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MULTI LAYER DEFECTS CALCULATION METHOD AND SYSTEM

FIELD OF INVENTION

The present invention relates broadly to multi-layer fabrication processes, and more particularly to a method and system for multi-layer defects calculation.

BACKGROUND

In multi-layer processes such as semiconductor wafer fabrication, it is important to obtain data on process defects in wafer fabrication processes, which influence the yield of the product. Such data is used for defect monitoring and triggering, and may be used for yield lost prediction and yield forecast.

Currently, average defect count values are used to monitor for defects in such fabrication processes. However, it has been recognised by the present inventors that the current approach can be inaccurate and indeed statistically wrong, where the nature of the process of the defect event does not follow a specific distribution, as is typically the case in for example semiconductor wafer fabrication for backend multi-layer processes.

SUMMARY

In accordance with a first aspect of the present invention there is provided a method for multi-layer defects calculation, the method comprising obtaining raw defect count data representative of each single layer in a multi-layer fabrication process; deriving a cumulative probability for a non-zero defect event from the raw defect count data; deriving an average defect count for the non-zero defect event based on the raw defect count data; and calculating a multi-layer defect count value

utilising a binomial distribution probability mass function based on the non-zero defect event and a zero defect event.

The binomial distribution probability mass function may comprise

$$\sum_{x=0}^{N}\binom{N}{x}p^{x}(1-p)^{N-x}\cdot xy$$

where N = total number of layers

x = number of affected layers

p = the cumulative probability for the non-zero defect event

y = average defect count for the non-zero defect event

The binomial distribution probability mass function may comprise

$$\sum_{z=1}^{M}\sum_{x=0}^{N}\binom{N}{x}p_z^{x}\left(1-p_z^{x}\right)^{N-x}\cdot xy_z$$

where N = total number of layers

x = number of affected layers

z = 1st, 2nd, 3rd, ..., Mth type of defect

p_z = the cumulative probability of the non-zero defect event for defect type z

y_z = average defect count of the non-zero defect event for defect type z

The method may be performed periodically, and further comprises monitoring the calculated multi-layer defect counts as a function of time.

The method may further comprise correlating the calculated multi-layer defect count value to the yield of an associated semiconductor wafer fabrication process.

The method may comprise monitoring a defect event rate.

The calculated multi-layer defect counts may be used to provide an early warning relating to the fabrication process.

In accordance with a second aspect of the present invention there is provided a system for executing multi-layer defects calculation, the system comprising an interface for entering raw defect count data representative of each single layer in a

multi-layer fabrication process; a processor unit deriving a cumulative probability for a non-zero defect event from the raw defect count data, deriving an average defect count for the non-zero defect event based on the raw defect count data, and calculating a multi-layer defect count value utilising a binomial distribution probability mass function based on the non-zero defect event and a zero defect event; and an output unit for output of the calculated multi-layer defect count value.

The binomial distribution probability mass function may comprise

$$\sum_{x=0}^{N}\binom{N}{x}p^{x}(1-p)^{N-x}\cdot xy$$

where N = total number of layers

x = number of affected layers

p = the cumulative probability for the non-zero defect event

y = average defect count for the non-zero defect event

The binomial distribution probability mass function may comprise

$$\sum_{z=1}^{M}\sum_{x=0}^{N}\binom{N}{x}p_z^{x}\left(1-p_z^{x}\right)^{N-x}\cdot xy_z$$

where N = total number of layers

x = number of affected layers

z = 1st, 2nd, 3rd, ..., Mth type of defect

p_z = the cumulative probability of the non-zero defect event for defect type z

y_z = average defect count of the non-zero defect event for defect type z

The raw defect count data representative of each single layer may be entered at the interface periodically, and the processor unit may further monitor the periodically calculated multi-layer defect counts as a function of time.

The processor unit may further derive a correlation of the calculated multi-layer defect count value to the yield of an associated semiconductor wafer fabrication process for output through the output unit.

The processor unit may further monitor a defect event rate.

The calculated multi-layer defect counts may be used to provide an early warning relating to the fabrication process at the output unit.

In accordance with a third aspect of the present invention there is provided a data storage medium having stored thereon computer program code means for instructing a computer to execute a method for multi-layer defects calculation, the method comprising

obtaining raw defect count data representative of each single layer in a multi-layer fabrication process;

deriving a cumulative probability for a non-zero defect event from the raw defect count data;

deriving an average defect count for the non-zero defect event based on the raw defect count data; and

calculating a multi-layer defect count value utilising a binomial distribution probability mass function based on the non-zero defect event and a zero defect event.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

Figure 1 shows a plot of defect raw data as a function of processing date.

Figure 2 shows a plot of cumulative probability versus defect count, in accordance with an example embodiment of the present invention.

Figure 3 shows a graph illustrating overall Metal Extra Pattern (MEP) tail probability trend versus production cycles, in accordance with an example embodiment of the present invention.

Figure 4 shows a graph illustrating yield to backend defect counts correlation, in accordance with an example embodiment of the present invention.

Figure 5 shows a comparative yield to backend defect count correlation for a prior art approach.

Figure 6 is a schematic drawing illustrating a computer system for implementation of a method of multi-layer defects calculation, in accordance with an example embodiment of the present invention.

Figure 7 shows a flow chart of a process in accordance with an example embodiment of the present invention.

DETAILED DESCRIPTION

It has been recognised by the present inventors, that fabrication process defect counts, for example in semiconductor wafer fabrication for backend multi-layer processes, do not follow a specific distribution. Therefore, in the example embodiment two possibilities are assigned. More specifically a wafer is either defect-free or the wafer has defects. In the multi-layer defects calculation of the example embodiment, as the defect occurrences are independent events with only two assigned possibilities (defect-free or with defects), the continuous event can be modelled into discrete probability, using binomial approximation. As a result, a binomial approximation distribution probability mass function can be applied to calculate the multiple layer defects.

In the example embodiment, single-layer defect count raw data (see plot 100 in Figure 1), is transformed into a cumulative probability plot 200 shown in Figure 2. From the cumulative probability plot 200, an average defect count of non-zero defect count events is determined, indicated as "y", not to scale, in Figure 1. Also, the (cumulative) probability of occurrence (indicated as "p" in Figure 1) of the non-zero defect event for a given period of time is determined.

In the example embodiment, it is assumed that a particular process has N repeated layers with two possibilities of events:

- event with defects with probability of p
- defect - free event with probability of $1-p$.

Under the model of the example embodiment, these events are independent of each other, that is a present event has no influence to the next event and a present layer has no influence on the subsequent layers. Hence, binomial distribution probability calculations can be used for multi-layer defects calculations.

The binomial probability mass function in the example embodiment is given by:

$$\binom{N}{x} p^x (1-p)^{N-x}$$

with x the number of affected layers.

The total defect count of a wafer for a specific defect type can then be obtained in the example embodiment as:

$$\sum_{x=0}^{N} \binom{N}{x} p^x (1-p)^{N-x} \cdot xy$$

with y the average defect count of non-zero defect event, as described above with reference to Figure 2. The multi-layer defect calculation can be extended in the example embodiment to apply for different defect types in a multi-layer process, e.g. metal layer, via layer, oxide layer, . . ., etc. The total defect count can be obtained it such an embodiment as:

$$\sum_{z=1}^{M} \sum_{x=0}^{N} \binom{N}{x} p_z^x \left(1-p_z^x\right)^{N-x} \cdot xy_z$$

with z the 1st , 2nd, 3rd, . . . Mth type of defect, p_z the probability of non-zero defect event with defect type z, and y_z the average defect count of non-zero defect event for the type z defect.

It will be appreciated by a person skilled in the art that it is also possible to express the total defect count of a wafer for a single-layer process for different defect types based on a binomial probability mass function, if desired.

In the example embodiment, rather then attempting to control the defect count on a wafer, which is in practice difficult since the fabrication process defects do not follow the specific distribution as mentioned above, a defect event rate is recognised as controllable. It is found that it is more practical to monitor the defect event rate rather then the defect counts per wafer, for facilitating for example defect monitoring and triggering, or more accurate yield predictions.

Figure 3 shows an overall Metal Extra Pattern (MEP) tail probability trend graph 300. In the graph 300, the *p*-values and total defect count values are plotted along the vertical axes, with time as the horizontal axis, in units of working weeks. In the graph 300, the MEP occurrences and total counts are plotted for all metal layers. It is noted that the total counts in Figure 3 are the total defect counts as calculated based on the binomial probability mass function calculations of the example embodiment.

It will be appreciated by the person skilled in the art that the example embodiment can facilitate yield loss prediction and yield forecast data, which may for example provide early warning to re-input wafers to meet customer chips shipment quantity requirements should the yield loss be significant. Figures 4 and 5 show yield to backend defect count correlation graphs 400 and 500 respectively, for a backend defect count in accordance with the example embodiment and a previous approach, respectively. The data shown in Figures 4 and 5 relate to the same multi-layer wafer fabrication process. As is evident from a comparison of Figures 4 and 5, the data obtained using an example embodiment of the present invention shows a stronger correlation. Therefore, a more accurate yield prediction may be obtained in the example embodiment.

The example embodiment described provides a mathematical model to accurately calculate defects for multiple process layers despite the following practical limitations in typical wafer fabrication processes:

- small defect proportion and defect scanned sampling size,
- event of defect is sporadic and its characteristic is chaotic.

In the example embodiment, limited defect scan data on single layer defect occurrences are utilised to estimate yield impact for multiple layers. The example embodiment can facilitate accurate defect monitoring and accurate yield prediction before wafers are electrically tested.

The method and system of the example embodiment can be implemented on a computer system 600, schematically shown in Figure 6. It may be implemented as software, such as a computer program being executed within the computer system 600, and instructing the computer system 600 to conduct the method of the example embodiment.

The computer system 600 comprises a computer module 602, input modules such as a keyboard 604 and mouse 806 and a plurality of output devices such as a display 608, and printer 610.

The computer module 602 is connected to a computer network 612 via a suitable transceiver device 614, to enable access to e.g. the Internet or other network systems such as Local Area Network (LAN) or Wide Area Network (WAN).

The computer module 602 in the example includes a processor 618, a Random Access Memory (RAM) 620 and a Read Only Memory (ROM) 622. The computer module 602 also includes a number of Input/Output (I/O) interfaces, for example I/O interface 624 to the display 608, and I/O interface 626 to the keyboard 604.

The components of the computer module 602 typically communicate via and interconnected bus 628 and in a manner known to the person skilled in the relevant art.

The application program is typically supplied to the user of the computer system 800 encoded on a data storage medium such as a CD-ROM or floppy disk and read utilising a corresponding data storage medium drive of a data storage device 630. The application program is read and controlled in its execution by the processor 618. Intermediate storage of program data maybe accomplished using RAM 620.

Figure 7 shows a flow chart 700 of a process in accordance with an example embodiment of the present invention. At step 702, raw defect count data representative of each single layer in a multi-layer fabrication process is obtained. At step 704, a cumulative probability for a non-zero defect event is derived from the raw defect count data. At step 706, an average defect count for the non-zero defect event is derived based on the raw defect count data. At step 708, a multi-layer defect count value is calculated utilising a binomial distribution probability mass function based on the non-zero defect event and a zero defect event.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A method for multi-layer defects calculation, the method comprising

obtaining raw defect count data representative of each single layer in a multi-layer fabrication process;

deriving a cumulative probability for a non-zero defect event from the raw defect count data;

deriving an average defect count for the non-zero defect event based on the raw defect count data; and

calculating a multi-layer defect count value utilising a binomial distribution probability mass function based on the non-zero defect event and a zero defect event.

2. The method as claimed in claim 1, wherein the binomial distribution probability mass function comprises

$$\sum_{x=0}^{N}\binom{N}{x}p^{x}(1-p)^{N-x}\cdot xy$$

where N = total number of layers

x = number of affected layers

p = the cumulative probability for the non-zero defect event

y = average defect count for the non-zero defect event

3. The method as claimed in claim 1, wherein the binomial distribution probability mass function comprises:

$$\sum_{z=1}^{M}\sum_{x=0}^{N}\binom{N}{x}p_{z}^{x}\left(1-p_{z}^{x}\right)^{N-x}\cdot xy_{z}$$

where N = total number of layers

x = number of affected layers

z = 1st, 2nd, 3rd, ..., Mth type of defect

p_z = the cumulative probability of the non-zero defect event for defect type z

y_z = average defect count of the non-zero defect event for defect type z

4. The method as claimed in any one of the preceding claims, wherein the method is performed periodically, and further comprises monitoring the calculated multi-layer defect counts as a function of time.

5. The method as claimed in any one the preceding claims, wherein the method further comprises correlating the calculated multi-layer defect count value to the yield of an associated semiconductor wafer fabrication process.

6. The method as claimed in any one of the preceding claims, wherein the method comprises monitoring a defect event rate.

7. The method as claimed in any one of the preceding claims, wherein the calculated multi-layer defect counts is used to provide an early warning relating to the fabrication process.

8. A system for executing multi-layer defects calculation, the system comprising

an interface for entering raw defect count data representative of each single layer in a multi-layer fabrication process;

a processor unit deriving a cumulative probability for a non-zero defect event from the raw defect count data, deriving an average defect count for the non-zero defect event based on the raw defect count data, and calculating a multi-layer defect count value utilising a binomial distribution probability mass function based on the non-zero defect event and a zero defect event; and

an output unit for output of the calculated multi-layer defect count value.

9. The system as claimed in claim 8, wherein the binomial distribution probability mass function comprises

$$\sum_{x=0}^{N}\binom{N}{x}p^{x}(1-p)^{N-x}\cdot xy$$

where N = total number of layers

x = number of affected layers

p = the cumulative probability for the non-zero defect event

y = average defect count for the non-zero defect event

10. The system as claimed in claim 8, wherein the binomial distribution probability mass function comprises:

$$\sum_{z=1}^{M}\sum_{x=0}^{N}\binom{N}{x}p_z^x\left(1-p_z^x\right)^{N-x}\cdot xy_z$$

where N = total number of layers

x = number of affected layers

z = 1st, 2nd, 3rd, ..., Mth type of defect

p_z = the cumulative probability of the non-zero defect event for defect type z

y_z = average defect count of the non-zero defect event for defect type z

11. The system as claimed in any one of claims 8 to 10, wherein the raw defect count data representative of each single layer is entered at the interface periodically, and the processor unit further monitors the periodically calculated multi-layer defect counts as a function of time.

12. The system as claimed in any one of claims 8 to 11, wherein the processor unit further derives a correlation of the calculated multi-layer defect count value to the yield of an associated semiconductor wafer fabrication process for output through the output unit.

13. The method as claimed in any one of claims 8 to 12, wherein the processor unit further monitors a defect event rate.

14. The method as claimed in any one of claims 8 to 13, wherein the calculated multi-layer defect counts is used to provide an early warning relating to the fabrication process at the output unit.

15. A data storage medium having stored thereon computer program code means for instructing a computer to execute a method for multi-layer defects calculation, the method comprising

obtaining raw defect count data representative of each single layer in a multi-layer fabrication process;

deriving a cumulative probability for a non-zero defect event from the raw defect count data;

deriving an average defect count for the non-zero defect event based on the raw defect count data; and

calculating a multi-layer defect count value utilising a binomial distribution probability mass function based on the non-zero defect event and a zero defect event.