the destination and outputs the data to one of a plurality of transporters **550**. Adapting the data may include further formatting and/or other operations for the designated transport target. The selected one of the transporters forwards or transports the data to the correct target (for example machine learning, archive or FTP). In some examples, the transporter **550** includes at least one of a machine learning (ML) transporter **552**, an archive transporter **554**, a file transfer protocol (FTP) transporter (not shown) or another transporter **558**.

Referring now to FIG. **6**, an image **600** includes a data generating object **610** that generates data that is output to a data dispatcher **614**. In some examples, the image **600** includes a Smalltalk image and the data generating object **610** is a Smalltalk object, although other types of images and objects can be used. In some examples, the data generating object **610** generates data relating to a recipe, process events, hardware calibration, process fine tuning, etc.

The data dispatcher **614** forwards the data from the data dispatcher **614** to one of a plurality of data sinks **618** based on the data category. One of the plurality of data sinks **618** sends the data to a data formatter **620** that applies one of the plurality of data formats to the data. In some examples, the data formatter **620** applies a TDMS compatible format to the data.

The data formatter **620** returns the formatted data to the data sink **618**. The data sink **618** forwards the formatted data to a data manager interface **624**. The data manager interface **624** converts the formatted data into a string (such as Javascript Object Notation (JSON)) and sends the data to the data manager **540** of the data diagnostic services computer **350**.

Referring now to FIG. **7**, the method **650** for operating the image **600** is shown. At **660**, the data generating object **610** sends data to the data dispatcher **614**. The data dispatcher **614** forwards the data to one of a plurality of data sinks **618** based on the data category at **664**. At **668**, the data sink **600** sends the data to the data formatter **620**. At **672**, the data formatter **620** formats the data (using a format based on the category) and sends the data back to the data sink **618**. At **676**, the data manager interface **624** converts the formatted data and sends the data to the data manager **540**.

Referring now to FIG. **8**, an image **810** (associated with one of the controllers) includes a variable handler **812** that generates variable updates that are output to a variable handler **820** of an image **822**. For example, variable updates for the processing chambers are sent. The variable handler **820** generates variable updates (such as variable updates for the substrate processing tool) that are output to a trace data collector **824**. The trace data collector **824** outputs sample records (such as tool sample records) to a trace data agent **830**. The trace data agent **830** generates sample reports that are output is a binary array to the data manager **540** of the data diagnostic services computer **350**. In some examples, the trace data agent **830** outputs binary data such as an array via streaming sockets.

Referring now to FIG. **9**, a method **900** is shown. When a process event occurs as determined at **910**, the process event is sent to a delivery interface at **920**. At **924**, the delivery interface forwards the process events to the data dispatcher. At **928**, the data dispatcher determines the category of the incoming data and forwards the data to a corresponding one of the data sinks. At **934**, the data sink sends the data (such as a Smalltalk object) received from the data dispatcher to a corresponding data formatter. At **938**, the data formatter formats the data into managed data object and sends the data to the data sink. At **950**, the data sink forwards the data to the data manager interface. At **954**, the data manager interface converts the managed data object into a string (such as a JSON string) and sends the string to the data manager over a connection such as an HTTP connection.

The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure. Further, although each of the embodiments is described above as having certain features, any one or more of those features described with respect to any embodiment of the disclosure can be implemented in and/or combined with features of any of the other embodiments, even if that combination is not explicitly described. In other words, the described embodiments are not mutually exclusive, and permutations of one or more embodiments with one another remain within the scope of this disclosure.

Spatial and functional relationships between elements (for example, between modules, circuit elements, semiconductor layers, etc.) are described using various terms, including “connected,” “engaged,” “coupled,” “adjacent,” “next to,” “on top of,” “above,” “below,” and “disposed.” Unless explicitly described as being “direct,” when a relationship between first and second elements is described in the above disclosure, that relationship can be a direct relationship where no other intervening elements are present between the first and second elements, but can also be an indirect relationship where one or more intervening elements are present (either spatially or functionally) between the first and second elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive logical OR, and should not be construed to mean “at least one of A, at least one of B, and at least one of C.”

In some implementations, a controller is part of a system, which may be part of the above-described examples. Such systems can comprise semiconductor processing equipment, including a processing tool or tools, chamber or chambers, a platform or platforms for processing, and/or specific processing components (a substrate pedestal, a gas flow system, etc.). These systems may be integrated with electronics for controlling their operation before, during, and after processing of a semiconductor wafer or substrate. The electronics may be referred to as the “controller,” which may control various components or subparts of the system or systems. The controller, depending on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, including the delivery of processing gases, temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and operation settings, wafer transfers into and out of a tool and other transfer tools and/or load locks connected to or interfaced with a specific system.

Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control operation, enable cleaning operations, enable endpoint measurements, and the like. The integrated circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software). Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some embodiments, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

The controller, in some implementations, may be a part of or coupled to a computer that is integrated with the system, coupled to the system, otherwise networked to the system, or a combination thereof. For example, the controller may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process. In some examples, a remote computer (e.g. a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control. Thus as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

Without limitation, example systems may include a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

As noted above, depending on the process step or steps to be performed by the tool, the controller might communicate with one or more of other tool circuits or modules, other tool components, cluster tools, other tool interfaces, adjacent tools, neighboring tools, tools located throughout a factory, a main computer, another controller, or tools used in material transport that bring containers of wafers to and from tool locations and/or load ports in a semiconductor manufacturing factory.

What is claimed is:

1. A data collection system for semiconductor manufacturing, comprising:

T substrate processing tools, wherein each of the T substrate processing tools includes:

N processing chambers, wherein each of the N processing chambers includes a processing chamber controller configured to receive a plurality of different types of data during operating of the corresponding one of the N processing chambers,

wherein the plurality of different types of data have different formats,

wherein the processing chamber controller is further configured to format the plurality of different types of data into formatted data, and

wherein T and N are integers; and

a data diagnostic services computer configured to:

receive and store the formatted data as categories in a common file having a table-like data structure including rows with contextual data; and

in response to a request, generate an output file including a subset of the data from the common file.

2. The data collection system of claim **1**, wherein:

the contextual data includes a material identification field and a time field; and

the plurality of different types of data comprise at least three or more data types selected from a group consisting of recipes, hardware calibration, process fine-tuning, optical emission spectroscopy, high speed data, and variable traces.

3. The data collection system of claim **2**, wherein the data diagnostic services computer is configured to generate the output file based on at least one of:

a subset of the categories;

a subset of the material identification field; and

a subset of the time field.

4. The data collection system of claim **1**, wherein the common file has a three-level hierarchy including file, group and category.

5. The data collection system of claim **1**, wherein the common file has a technical data management solution (TDMS) format.

6. The data collection system of claim **5**, wherein data is stored in the common file in binary format.

7. The data collection system of claim **1**, further comprising a machine learning computer configured to communicate with the diagnostics data services computer and to perform machine learning on data in the output file.

8. The data collection system of claim **1**, wherein the processing chamber controller includes:

a data generating object configured to transmit the plurality of different data types;

a data dispatcher configured to receive the plurality of different data types from the data generating object;

a plurality of data sinks, wherein each of the plurality of data sinks is configured to receive a corresponding one of the plurality of different data types from the data dispatcher;

a plurality of data formatters, wherein each of the plurality of data formatters is configured to receive the corresponding one of the plurality of different data types from the data sink and to output the formatted data back to the corresponding one of plurality of data sinks; and

a data interface manager configured to forward the formatted data from the plurality of data sinks to the data diagnostics services computer.

9. The data collection system of claim **1**, wherein the data diagnostic services computer includes:

a data manager configured to receive the formatted data from the processing chamber controller; and

a data store configured to store and control access to the common file.

10. The data collection system of claim **9**, further comprising a data adapter configured to receive the request and to generate the output file.

11. The data collection system of claim **10**, wherein the data adapter is further configured to adapt the output file to one of a plurality of data transporters.

12. The data collection system of claim **11**, wherein the plurality of data transporters include at least one of a file transfer protocol (FTP) transporter, a machine learning transporter, and an archive transporter.

13. The data collection system of claim **1**, further comprising:

a host server including a file selector configured to select R portions of data from R output files of R of the T substrate processing tools, wherein R is an integer greater than one and less than or equal to T; and

a machine learning computer configured to combine and perform machine learning on data in the R output files.

14. A data collection method for semiconductor manufacturing, comprising:

receiving a plurality of different types of data during operating of ones of N processing chambers of T substrate processing tools,

wherein T and N are integers greater than zero, and

wherein the plurality of different types of data have different formats;

formatting the plurality of different types of data into formatted data;

storing the formatted data as categories in a common file having a table-like data structure including rows with contextual data; and

in response to a request, generating an output file including a subset of th the data from the common file.

15. The data collection method of claim **14**, wherein:

the contextual data includes a material identification field and a time field; and

the plurality of different types of data comprise at least three or more data types selected from a group consisting of recipes, hardware calibration, process fine-tuning, optical emission spectroscopy, high speed data, and variable traces.

16. The data collection method of claim **15**, wherein generating the output file includes generating the output file based on at least one of:

a subset of the categories;

a subset of the material identification field; and

a subset of the time field.

17. The data collection method of claim **14**, wherein the common file has a three-level hierarchy including file, group and category.

18. The data collection method of claim **14**, wherein the common file has a technical data management solution (TDMS) format.

19. The data collection method of claim **18**, wherein the data is stored in the common file in binary format.

20. The data collection method of claim **14** further comprising performing machine learning on data in the output file.

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