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(54) **PLASMA PROCESSING APPARATUS**

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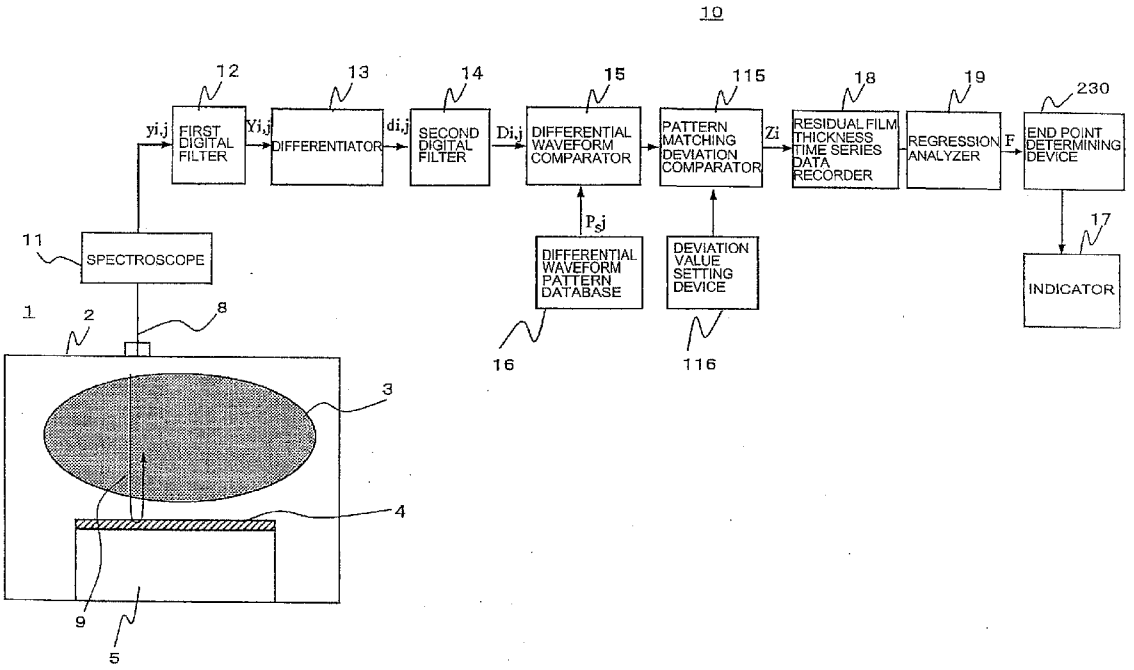
C23F 1/00 (2006.01)

(52) **U.S. Cl.** **156/345.25**

(57) **ABSTRACT**

To provide a plasma processing apparatus using a measuring method of a film thickness of a material to be processed, which method is capable of accurately measuring an actual residual film amount and an etching depth of the layer to be processed. The plasma processing apparatus includes: a detector **11** adapted to detect interference light of a plurality of wavelengths from the surface of a sample in a vacuum container; pattern comparing means **15** adapted to compare actual deviation pattern data relating to the interference light obtained at an arbitrary time point during the processing of the sample, with a plurality of standard deviation patterns which are data of interference light of a plurality of wavelengths relating to processing of another sample obtained before the processing of the sample, and which correspond to a plurality of thicknesses of the film, and adapted to calculate a deviation between the actual deviation pattern data and the standard deviation patterns; deviation comparing means **115** adapted to compare the deviation between the actual deviation pattern data and the standard deviation patterns, with a deviation set beforehand, and to output data relating to the film thickness of the sample at the time; residual film thickness time series data recording means **18** adapted to record the data relating to the film thickness as time series data; and an end point determining device **230** adapted to determine that etching of a predetermined amount is ended, by using the data of the film thickness.



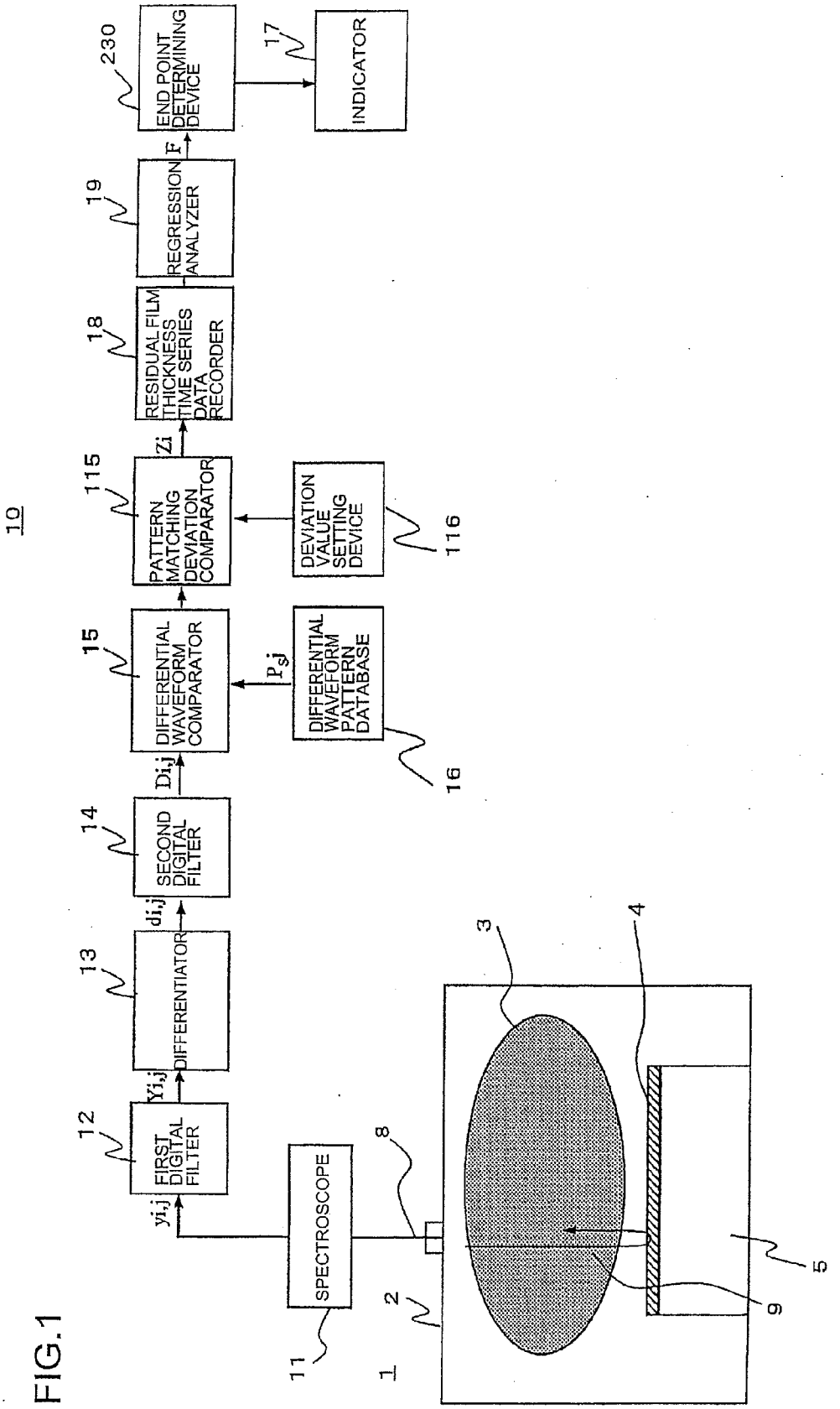

10
230
END POINT DETERMINING DEVICE
17
INDICATOR
19
REGRESSION ANALYZER
F
18
RESIDUAL FILM THICKNESS TIME SERIES DATA RECORDER
Zi
115
PATTERN MATCHING DEVIATION COMPARATOR
DEVIATION VALUE SETTING DEVICE
116
15
DIFFERENTIAL WAVEFORM COMPARATOR
Psj
DIFFERENTIAL WAVEFORM PATTERN DATABASE
16
Di,j
14
SECOND DIGITAL FILTER
di,j
13
DIFFERENTIATOR
Yi,j
12
FIRST DIGITAL FILTER
yi,j
SPECTROSCOPE
11
8
1
2
3
4
5
9

FIG.1

FIG.2

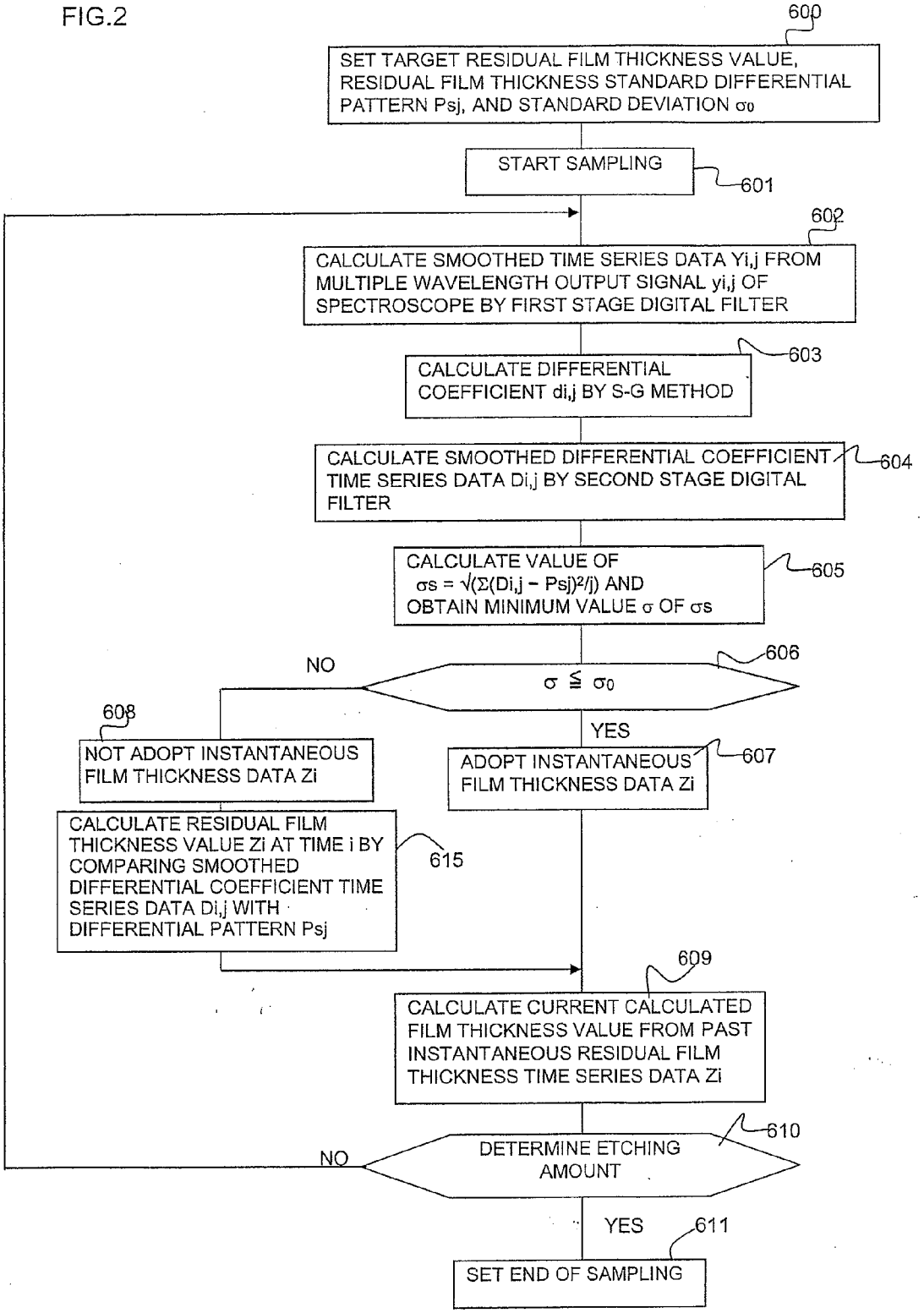

600
SET TARGET RESIDUAL FILM THICKNESS VALUE, RESIDUAL FILM THICKNESS STANDARD DIFFERENTIAL PATTERN Psj, AND STANDARD DEVIATION σ0
START SAMPLING
601
602
CALCULATE SMOOTHED TIME SERIES DATA Yi,j FROM MULTIPLE WAVELENGTH OUTPUT SIGNAL yi,j OF SPECTROSCOPE BY FIRST STAGE DIGITAL FILTER
603
CALCULATE DIFFERENTIAL COEFFICIENT di,j BY S-G METHOD
604
CALCULATE SMOOTHED DIFFERENTIAL COEFFICIENT TIME SERIES DATA Di,j BY SECOND STAGE DIGITAL FILTER
605
CALCULATE VALUE OF σs = √(Σ(Di,j − Psj)²/j) AND OBTAIN MINIMUM VALUE σ OF σs
606
σ ≦ σ0
NO
YES
608
NOT ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
607
ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
615
CALCULATE RESIDUAL FILM THICKNESS VALUE Zi AT TIME i BY COMPARING SMOOTHED DIFFERENTIAL COEFFICIENT TIME SERIES DATA Di,j WITH DIFFERENTIAL PATTERN Psj
609
CALCULATE CURRENT CALCULATED FILM THICKNESS VALUE FROM PAST INSTANTANEOUS RESIDUAL FILM THICKNESS TIME SERIES DATA Zi
610
DETERMINE ETCHING AMOUNT
NO
YES
611
SET END OF SAMPLING

FIG.3

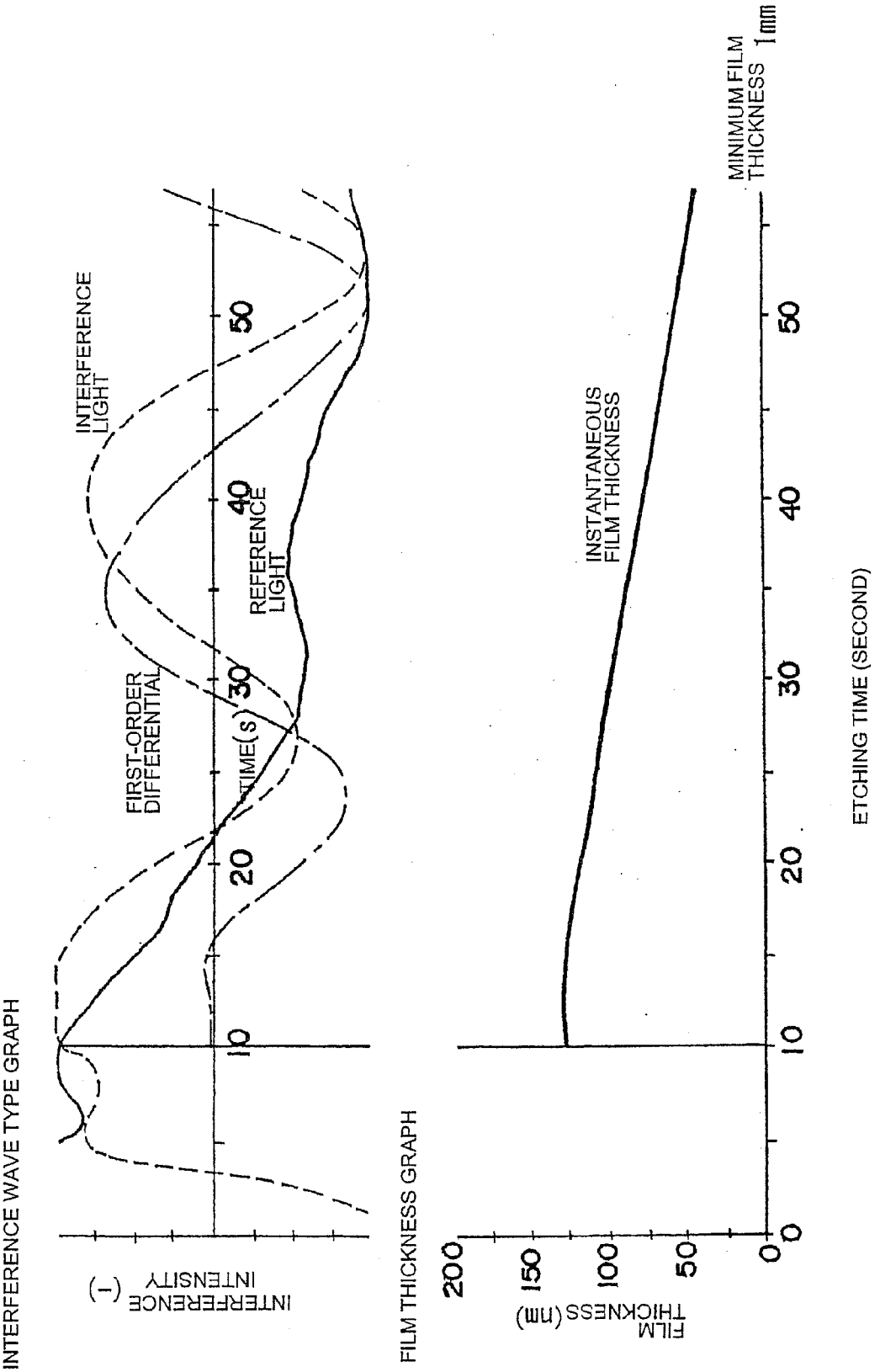

INTERFERENCE WAVE TYPE GRAPH
INTERFERENCE INTENSITY (-)
TIME(s)
10
20
30
40
50
INTERFERENCE LIGHT
FIRST-ORDER DIFFERENTIAL
REFERENCE LIGHT
FILM THICKNESS GRAPH
FILM THICKNESS (nm)
0
50
100
150
200
INSTANTANEOUS FILM THICKNESS
MINIMUM FILM THICKNESS 1mm
ETCHING TIME (SECOND)

FIG.4

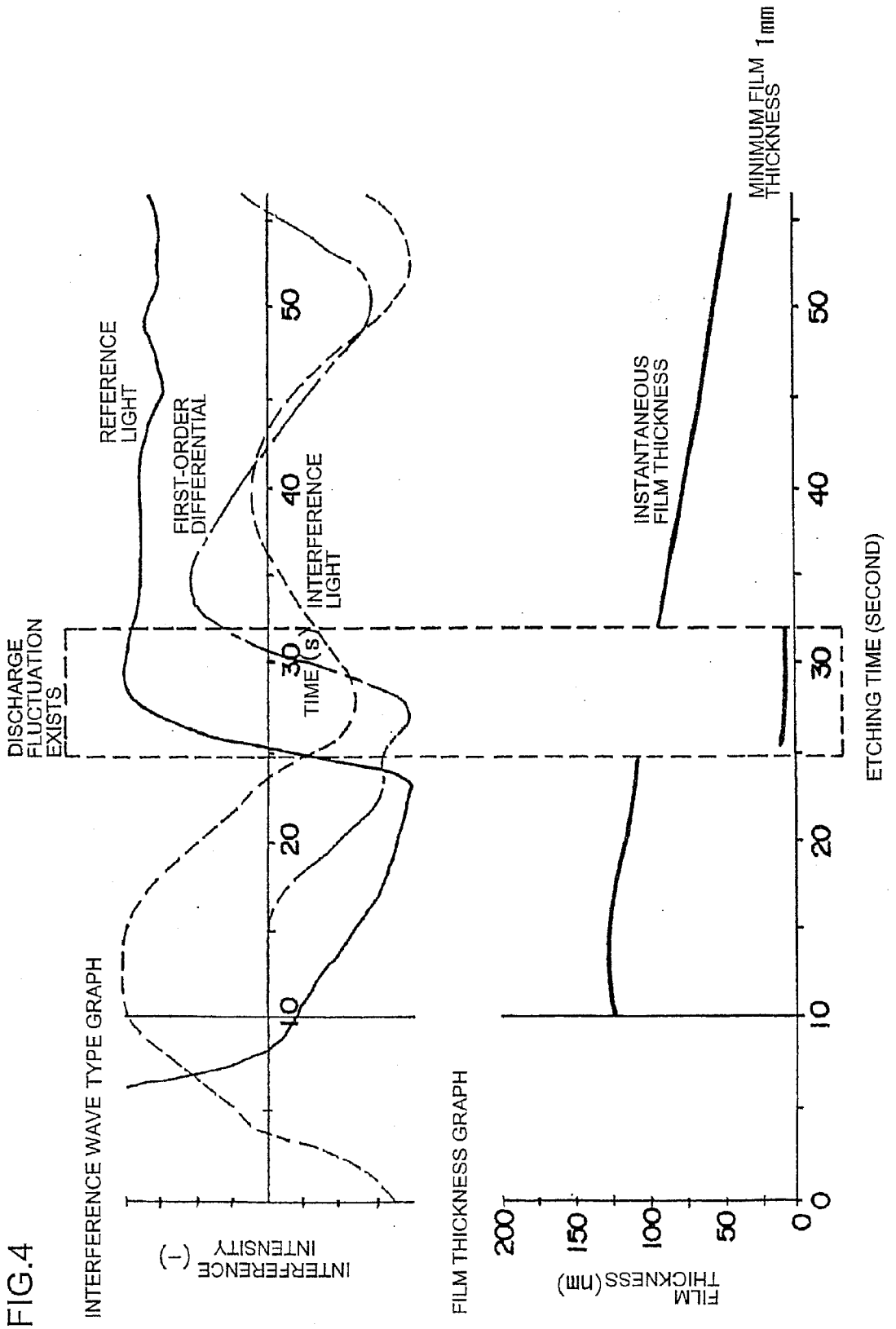

INTERFERENCE WAVE TYPE GRAPH
INTERFERENCE INTENSITY (-)
REFERENCE LIGHT
FIRST-ORDER DIFFERENTIAL
INTERFERENCE LIGHT
DISCHARGE FLUCTUATION EXISTS
TIME (S)
10
20
30
40
50
FILM THICKNESS GRAPH
FILM THICKNESS (nm)
200
150
100
50
0
INSTANTANEOUS FILM THICKNESS
MINIMUM FILM THICKNESS 1mm
ETCHING TIME (SECOND)

FIG.5

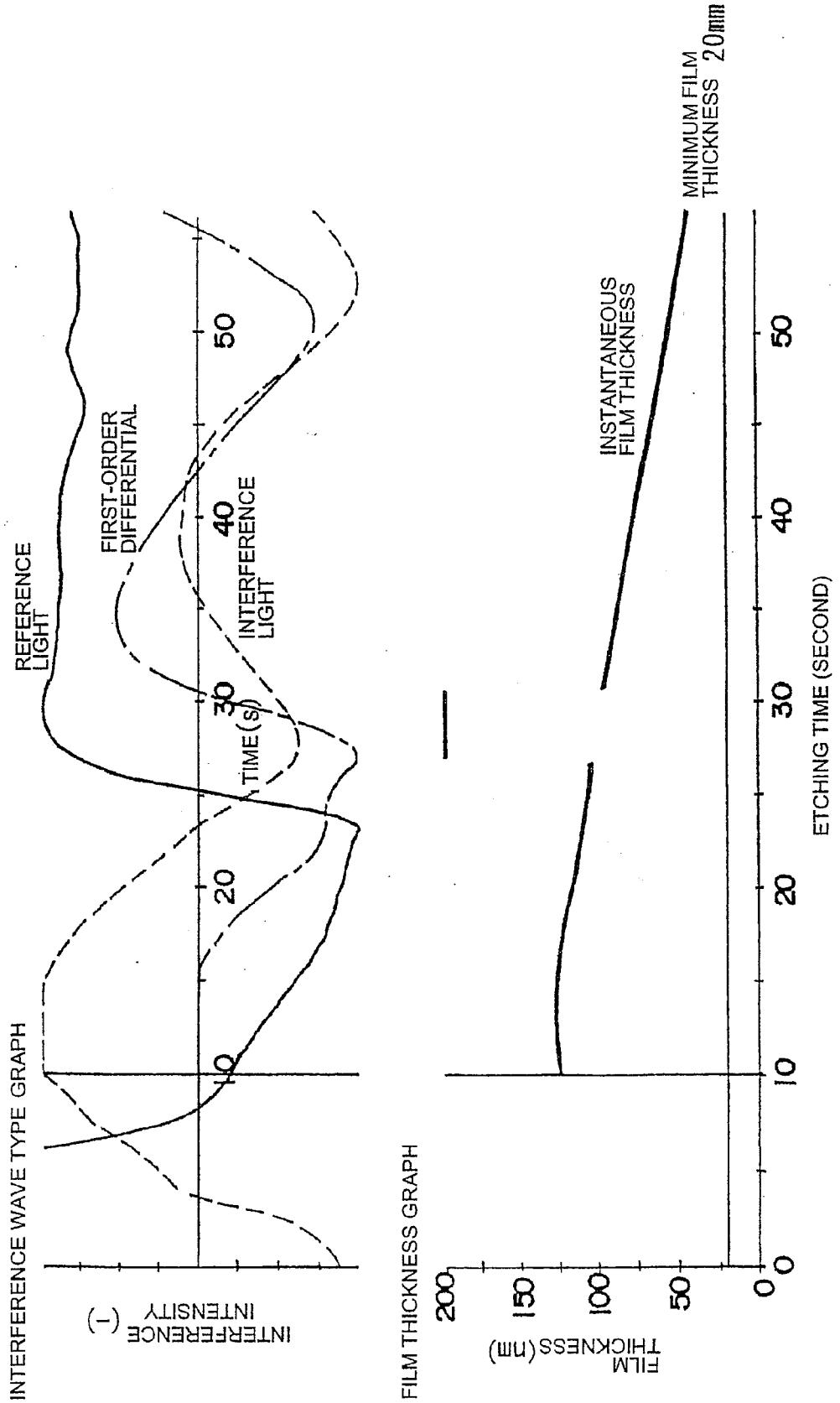

INTERFERENCE WAVE TYPE GRAPH
INTERFERENCE INTENSITY (-)
REFERENCE LIGHT
FIRST-ORDER DIFFERENTIAL
INTERFERENCE LIGHT
TIME (s)
0
20
30
40
50
FILM THICKNESS GRAPH
FILM THICKNESS (nm)
200
150
100
50
0
INSTANTANEOUS FILM THICKNESS
MINIMUM FILM THICKNESS 20nm
0
10
20
30
40
50
ETCHING TIME (SECOND)

FIG.6

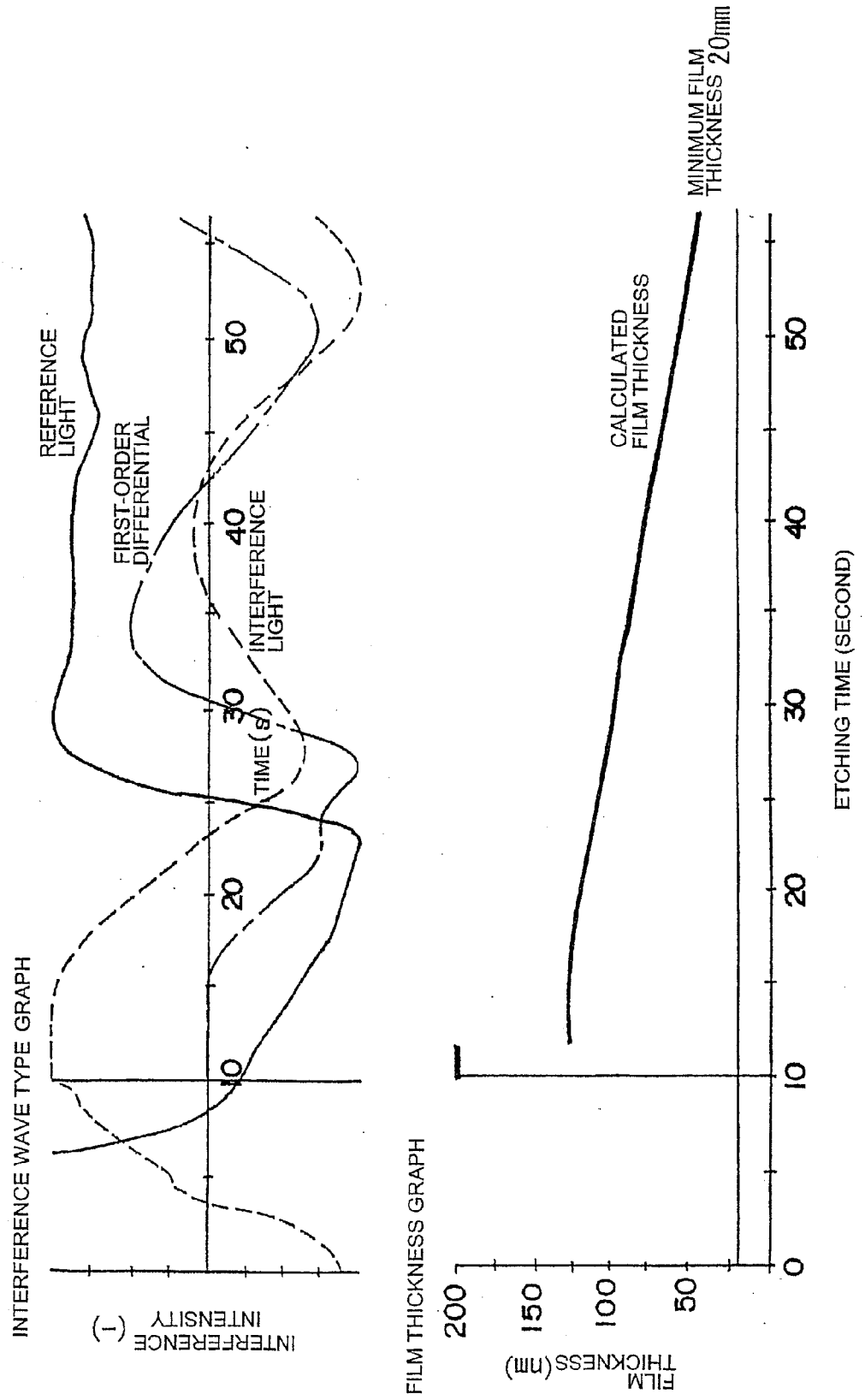
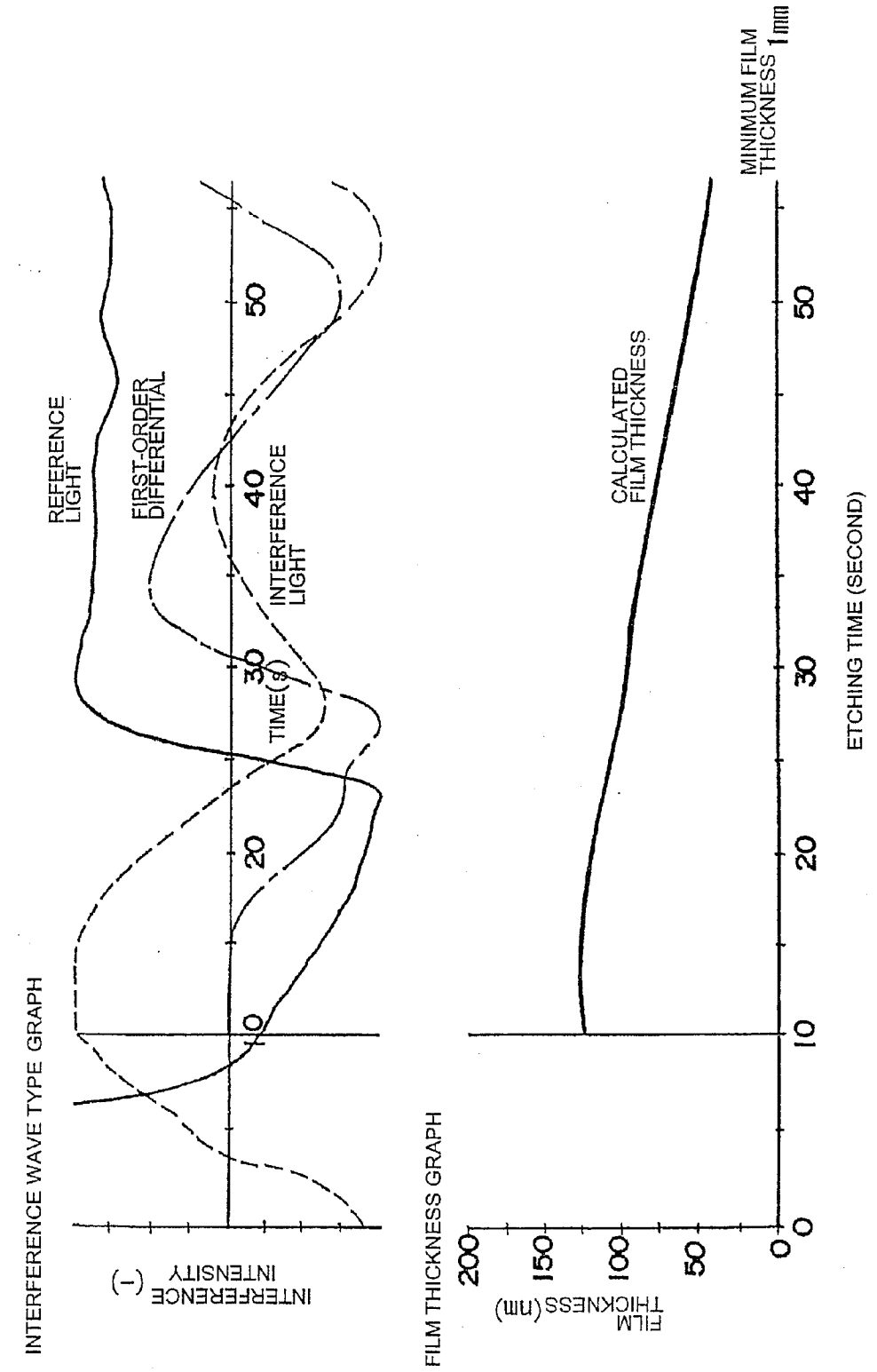

INTERFERENCE WAVE TYPE GRAPH
INTERFERENCE INTENSITY (-)
TIME (s)
REFERENCE LIGHT
FIRST-ORDER DIFFERENTIAL
INTERFERENCE LIGHT
10
20
30
40
50
FILM THICKNESS GRAPH
FILM THICKNESS (nm)
200
150
100
50
0
CALCULATED FILM THICKNESS
MINIMUM FILM THICKNESS 20nm
ETCHING TIME (SECOND)

FIG.7


INTERFERENCE WAVE TYPE GRAPH
REFERENCE LIGHT
FIRST-ORDER DIFFERENTIAL
INTERFERENCE LIGHT
INTERFERENCE INTENSITY (-)
TIME(s)
0
20
30
40
50
FILM THICKNESS GRAPH
CALCULATED FILM THICKNESS
MINIMUM FILM THICKNESS 1mm
FILM THICKNESS (nm)
ETCHING TIME (SECOND)
0
50
100
150
200
10
20
30
40
50

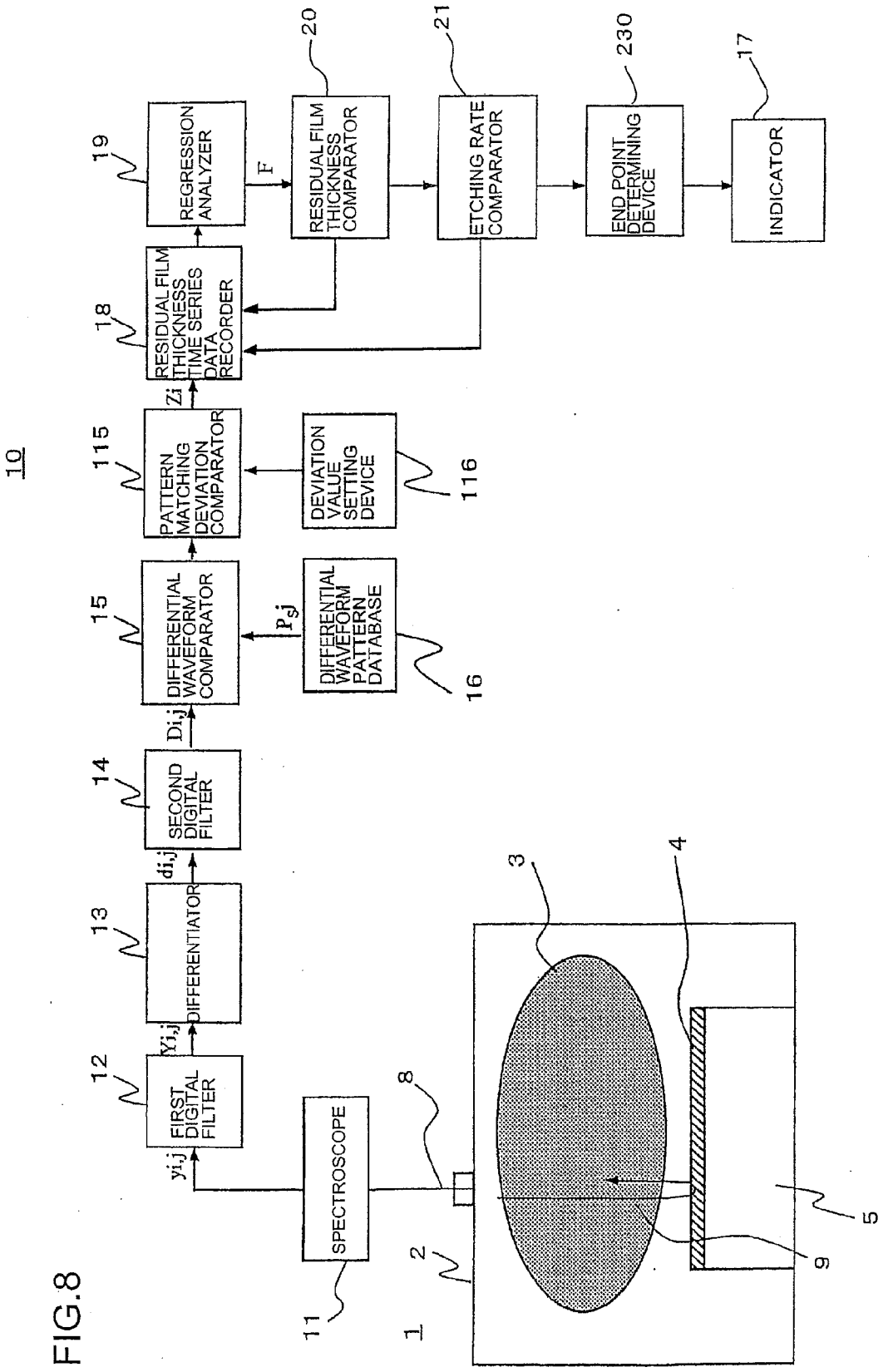

10
1
2
3
4
5
8
9
11
SPECTROSCOPE
12
FIRST DIGITAL FILTER
yi,j
Yi,j
13
DIFFERENTIATOR
di,j
14
SECOND DIGITAL FILTER
Di,j
15
DIFFERENTIAL WAVEFORM COMPARATOR
Pj
16
DIFFERENTIAL WAVEFORM PATTERN DATABASE
115
PATTERN MATCHING DEVIATION COMPARATOR
Zi
116
DEVIATION VALUE SETTING DEVICE
18
RESIDUAL FILM THICKNESS TIME SERIES DATA RECORDER
19
REGRESSION ANALYZER
F
20
RESIDUAL FILM THICKNESS COMPARATOR
21
ETCHING RATE COMPARATOR
230
END POINT DETERMINING DEVICE
17
INDICATOR

FIG.8

FIG.9

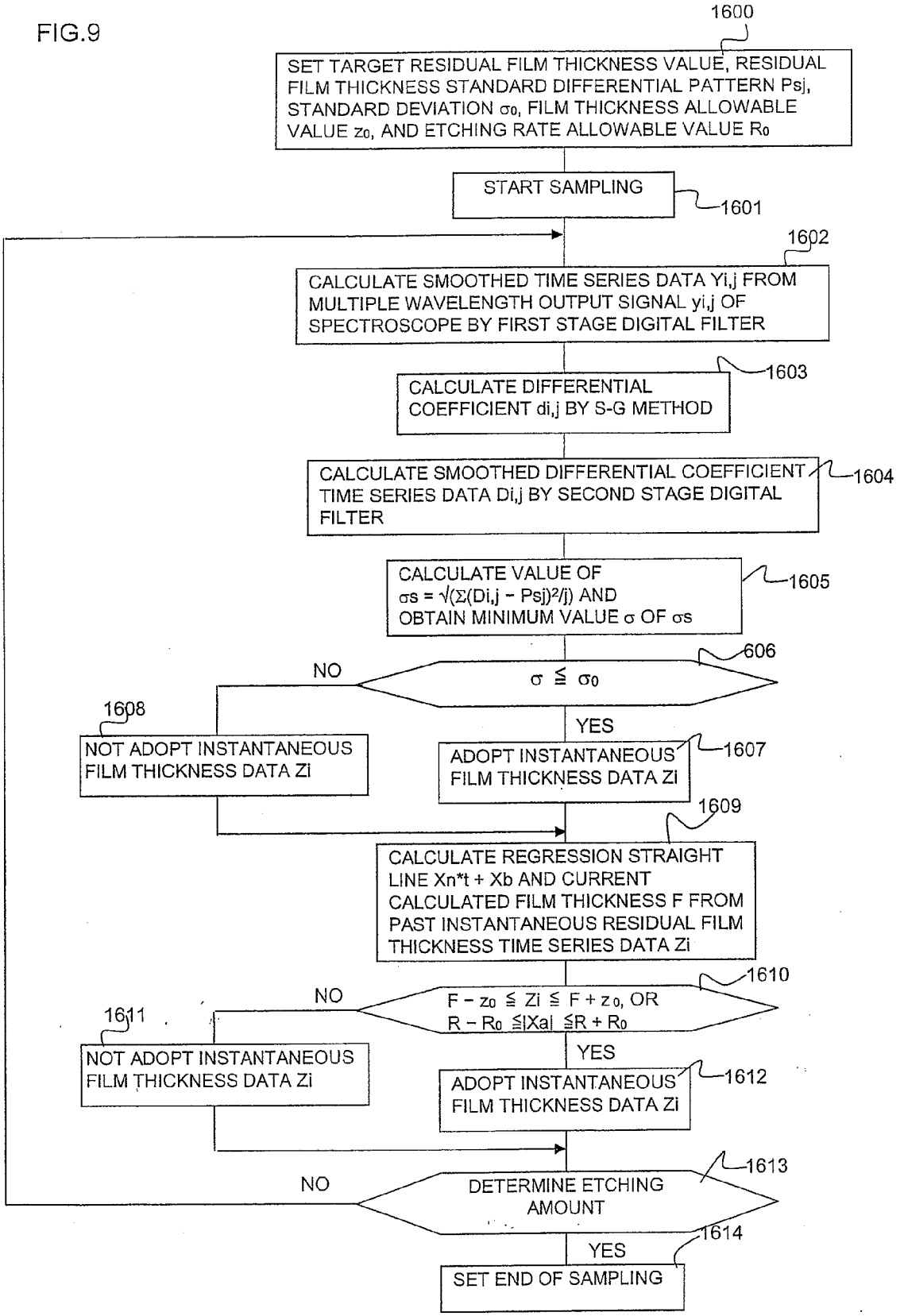

1600
SET TARGET RESIDUAL FILM THICKNESS VALUE, RESIDUAL FILM THICKNESS STANDARD DIFFERENTIAL PATTERN Psj, STANDARD DEVIATION σ0, FILM THICKNESS ALLOWABLE VALUE z0, AND ETCHING RATE ALLOWABLE VALUE R0
START SAMPLING
1601
1602
CALCULATE SMOOTHED TIME SERIES DATA Yi,j FROM MULTIPLE WAVELENGTH OUTPUT SIGNAL yi,j OF SPECTROSCOPE BY FIRST STAGE DIGITAL FILTER
1603
CALCULATE DIFFERENTIAL COEFFICIENT di,j BY S-G METHOD
1604
CALCULATE SMOOTHED DIFFERENTIAL COEFFICIENT TIME SERIES DATA Di,j BY SECOND STAGE DIGITAL FILTER
1605
CALCULATE VALUE OF σs = √(Σ(Di,j − Psj)²/j) AND OBTAIN MINIMUM VALUE σ OF σs
606
σ ≦ σ0
NO
YES
1608
NOT ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
1607
1609
CALCULATE REGRESSION STRAIGHT LINE Xn*t + Xb AND CURRENT CALCULATED FILM THICKNESS F FROM PAST INSTANTANEOUS RESIDUAL FILM THICKNESS TIME SERIES DATA Zi
1610
NO
F − z0 ≦ Zi ≦ F + z0, OR R − R0 ≦|Xa| ≦R + R0
1611
YES
NOT ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
1612
1613
NO
DETERMINE ETCHING AMOUNT
1614
YES
SET END OF SAMPLING

FIG.10

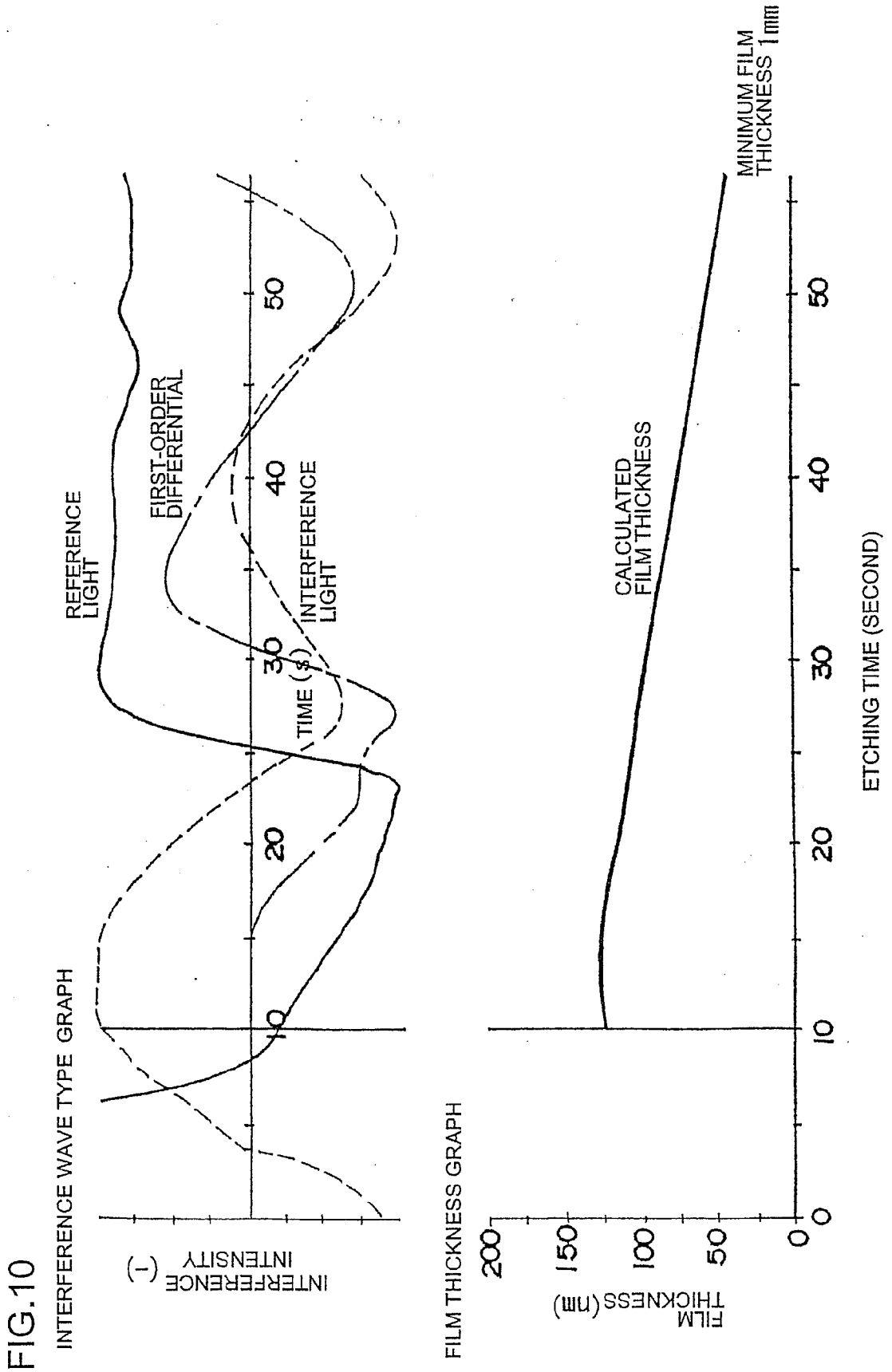

INTERFERENCE WAVE TYPE GRAPH
INTERFERENCE INTENSITY (-)
REFERENCE LIGHT
FIRST-ORDER DIFFERENTIAL
INTERFERENCE LIGHT
TIME (s)
10
20
30
40
50
FILM THICKNESS GRAPH
FILM THICKNESS (nm)
200
150
100
50
0
CALCULATED FILM THICKNESS
MINIMUM FILM THICKNESS 1mm
10
20
30
40
50
ETCHING TIME (SECOND)

FIG.11

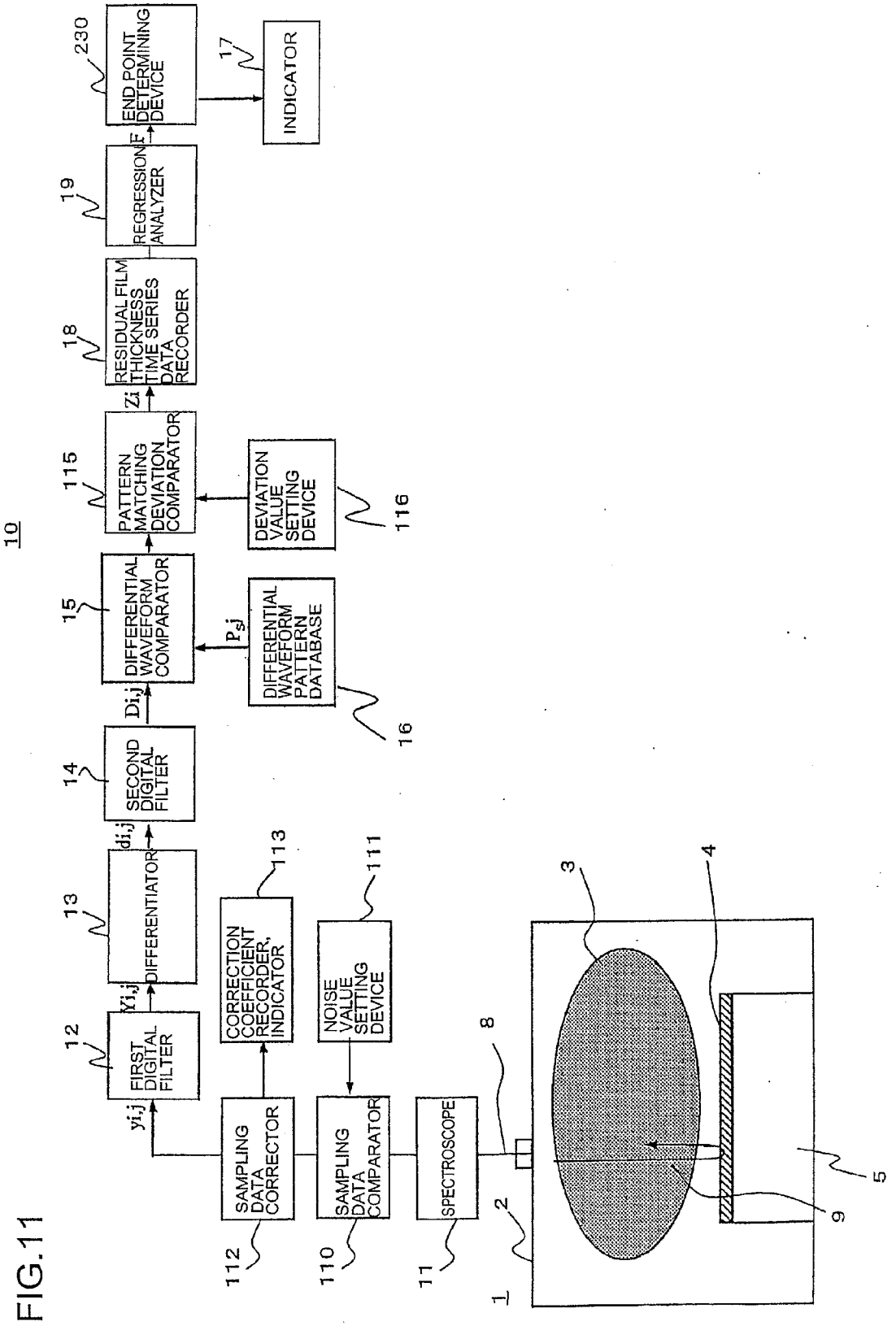

10
1
2
3
4
5
8
9
11
SPECTROSCOPE
110
SAMPLING DATA COMPARATOR
111
NOISE VALUE SETTING DEVICE
112
SAMPLING DATA CORRECTOR
113
CORRECTION COEFFICIENT RECORDER, INDICATOR
12
FIRST DIGITAL FILTER
13
DIFFERENTIATOR
14
SECOND DIGITAL FILTER
15
DIFFERENTIAL WAVEFORM COMPARATOR
16
DIFFERENTIAL WAVEFORM PATTERN DATABASE
115
PATTERN MATCHING DEVIATION COMPARATOR
116
DEVIATION VALUE SETTING DEVICE
18
RESIDUAL FILM THICKNESS TIME SERIES DATA RECORDER
19
REGRESSION ANALYZER
230
END POINT DETERMINING DEVICE
17
INDICATOR
yi,j
Yi,j
di,j
Di,j
Pe,j
Zi
F

FIG.12

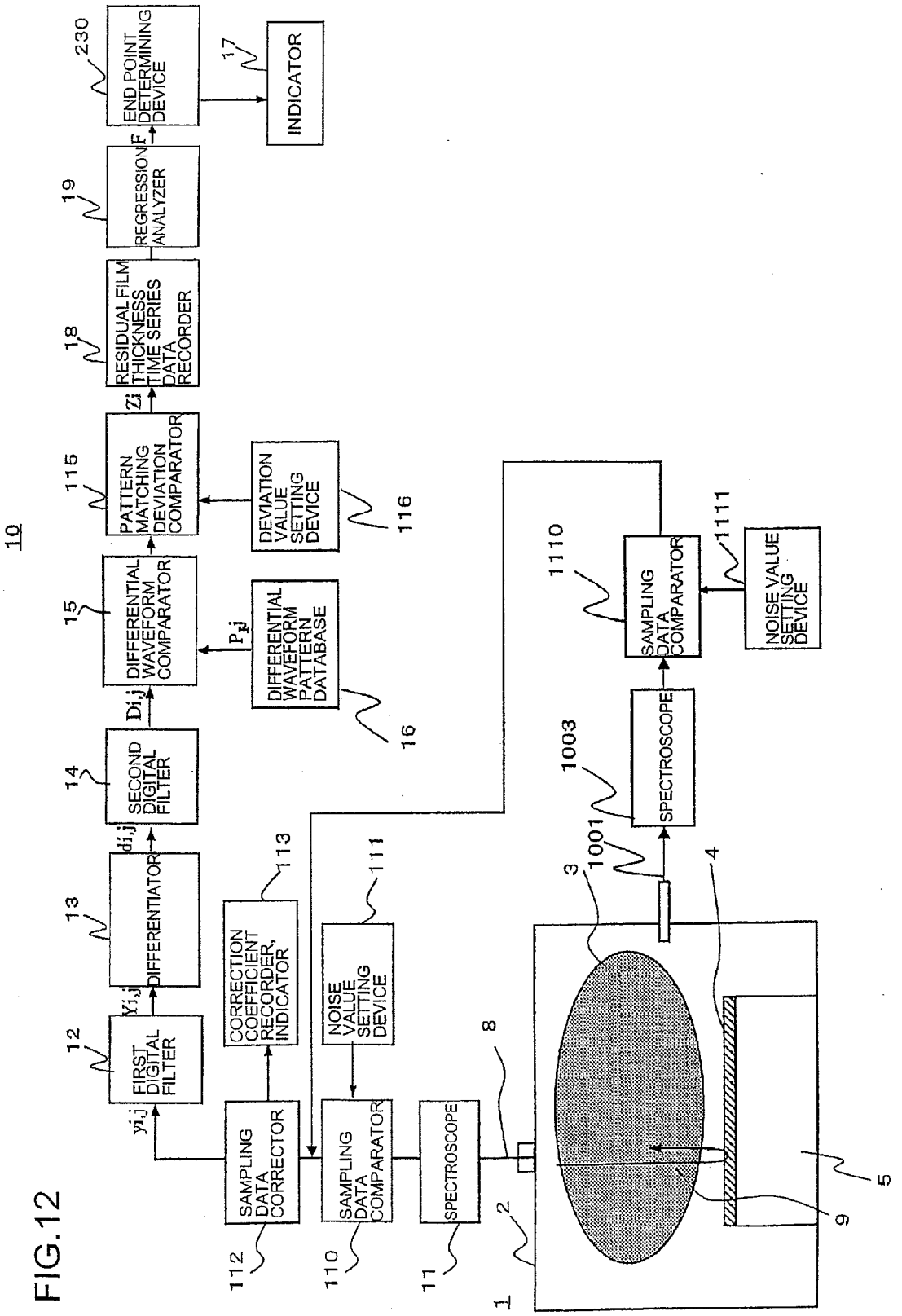

10
1
2
3
4
5
8
9
11
110
111
112
113
12
13
14
15
16
17
18
19
115
116
230
1001
1003
1110
1111
SPECTROSCOPE
SAMPLING DATA COMPARATOR
SAMPLING DATA CORRECTOR
NOISE VALUE SETTING DEVICE
CORRECTION COEFFICIENT RECORDER, INDICATOR
FIRST DIGITAL FILTER
DIFFERENTIATOR
SECOND DIGITAL FILTER
DIFFERENTIAL WAVEFORM COMPARATOR
DIFFERENTIAL WAVEFORM PATTERN DATABASE
DEVIATION VALUE SETTING DEVICE
PATTERN MATCHING DEVIATION COMPARATOR
RESIDUAL FILM THICKNESS TIME SERIES DATA RECORDER
REGRESSION ANALYZER
END POINT DETERMINING DEVICE
INDICATOR
SAMPLING DATA COMPARATOR
NOISE VALUE SETTING DEVICE
yi,j
Yi,j
di,j
Di,j
Pij
Zi
F

FIG.13

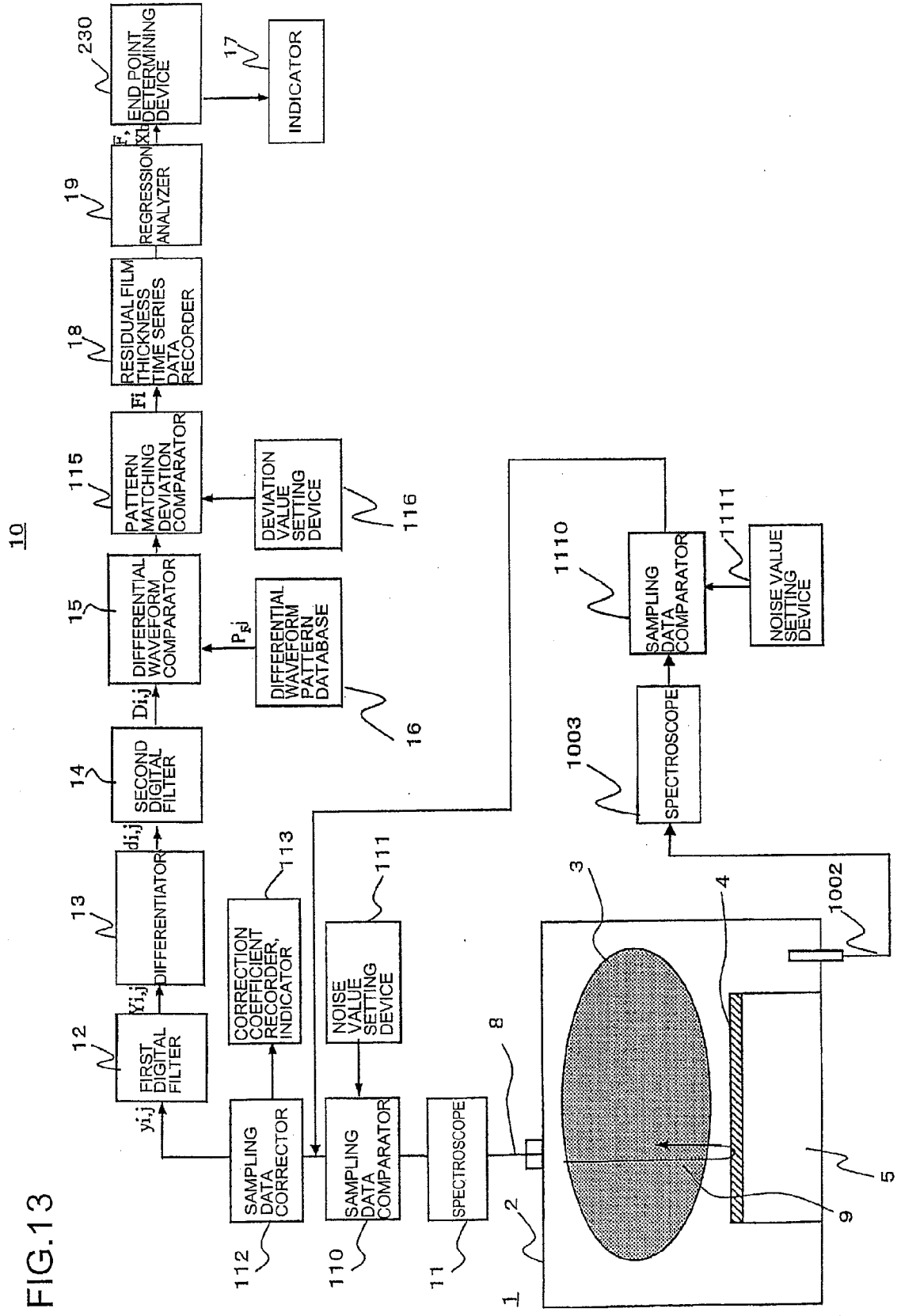

10
1
2
3
4
5
8
9
11
SPECTROSCOPE
110
SAMPLING DATA COMPARATOR
111
NOISE VALUE SETTING DEVICE
112
SAMPLING DATA CORRECTOR
113
CORRECTION COEFFICIENT RECORDER, INDICATOR
12
FIRST DIGITAL FILTER
13
DIFFERENTIATOR
14
SECOND DIGITAL FILTER
15
DIFFERENTIAL WAVEFORM COMPARATOR
16
DIFFERENTIAL WAVEFORM PATTERN DATABASE
115
PATTERN MATCHING DEVIATION COMPARATOR
116
DEVIATION VALUE SETTING DEVICE
18
RESIDUAL FILM THICKNESS TIME SERIES DATA RECORDER
19
REGRESSION ANALYZER
230
END POINT DETERMINING DEVICE
17
INDICATOR
1002
1003
SPECTROSCOPE
1110
SAMPLING DATA COMPARATOR
1111
NOISE VALUE SETTING DEVICE

FIG.14

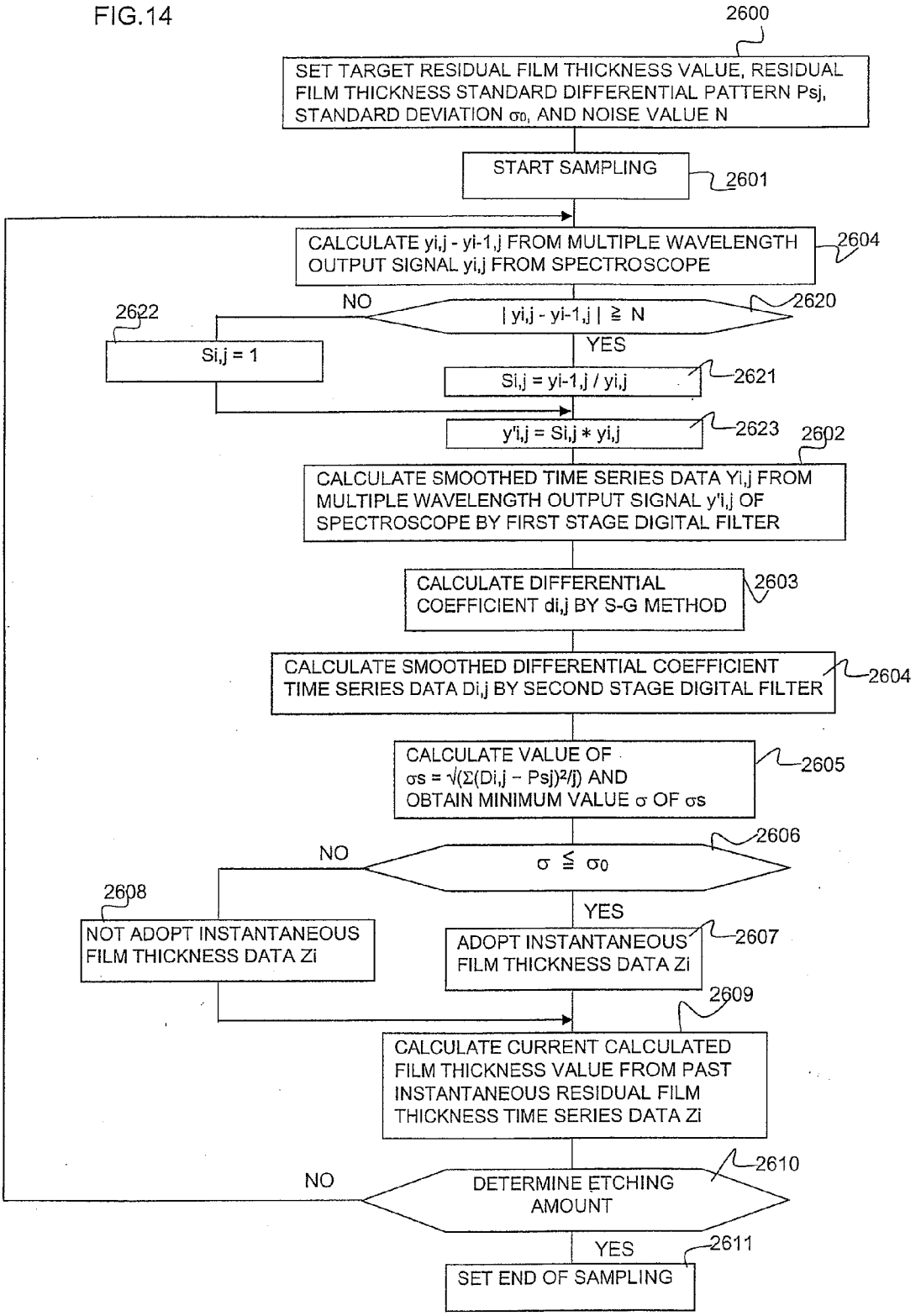

2600
SET TARGET RESIDUAL FILM THICKNESS VALUE, RESIDUAL FILM THICKNESS STANDARD DIFFERENTIAL PATTERN Psj, STANDARD DEVIATION σ0, AND NOISE VALUE N
START SAMPLING
2601
CALCULATE yi,j - yi-1,j FROM MULTIPLE WAVELENGTH OUTPUT SIGNAL yi,j FROM SPECTROSCOPE
2604
NO
| yi,j - yi-1,j | ≧ N
2620
2622
Si,j = 1
YES
Si,j = yi-1,j / yi,j
2621
y'i,j = Si,j * yi,j
2623
2602
CALCULATE SMOOTHED TIME SERIES DATA Yi,j FROM MULTIPLE WAVELENGTH OUTPUT SIGNAL y'i,j OF SPECTROSCOPE BY FIRST STAGE DIGITAL FILTER
CALCULATE DIFFERENTIAL COEFFICIENT di,j BY S-G METHOD
2603
CALCULATE SMOOTHED DIFFERENTIAL COEFFICIENT TIME SERIES DATA Di,j BY SECOND STAGE DIGITAL FILTER
2604
CALCULATE VALUE OF σs = √(Σ(Di,j − Psj)²/j) AND OBTAIN MINIMUM VALUE σ OF σs
2605
2606
NO
σ ≦ σ0
2608
YES
NOT ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
2607
2609
CALCULATE CURRENT CALCULATED FILM THICKNESS VALUE FROM PAST INSTANTANEOUS RESIDUAL FILM THICKNESS TIME SERIES DATA Zi
2610
NO
DETERMINE ETCHING AMOUNT
YES
2611
SET END OF SAMPLING

FIG. 15

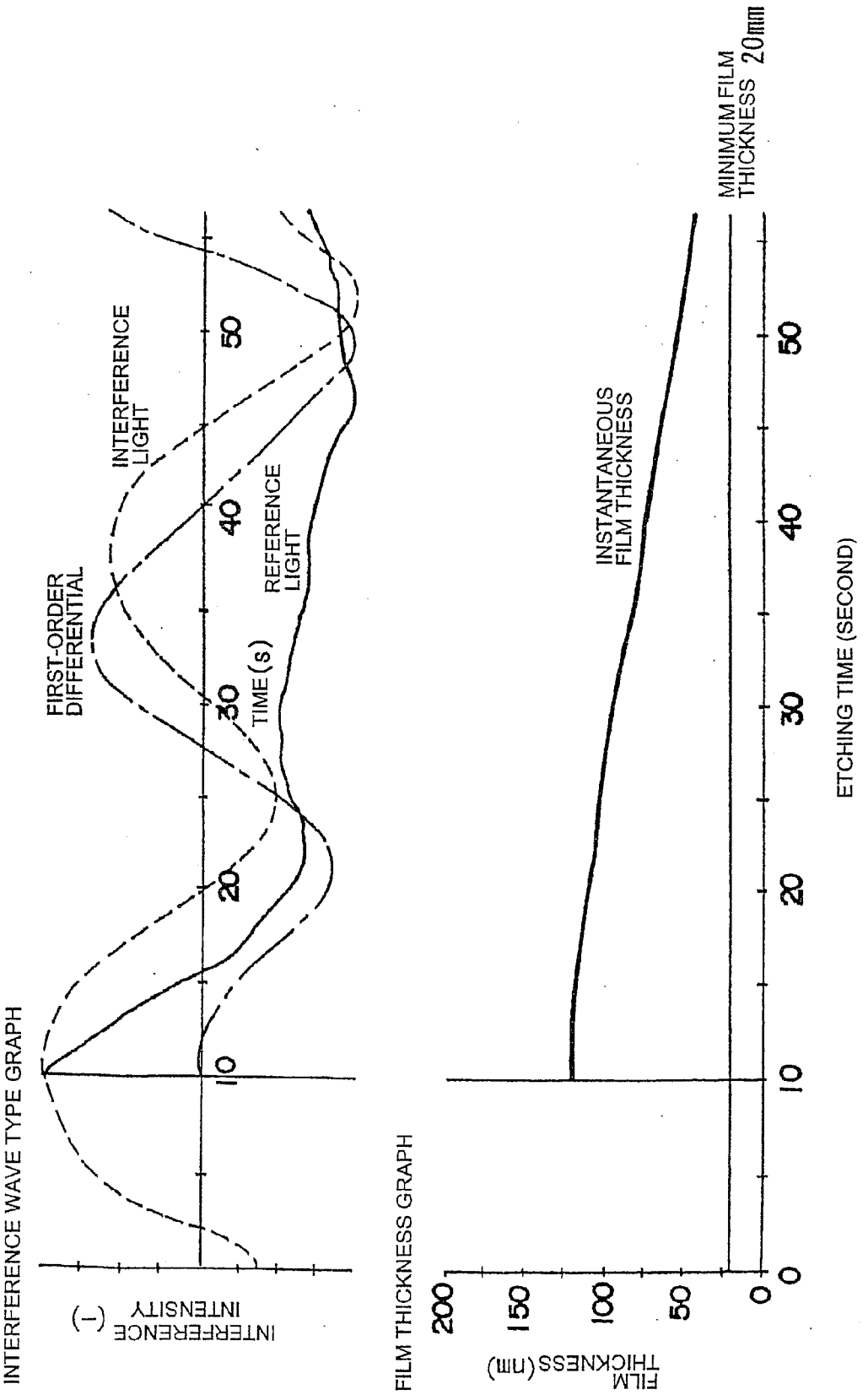

INTERFERENCE WAVE TYPE GRAPH
INTERFERENCE INTENSITY (-)
FIRST-ORDER DIFFERENTIAL
INTERFERENCE LIGHT
REFERENCE LIGHT
TIME (s)
10
20
30
40
50
FILM THICKNESS GRAPH
FILM THICKNESS (nm)
200
150
100
50
0
INSTANTANEOUS FILM THICKNESS
MINIMUM FILM THICKNESS 20nm
10
20
30
40
50
ETCHING TIME (SECOND)

FIG.16

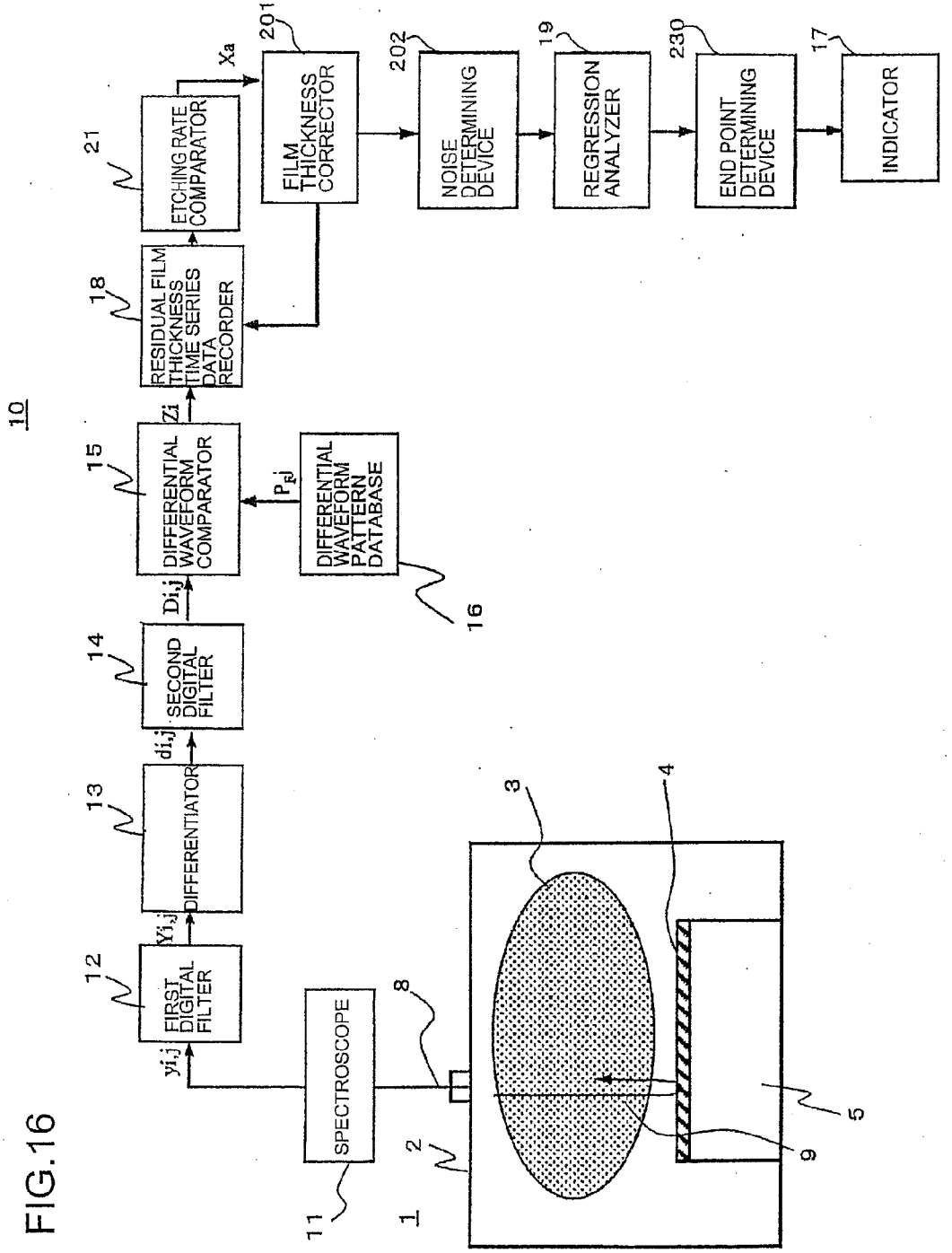

10
1
2
3
4
5
8
9
11
SPECTROSCOPE
12
FIRST DIGITAL FILTER
13
DIFFERENTIATOR
14
SECOND DIGITAL FILTER
15
DIFFERENTIAL WAVEFORM COMPARATOR
16
DIFFERENTIAL WAVEFORM PATTERN DATABASE
18
RESIDUAL FILM THICKNESS TIME SERIES DATA RECORDER
21
ETCHING RATE COMPARATOR
201
FILM THICKNESS CORRECTOR
202
NOISE DETERMINING DEVICE
19
REGRESSION ANALYZER
230
END POINT DETERMINING DEVICE
17
INDICATOR
yi,j
Yi,j
di,j
Di,j
Zi
Pεj
Xa

FIG.17

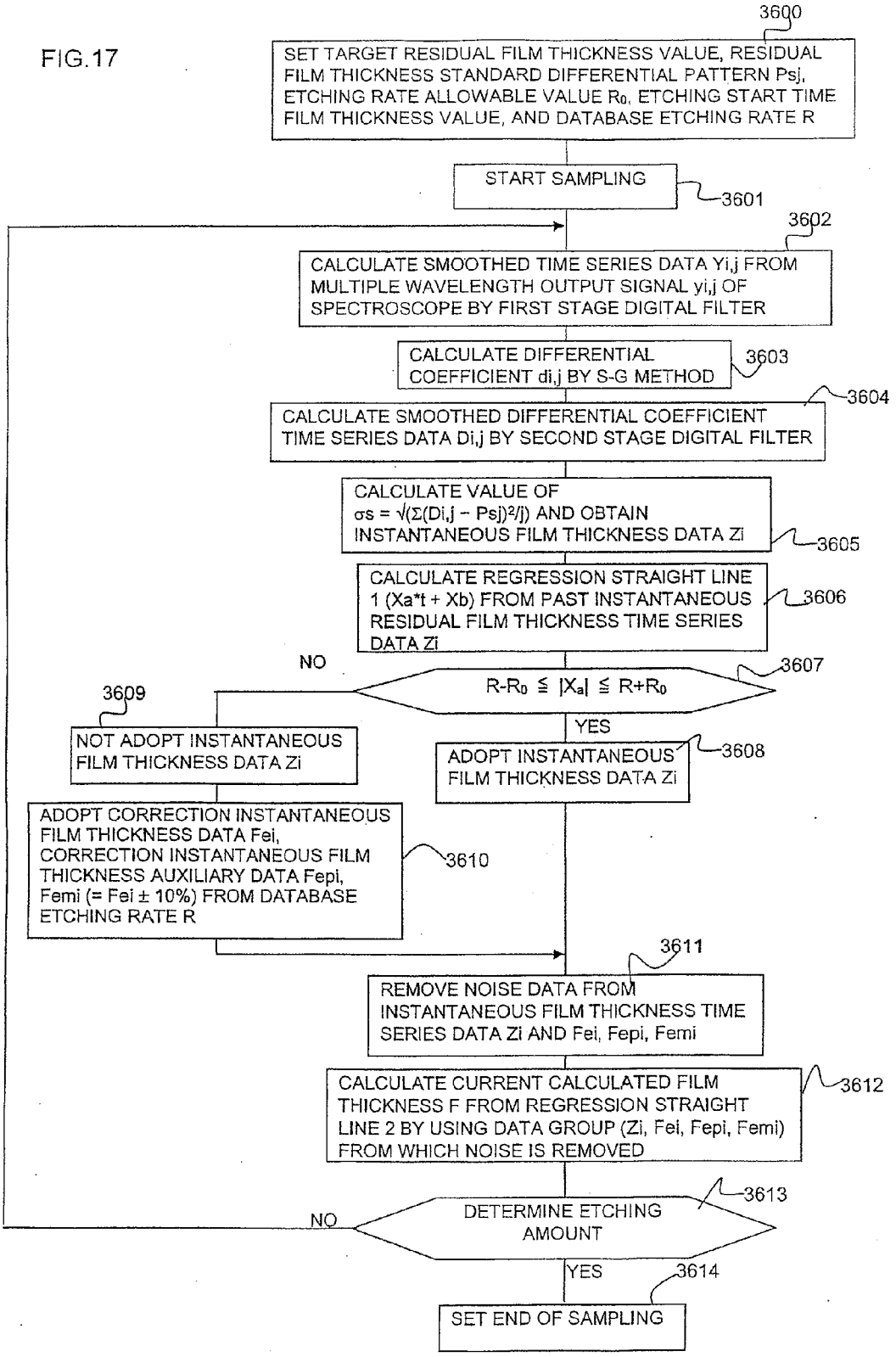
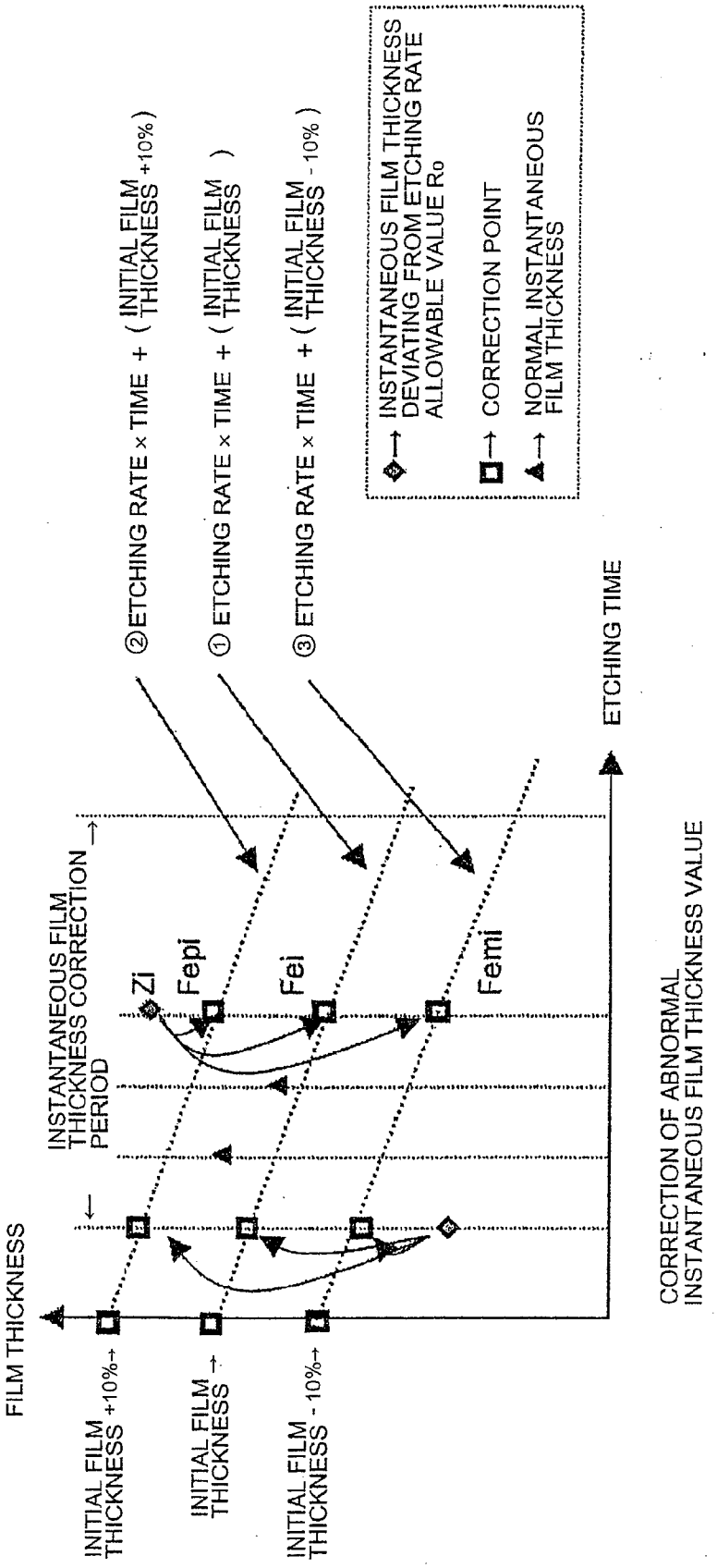

3600
SET TARGET RESIDUAL FILM THICKNESS VALUE, RESIDUAL FILM THICKNESS STANDARD DIFFERENTIAL PATTERN Psj, ETCHING RATE ALLOWABLE VALUE R0, ETCHING START TIME FILM THICKNESS VALUE, AND DATABASE ETCHING RATE R
START SAMPLING
3601
3602
CALCULATE SMOOTHED TIME SERIES DATA Yi,j FROM MULTIPLE WAVELENGTH OUTPUT SIGNAL yi,j OF SPECTROSCOPE BY FIRST STAGE DIGITAL FILTER
CALCULATE DIFFERENTIAL COEFFICIENT di,j BY S-G METHOD
3603
3604
CALCULATE SMOOTHED DIFFERENTIAL COEFFICIENT TIME SERIES DATA Di,j BY SECOND STAGE DIGITAL FILTER
CALCULATE VALUE OF σs = √(Σ(Di,j − Psj)²/j) AND OBTAIN INSTANTANEOUS FILM THICKNESS DATA Zi
3605
CALCULATE REGRESSION STRAIGHT LINE 1 (Xa*t + Xb) FROM PAST INSTANTANEOUS RESIDUAL FILM THICKNESS TIME SERIES DATA Zi
3606
NO
R-R0 ≦ |Xa| ≦ R+R0
3607
3609
YES
NOT ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
ADOPT INSTANTANEOUS FILM THICKNESS DATA Zi
3608
ADOPT CORRECTION INSTANTANEOUS FILM THICKNESS DATA Fei, CORRECTION INSTANTANEOUS FILM THICKNESS AUXILIARY DATA Fepi, Femi (= Fei ± 10%) FROM DATABASE ETCHING RATE R
3610
3611
REMOVE NOISE DATA FROM INSTANTANEOUS FILM THICKNESS TIME SERIES DATA Zi AND Fei, Fepi, Femi
CALCULATE CURRENT CALCULATED FILM THICKNESS F FROM REGRESSION STRAIGHT LINE 2 BY USING DATA GROUP (Zi, Fei, Fepi, Femi) FROM WHICH NOISE IS REMOVED
3612
3613
NO
DETERMINE ETCHING AMOUNT
YES
3614
SET END OF SAMPLING

FIG.18


FILM THICKNESS
INITIAL FILM THICKNESS +10%
INITIAL FILM THICKNESS
INITIAL FILM THICKness - 10%
INSTANTANEOUS FILM THICKNESS CORRECTION PERIOD
Zi
Fepi
Fei
Femi
② ETCHING RATE × TIME + (INITIAL FILM THICKNESS +10%)
① ETCHING RATE × TIME + (INITIAL FILM THICKNESS)
③ ETCHING RATE × TIME + (INITIAL FILM THICKNESS - 10%)
INSTANTANEOUS FILM THICKNESS DEVIATING FROM ETCHING RATE ALLOWABLE VALUE Ro
CORRECTION POINT
NORMAL INSTANTANEOUS FILM THICKNESS
ETCHING TIME
CORRECTION OF ABNORMAL INSTANTANEOUS FILM THICKNESS VALUE

PLASMA PROCESSING APPARATUS

[0001] The present application is based on and claims priority of Japanese patent application No. 2007-057426 filed on Mar. 7, 2007, the entire contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a film thickness and etching depth measuring method for detecting an etching amount of a material to be processed by an emission spectroscopy method in the manufacture of a semiconductor integrated circuit or the like, and to a processing method of the material to be processed by using the measuring method. More particularly, the present invention relates to a measuring method and device of a depth and a film thickness of a material to be processed, suitable for accurately measuring etching amounts of respective layers provided on a substrate in an etching processing using plasma discharge, and for obtaining a desired film thickness and an etching depth of the layers, and relates to a processing method and device of the material to be processed, using the measuring method.

[0004] 2. Description of the Related Art

[0005] In the manufacture of a semiconductor wafer, dry etching is widely used for removing a layer of various materials formed on the surface of a wafer, and particularly for removing a layer of a dielectric material or forming a pattern of the dielectric material. For the control of process parameters, it is most important to accurately determine an etching end point to stop the etching at a desired film thickness and etching depth during the processing of the layers.

[0006] During the dry etching processing of the semiconductor wafer, the emission intensity of a specific wavelength in plasma light is changed in accordance with the progress of etching of a specific film. Thus, conventionally, as one of the methods for detecting the etching end point of the semiconductor wafer, there is a method for detecting the change in the emission intensity of the specific wavelength from plasma during the dry etching processing, and detecting the etching end point of the specific film on the basis of the detection result. In this case, it is necessary to prevent an erroneous detection based on fluctuation of a detected waveform due to a noise. As a method for accurately detecting the change in the emission intensity, there are known a detecting method based on a moving average method (see, for example, Japanese Patent Laid-Open Publication No. 61-53728 (Patent Document 1)), a method for reducing a noise by an approximate processing based on a primary least-squares method (see, for example, Japanese Patent Laid-Open Publication No. 63-200533 (Patent Document 2)), and the like.

[0007] In accordance with the miniaturization and high integration of a semiconductor in recent years, an opening ratio (area to be etched in a semiconductor wafer) is reduced, whereby the emission intensity of the specific wavelength taken into a photodetector from a photosensor is made weak. As a result, the level of a sampling signal from the photodetector is lowered to make it difficult for an end point determining device to surely detect the etching end point on the basis of the sampling signal from the photodetector.

[0008] Further, in the case of detecting the etching end point and stopping the etching processing, it is actually important that the remaining thickness of the dielectric layer is equal to a predetermined value. In the conventional process, the whole process is monitored by using a time and thickness control technique based on a premise that the etching rate of each layer is constant. The values of the etching rate are obtained by, for example, processing a sample wafer in advance. In this method, the etching process is stopped once time period corresponding to a predetermined etching film thickness has lapsed, on the basis of a time monitoring method.

[0009] However, it is known that an actual film, for example, an SiO2 layer formed by a LPCVD (low pressure chemical vapor deposition) technique has a low reproducibility of thickness. The allowable thickness error due to the process fluctuation during the LPCVD processing corresponds to about 10% of the initial thickness of the SiO2 layer. Therefore, the actual final thickness of the SiO2 layer remaining on a silicon substrate cannot be accurately measured by the method based on the time monitoring. Thus, the actual thickness of the remaining layer is finally measured by a technique using a standard spectroscopic interferometer. When it is found that the layer is excessively etched, the wafer is judged as unacceptable and discarded.

[0010] Further, in an insulating film etching device, there are known time-based changes such as a decrease in the etching rate in accordance with repetition of etching. This may result in a case where the etching is stopped in the midway, and hence is a problem which must be solved. In addition, for the stable process operation, it is important to monitor the time-based fluctuation of the etching rate. In the conventional method, however, only the time for determining the etching end point is monitored, and any suitable method is not used to cope with the time-based change and fluctuation of the etching rate. Further, for determining the etching end point in the case where the etching time is as short as about ten seconds, it is necessary to adapt the end point determining method to shorten the determination preparation time period, and also to sufficiently shorten the interval of determination time. However, these measures are not always enough. Further, in an insulating film, the area to be etched is 1% or less in many cases, and the change in the plasma emission intensity from a reaction product generated in accordance with the etching is small. Therefore, an end point determining system capable of detecting even a slight change is necessary, but there is no such system that is practical and inexpensive.

[0011] On the other hand, there is also known various methods using an interferometer as the other methods for detecting the etching end point of the semiconductor wafer. That is, a first method is a method in which the etching end point detection is performed by detecting interference light (plasma light) by the use of three kinds of color filters of red, green and blue (see, for example, Japanese Patent Laid-Open Publication No. 5-179467 (Patent Document 3)). A second method is a method in which extreme values of an interference waveform (maximum and minimum values: zero-crossing points of a differential waveform) are counted by using the time change of an interference waveform of two wavelengths and the differential waveform of the interference waveform, and in which an etching rate is calculated by measuring the time until the counted value reaches a predetermined value, and the remaining etching time until reaching a predetermined film thickness is obtained on the basis of the calculated etching rate, to stop the etching processing on the basis of the remaining etching time (see, for example, Japanese Patent Laid-Open Publication No. 8-274082 (U.S. Pat. No. 5,658,418

Specification) (Patent Document 4)). A third method is a method in which a waveform (with the wavelength taken as a parameter) of difference between a light intensity pattern (with the wavelength taken as a parameter) of interference light before processing and a light intensity pattern after the processing or during the processing is obtained, and in which a level difference (film thickness) is measured by the comparison between the obtained difference waveform and difference waveforms stored in a database (see, for example, Japanese Patent Laid-Open Publication No. 2000-97648 (Patent Document 5)). A fourth method is a method which relates to a rotary coating device, and in which a film thickness is obtained by measuring the time change in interference light over multiple wavelengths (see, for example, Japanese Patent Laid-Open Publication No. 2000-106356 (Patent Document 6)). A fifth method is a method in which a characteristic behavior of the time change of interference light is obtained by measurement and stored in a database, and the etching end determination is performed by the comparison between the database and a measured interference waveform, and prompts to change etching process conditions on the basis of the determination (see, for example, U.S. Pat. No. 6,081,334 Specification (Patent Document 7)).

[0012] In the method using the interferometer, monochromatic radiation emitted from a laser is made incident on a wafer including a laminated structure of different kinds of materials, at the vertical incident angle. For example, in a wafer in which an SiO2 layer is laminated on a Si3N4 layer, an interference fringe is formed by the emitted light reflected by the upper surface of the SiO2 layer, and the emitted light reflected by the interface formed between the SiO2 layer and the Si3N4 layer. The reflected emitted light is irradiated on a suitable detector, to generate a signal whose intensity is changed with the thickness of the SiO2 layer during the etching process. As soon as the upper surface of the SiO2 layer is exposed during the etching process, the etching rate and the current etching thickness can be continuously and accurately monitored. There is also known a method for measuring a predetermined emitted light emitted from plasma instead of the laser by a spectrometer.

[0013] The above described known techniques cause the following problems.

[0014] A. In the case of film thickness determination in a thick film processing process (resist etch-back with film thickness of several μm and the like), the interference light changes with time in a complicated manner for several tens periods or more, which causes the film thickness determination to be influenced by a slight disturbance.

[0015] B. In the case of film thickness determination in a thin film processing process (etch-back of a gate oxide film, an oxide film or the like), a weak change in interference light needs to be measured, which causes the film thickness determination to be influenced by a slight disturbance. That is, the time change in the interference light during the thin film processing is not more than ½ to ¼ periods, and the interference fringe is slightly changed, so that it is necessary to eliminate the effect of a noise in the film thickness determination.

[0016] C. In a wafer for processing in the mass production process, peripheral circuits or the like are mixedly provided, and various kinds of materials (a mask material, a material to be etched, the other materials in the peripheral circuits) are simultaneously subjected to etching processing, and hence interference lights from different materials are superimposed with each other in a complicated manner. In addition, there is a variation in the film thickness of various materials of the wafer for processing in a lot or between the lots, and hence the time change of the interference light during etching processing is changed in a lot or between the lots.

[0017] D. In the mass production processing of small amount and many kinds, since various etching processes are mixedly performed, the etching device is liable to change with time, so that an abnormal discharge or the like is caused to make the plasma fluctuate. Thereby, plasma light emission is changed and a disturbance is superimposed on the interference light, to influence the determination.

[0018] For the above described reasons, it has been difficult to accurately measure and control, in a required precision, a residual amount of film and an etching depth of a processed layer, and especially of a processed layer in the plasma etching processing.

[0019] An object of the present invention is to provide an etching end point determining method using a measuring method of a film thickness or an etching depth of a material to be processed, which is capable of accurately measuring online an actual residual amount of film and an etching depth of a layer to be processed in a plasma etching process in a semiconductor element manufacturing process, and to provide a plasma processing apparatus adapted to perform the etching end point determining method, a plasma processing method of a material to be processed, using the plasma processing apparatus, and a plasma processing apparatus using the plasma processing method.

[0020] Further object of the present invention is to provide an etching processing method which is capable of performing highly precise online control to make each layer of a semiconductor element processed into a predetermined film thickness and etching depth in a semiconductor element manufacturing process.

[0021] Further object of the present invention is to provide a measuring device of a film thickness and an etching depth of a material to be processed, which is capable of accurately measuring online an actual film thickness and etching depth of a material to be processed in a semiconductor element manufacturing process.

SUMMARY OF THE INVENTION

[0022] In order to solve the above described problems of the prior art, and to attain the above described objects of the present invention, the present inventors have obtained a time differential waveform of interference waveform for each of a plurality of wave lengths, and obtained a pattern showing a wavelength dependence of a differential value of the interference waveform (that is, a pattern of the differential value of the interference waveform, with the wavelength taken as a parameter), thereby effecting following malfunction operation prevention measures at the time of measuring a film thickness by using the pattern.

[0023] 1) In a standard pattern database of an interference waveform corresponding to an etching amount (film thickness and depth) of a material to be etched, a comparison with a standard pattern whose etching amount is not more than a target etching amount, is not performed.

[0024] 2) In the pattern matching between an interference waveform pattern measured at the time of etching and the standard pattern, a standard deviation value is monitored, and

when the standard deviation value is large, the etching amount at the time point is estimated on the basis of the past etching amount transition.

[0025] 3) When the etching amount obtained from the pattern matching with the standard pattern is greatly different from the amount estimated from the past etching amount transition, the etching amount at the time point is estimated on the basis of the past etching amount transition.

[0026] 4) When the etching rate obtained from the past etching amount transition is compared with the etching rate of the standard pattern database and the obtained etching rate is greatly different from the standard pattern, the etching amount at the time point is estimated on the basis of the past etching amount transition.

[0027] 5) When the etching rate obtained from the past etching amount transition is compared with the etching rate of the standard pattern database and the obtained etching rate is greatly different from the standard pattern, the etching amount which can be obtained by the pattern matching with the standard pattern is replaced by the etching amount which can be obtained from the etching rate of the standard pattern at the time point, and the etching amount at the time point is estimated on the basis of the replaced etching amount and the past etching amount transition.

[0028] The reason for using the pattern showing the wavelength dependence of a time differential value of an interference waveform in the present invention is that the measurement is based on the in-situ (real time) measurement during etching, and hence the film thickness of a processed film is changed every moment. Therefore, it is possible to perform time differential processing of the interference waveform, in order to reduce the influences of contamination and scraping of a measuring window which cause a problem in the interference light intensity measurement, but the time differential processing of the interference waveform need not always be performed.

[0029] Further, when plasma light emission is abruptly changed by abnormal discharge associated with the time-based change of a device, or the like, the etching amount measurement based on the interference light and the etching end point determination based on plasma light emission are performed in such a manner that a change quantity (ratio: correction coefficient) of the light emission is obtained by comparing a current light emission waveform with past light emission waveforms, and a current and future light emission waveforms are corrected on the basis of the correction coefficient.

[0030] In order to solve the above described problems of the prior art and further to achieve the above described objects of the present invention, the present inventors have devised a method wherein a waveform is obtained by arranging in time series time differentials of interference waveforms for each of a plurality of wavelengths of a reflection wave from a sample (semiconductor element) during plasma processing, wherein on the basis of the obtained waveform, a pattern showing a wavelength dependence of a differential value of the interference waveform, that is, a pattern in which the differential values of the interference waveforms, with the wavelength taken as a parameter, are arranged in time series, is obtained, and wherein a film thickness measurement is performed by using a pattern which is obtained by arranging in time series differential values of changes in the intensity of interference light of a plurality of wavelengths relating to the processing of another sample, and obtained before the processing of the sample currently processed, and which is formed by a plurality of standard differential waveforms respectively corresponding to a plurality of thicknesses of the film to be processed of the sample.

[0031] The reasons for using the pattern showing the wavelength dependence of a time differential value of an interference waveform in the present invention are as follows.

[0032] A. In the present invention, since the measurement is based on the in-situ (real time) measurement during etching, a residual film thickness of a processed film which is changed every moment, can be subjected to a time differential processing by using an interference waveform, and further a noise of the interference waveform can be removed by the differential processing.

[0033] B. Due to the fact that refractive indices of materials to be etched (for example, silicon and a nitride film of a mask material) are different from each other with respect to the wavelength, a characteristic change (film thickness dependence) of the each material can be measured by the interference light measurement over multiple wavelengths.

[0034] According to an aspect of the present invention, a residual film thickness measuring method and an etching depth measuring method which are an etching amount measuring method of a material to be processed, includes:

[0035] A. a step of setting, with the wavelength taken as a parameter, a standard differential pattern PS of a differential value of interference light with respect to a predetermined etching amount of a first (sample) material to be processed;

[0036] B. a step of setting, with the wavelength taken as a parameter, a standard differential pattern PM of a differential value of interference light with respect to a predetermined etching amount of a mask material which prevents the first material to be processed from being scraped;

[0037] C. a step of measuring, respectively for a plurality of wavelengths, the interference light intensity of a second material to be processed, which has the same constitution as that of the first material to be processed and is to be actually subjected to etching processing, and of obtaining an actual differential pattern (Pr) of a differential value of the measured interference light intensity, with the wavelength taken as a parameter; and

[0038] D. a step of obtaining an etching amount of the second material to be processed on the basis of the standard differential patterns (PS and PM) and the actual differential pattern (Pr) of the differential value.

[0039] According to the present invention, in the plasma processing, especially in the plasma etching processing, it is possible to provide a measuring method of a residual film thickness or an etching depth of a material to be processed, which is capable of accurately measuring online an actual etching amount of the material to be processed, and to provide a processing method of a sample of the material to be processed by using the measuring method.

[0040] Further, it is possible to provide an etching process capable of performing highly precise online control to make each layer of a semiconductor element (semiconductor device) processed to a predetermined etching amount. Further, it is possible to provide a measuring device of a residual thickness or a measuring device of an etching-depth of a

material to be processed, which is capable of accurately measuring online an actual etching amount of a layer to be processed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041] FIG. **1** is a block diagram showing a whole constitution of an etching device of a semiconductor wafer, provided with an etching amount measuring device according to a first embodiment of the present invention;

[0042] FIG. **2** is a flow chart showing a procedure for obtaining a residual film thickness of a material to be processed, when an etching processing is performed by using the etching amount measuring device shown in FIG. **1**;

[0043] FIG. **3** is a figure showing time changes in interference light and reference light, and a result of film thickness transition during a normal etching processing according to the first embodiment of the present invention;

[0044] FIG. **4** is a figure showing changes in interference light and reference light, and a result of film thickness transition, when there is discharge fluctuation in the first embodiment of the present invention;

[0045] FIG. **5** is a figure showing time changes in interference light and reference light, and a result of film thickness transition, when a minimum film thickness setting processing according to the first embodiment of the present invention is performed;

[0046] FIG. **6** is a figure showing time changes in interference light and reference light, and a result of film thickness transition when a pattern matching deviation processing according to a second embodiment of the present invention is performed;

[0047] FIG. **7** is a figure showing time changes in interference light and reference light, and a result of film thickness transition when an allowable film thickness range processing according to a third embodiment of the present invention is performed;

[0048] FIG. **8** is a block diagram showing a whole constitution of an etching device of a semiconductor wafer, provided with an etching amount measuring device which performs a film thickness comparison and an etching rate comparison, according to a fourth embodiment of the present invention;

[0049] FIG. **9** is a flow chart showing a procedure for obtaining a residual film thickness of a material to be processed, when an etching processing is performed by using the etching amount measuring device shown in FIG. **8**;

[0050] FIG. **10** is a figure showing time changes in interference light and reference light, and a result of film thickness transition when an etching rate allowable range processing according to a fourth embodiment of the present invention is performed;

[0051] FIG. **11** is a block diagram showing a whole constitution of an etching device of a semiconductor wafer, provided with an etching amount measuring device according to a fifth embodiment of the present invention;

[0052] FIG. **12** is a block diagram showing a whole constitution of an etching device of a semiconductor wafer, provided with a reference light measuring device according to a modification of the fifth embodiment of the present invention;

[0053] FIG. **13** is a block diagram showing a whole constitution of an etching device of a semiconductor wafer, provided with the reference light measuring device according to the modification of the fifth embodiment of the present invention;

[0054] FIG. **14** is a flow chart showing a procedure for obtaining a residual film thickness of a material to be processed, when an etching processing is performed by using the etching amount measuring device shown in FIG. **11**;

[0055] FIG. **15** is a figure showing time changes in interference light and reference light, and a result of film thickness transition in the fifth embodiment of the present invention;

[0056] FIG. **16** is a block diagram showing a whole constitution of a semiconductor wafer etching device provided with an etching amount measuring device according to a sixth embodiment of the present invention;

[0057] FIG. **17** is a flow chart showing a procedure for obtaining a residual film thickness of a material to be processed, when an etching processing is performed by using the etching amount measuring device shown in FIG. **16**; and

[0058] FIG. **18** is a figure showing a concept for performing an instantaneous film thickness correction according to the sixth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0059] In the following, respective embodiments according to the present invention will be described. Note that in the following respective embodiments, an element having the same function as that in the first embodiment is denoted by the same reference numeral as that in the first embodiment, and the detailed explanation thereof is omitted.

Embodiment 1

[0060] In the following, a first embodiment according to the present invention will be described with reference to FIG. **1** to FIG. **5**. The first embodiment is adapted, when subjecting a material to be processed, such as a semiconductor wafer, to a plasma etching processing, to set a standard differential pattern PS showing a wavelength dependence (with the wavelength taken as a parameter) of a differential value of interference light with respect to an etching amount of each layer of the sample material to be processed (first material to be processed), then to respectively measure the intensity of interference light of a plurality of wavelengths at arbitrary time from the start of the plasma etching processing in an actual processing of a material to be processed (second material to be processed) having the same constitution as that of the sample material, to obtain an actual differential pattern (Pr) (with the wavelength taken as a parameter) showing a wavelength dependence of differential values of the measured interference light intensity, and to obtain an etching amount of the material to be processed by comparing the standard differential pattern (Ps) with the actual differential pattern (Pr) of the differential values.

[0061] First, with reference to FIG. **1**, there is explained a whole constitution of a plasma processing apparatus which is provided with a measuring device of an etching amount (a residual film thickness of a mask material or an etching depth of silicon) according to the present invention, and which is an etching device of a semiconductor wafer for forming a semiconductor element. An etching device (plasma processing apparatus) **1** is provided with a vacuum container **2**. An etching gas is introduced into the inside of the vacuum container **2** from gas introducing means (not shown) and is decomposed by microwave power or the like into a state of plasma **3**, so that a material to be processed **4** such as a semiconductor wafer on a sample stage **5**, are etched by the plasma **3**. An emitted light

of multiple wavelengths from a measuring light source (for example, halogen light source) provided in a spectroscope **11** of an etching amount measuring device **10** (a residual film thickness of a mask material or an etching depth of silicon) is introduced into the vacuum container **2** by an optical fibre **8** and made incident at the vertical incident angle onto the material to be processed **4**. An interference light from the material to be processed **4** is introduced to the spectroscope **11** of the etching amount measuring device **10** via the optical fibre **8**. On the basis of the state of the interference light, measurements of an etching depth of silicon or a residual thickness of a mask material, and a processing for determining an end point of etching processing are performed.

[0062] The etching amount measuring device **10** includes a spectroscope **11**, a first digital filter circuit **12**, a differentiator **13**, a second digital filter circuit **14**, a differential waveform comparator **15**, a differential waveform pattern database **16**, a pattern matching deviation comparator **115**, a deviation value setting device **116**, a residual film thickness time series data recorder **18**, a regression analyzer **19**, an end point determining device **230**, and an indicator **17** which displays a result from the end point determining device. Note that FIG. **1** shows a functional constitution of the etching amount measuring device **10**, an actual constitution of the etching amount measuring device **10** excluding the indicator **17** and the spectroscope **11**, can be constituted by a CPU, storage devices constituted by a ROM for storing a mask material residual film thickness measuring processing program or a silicon etching depth measuring processing program, and various data such as a differential waveform pattern database of interference light, a RAM for storing measurement data and an external storage device and the like, a data input/output device, and a communication control device.

[0063] In the spectroscope **11**, an emitted light of multiple wavelengths from a measuring light source (for example, halogen light source) is introduced into the inside of the vacuum container **2** by the optical fibre **8**, and made incident at the vertical incident angle onto the material to be processed **4**. An interference light from the material to be processed **4** is introduced into the spectroscope **11** of the etching amount measuring device **10** via the optical fibre **8**, and on the basis of the state of the interference light, an etching depth measurement of silicon or a residual film thickness measurement of a mask material, and an end point determination processing of etching processing are performed.

[0064] The emission intensity of the interference light of multiple wavelengths received by the spectroscope **11** are made into current detecting signals, each of which corresponds to emission intensity for each specific wavelength, and converted to voltage signals. The signals of a plurality of specific wavelengths (j denotes the number of wavelength) outputted as sampling signals by the spectroscope **11** are stored as time series data yi,j in a storage device such as a RAM (not shown). Next, the time series data yi,j at time i is subjected to a smoothing processing by the first digital filter circuit **12**, and stored as smoothed time series data Yi,j in a storage device such as a RAM (not shown). On the basis of the smoothed time series data Yi,j, time series data di,j of differential coefficient values (first-order differential values or second-order differential values) is calculated by the differentiator **13**, and stored in a storage device such as a RAM (not shown). The time series data di,j of the differential coefficient values is subjected to a smoothing processing by the second digital filter circuit **14**, and stored as smoothed differential coefficient time series data Di,j in a storage device such as a RAM (not shown). Then, an actual differential pattern (Prj) $=\Sigma j$ (Di,j) (wavelength j taken as a parameter) which shows the wavelength dependence of the differential value of the interference light intensity can be obtained from the smoothed differential coefficient time series data Di,j.

[0065] On the other hand, in the differential waveform pattern database **16**, there are set differential waveform pattern data values PSj of the interference light intensity with respect to the each wavelength corresponding to an etching depth which is obtained beforehand by using the first (sample) material to be processed, and expressed by a residual film thickness s of the material to be processed, so as to serve as a target of the etching amount measurement. In the differential waveform comparator **15**, the actual differential pattern (Prj) $=\Sigma$(Di,j) and the differential waveform pattern data value PSj of the film thickness s are compared with each other. In the pattern matching deviation comparator **115**, a pattern matching (minimum) deviation value σs at which a pattern matching deviation ($\sigma s=\sqrt{(\Sigma j(Di,j-PSj)\times(Di,j-PSj)/j)}$) is minimized, is obtained and compared with a pattern matching (set) deviation value $\sigma 0$ set beforehand in the deviation value setting device **116**. When the pattern matching (minimum) deviation value σs is not more than the pattern matching (set) deviation value $\sigma 0$, the film thickness value s is stored as an instantaneous film thickness Zi at time i in the film thickness time series data recorder **18**. When the pattern matching (minimum) deviation value σs is not less than the pattern matching (set) deviation value $\sigma 0$, the instantaneous film thickness Zi at time i is not stored.

[0066] In the regression analyzer **19**, a calculated film thickness F at time i is obtained on the basis of the regression straight line approximation using the instantaneous film thickness data before the time i. Whether or not the calculated film thickness F is not more than the target film thickness set beforehand is determined by the end point determining device **230**. The result of etching amount of the material to be processed which is obtained by the above described processing is displayed by the result indicator **17**.

[0067] Note that there is shown a case where only one spectroscope **11** is provided in the first embodiment, but when it is desired that the inside of the surface of a material to be processed is measured in an expanded state and controlled, a plurality of spectroscopes **11** may be provided.

[0068] Next, by using a flow chart shown in FIG. **2**, there is explained a procedure for obtaining an etching amount of a material to be processed, when performing etching processing by the etching amount measuring device **10** shown in FIG. **1**.

[0069] First, there are performed a setting of a target etching amount (target residual film thickness value), and a setting of differential patterns (residual film thickness standard differential patterns) PSj of wavelength regions (at least three wavelength regions) extracted from the differential waveform pattern database **16**, and a setting of a pattern matching (set) deviation value $\sigma 0$ (step **600**). That is, a standard differential pattern PSj corresponding to an etching amount (residual film thickness) s which is needed in accordance with processing conditions of a material to be processed is set beforehand in the differential waveform pattern database **16**.

[0070] In the subsequent step, a sampling (at every 0.25 to 0.5 seconds) of interference light from an object to be processed is started (step **601**). That is, a sampling start instruction is issued in accordance with the start of etching process-

ing. The emission intensity of multiple wavelengths which changes in accordance with the progress of etching is detected by a photodetector (spectroscope **11**) as a photodetection signal of a voltage corresponding to the emission intensity. The photodetection signal of each wavelength j from the spectroscope **11** is digitally converted so that a sampling signals yi,j are obtained.

[0071] Next, multiple wavelength output signals yi,j from the spectroscope **11** are smoothed by the first stage digital filter **12**, so that smoothed time series data Yi,j are calculated (step **602**). That is, a noise is reduced by the first stage digital filter, so that smoothed time series data Yi,j are obtained.

[0072] Next, differential coefficients di,j for each wavelength are calculated by differentiating the smoothed time series data Yi,j by the S-G method in the differentiator **13** (step **603**). That is, (first-order or second-order) differential coefficients di,j of signal waveforms for the respective wavelengths are obtained by the differential processing (the S-G method). Further, the smoothed differential coefficient time series data Di,j are calculated by the second stage digital filter **14** (step **604**). Then, in the differential waveform comparator **15**, a matching pattern (minimum) deviation value $\sigma s=\sqrt{(\Sigma (Di,j-PSj)2/j)}$ is calculated to obtain a minimum value σ of the matching pattern (minimum) deviation value σs with respect to the residual film thickness s (step **605**).

[0073] Next, in the pattern matching deviation comparator **115**, the determination whether $\sigma \leqq \sigma 0$ is performed by comparing the calculated matching pattern (minimum) deviation value σ with the matching pattern (set) deviation value σ**0** (step **606**). When $\sigma \leqq \sigma 0$, it is determined that the film thickness of the material to be processed is made into a residual film thickness s, and an instantaneous film thickness Zi at a time point i is stored in the residual film thickness time series data recorder **18** (step **607**). Except when $\sigma \leqq \sigma 0$, the instantaneous film thickness Zi at the time point i cannot be obtained from the standard differential pattern database, and the instantaneous film thickness is not stored in the residual film thickness time series data recorder **18** (step **608**). These smoothed differential coefficient time series data Di,j and the differential patterns PSj set beforehand in the differential waveform comparator **15** are compared with each other, so that a residual film thickness value Zi at the time point is calculated (step **615**).

[0074] Next, by the use of the stored past time series data Zi, a first-order regression straight line Y=Xa×t+Xb (Y: residual film amount, t: etching time, absolute value of Xa: etching rate, and Xb: initial film thickness) is obtained by the regression analyzer **19**, so that a calculated residual film amount F at time point i (present time) is calculated on the basis of the regression straight line (step **609**). Next, in the end point determining device **230**, the calculated residual film amount F and the target residual film thickness value are compared with each other to determine the etching amount (residual film thickness value). When the calculated residual film amount F is not more than the target residual film thickness value, it is determined that the etching amount of the material to be processed is made into a predetermined value, and the comparison result is displayed in the indicator **17** (step **610**). When the calculated residual film amount F is not less than the target residual film thickness value, the process returns to step **602** and these steps are repeated. Finally, when the calculated residual film amount F is not more than the target residual film thickness value in step **610**, the setting of the end of the sampling is performed (step **611**).

[0075] Here, the calculation of the smoothed differential coefficient time series data Di relating to a certain wavelength j at time point i is explained. As the first digital filter circuit **12**, for example, a second-order Butterworth type low pass filter is used. The smoothed time series data Yi can be obtained by the second-order Butterworth type low pass filter on the basis of the following formula (1).

$$Yi=b1yi+b2yi-1+b3yi-2-[a2Yi-1+a3Yi-2] \quad (1)$$

[0076] Here, numerical values of the coefficients b and a are different in dependence upon a sampling frequency and a cut-off frequency. For example, there are used a2=−1.143, a3=0.4128, b1=0.067455, b2=0.13491, b3=0.067455 (sampling frequency: 10 Hz, cut-off frequency: 2.5 Hz), or a2=−0.00073612, a3=0.17157, b1=0.29271, b2=0.58542, b3=0.29271 (cut-off frequency: 2.5 Hz), or the like.

[0077] The time series data di of second-order differential coefficient values are calculated as follows on the basis of the following formula (2) using the polynomial fitting smoothing differential method of the time series data Yi of five points by the differentiator (differential coefficient operation circuit) **13**.

$$di=\sum_{j=2}^{j=2} wjYi+j \quad (2)$$

Here, w−2=2, w−1=−1, w0=−2, w1=−1, and w2=2.

[0078] By the use of the time series data di of the differential coefficient values, the smoothed differential coefficient time series data Di can be obtained by the second digital filter circuit (second-order Butterworth type low pass filter, but the coefficients a and b of the digital filter circuit may be different) **14** based on the following formula (3).

$$Di=b1di+b2di-1+b3di-2-[a2-Di-1+a3Di-2] \quad (3)$$

[0079] FIG. **3** shows a relation between the interference intensity and the etching time when poly-silicon is subjected to an etching processing and the determination is made at a poly-silicon film thickness of 45 nm. An initial film thickness of poly-silicon as a material subjected to the etching processing is about 170 nm. In the figure, there are shown an interference light waveform of a wavelength of 500 nm observed from the wafer surface, a first-order differential waveform of the interference light waveform, a plasma light (reference light) of a wavelength of 500 nm obtained by not observing the wafer surface, and a time change (instantaneous film thickness transition) of the film thickness of poly-silicon during the etching processing, obtained by a matching comparison between the first-order differential waveform and a standard differential pattern. Here, the instantaneous film thickness transition is obtained in such a manner that the first-order differential pattern at each time point is compared with the standard differential pattern corresponding to each film thickness, to select a film thickness with a smallest pattern matching deviation, and the change of the selected film thickness is plotted.

[0080] FIG. **4** shows a change in the instantaneous film thickness transition generated when the above described etching processing of poly-silicon is continuously performed. In the figure, the instantaneous film thickness is abruptly reduced during the etching processing time period from about 25 seconds to about 31 seconds, so that the film thickness

reaches about 10 nm. This phenomenon is considered to be caused by a slight change in etching plasma due to reaction products accumulated in a part inside the chamber or by a slight change in electric power generating the plasma. However, after the instantaneous film thickness is abruptly reduced only during the etching processing time period from about 25 seconds to about 30 seconds, the transition of the instantaneous film thickness returned to the state before the abrupt change and the etching processing is normally ended. When such change in the instantaneous film thickness is caused, for example, the film thickness becomes below the determination film thickness of 45 nm at the time point of 25 seconds. Thus, the etching processing is ended at the film thickness of about 100 nm, and a defective element is manufactured. Therefore, the film thickness determining system needs to perform an accurate film thickness determination in correspondence with such abrupt change.

[0081] Here, in order to prevent the abrupt lowering of the instantaneous film thickness, the behavior of the interference waveform was analyzed. Generally, in the interference waveform change, when a material is made into a thin film, the interference light ceases to change in many wavelength regions, and hence first-order differential changes at these wavelengths simultaneously approach zero. Further, even when plasma fluctuation is caused, the corresponding changes are simultaneously caused in many wavelength regions, and the first-order differentials at the wavelengths are simultaneously changed. As the change in plasma is reduced, the first-order differential at the wavelengths approaches zero. Such behavior of the first-order differential is similar to that of the change in the interference light of a thin film. Therefore, in order to prevent such abrupt change, it is necessary to avoid the use of data for thin film thickness as much as possible among the data of standard differential patterns used for the thickness measurement. That is, it is necessary to perform the pattern matching processing with the standard differential pattern, in such a manner that a standard differential pattern of a film thickness less than a target determination film thickness is not used for obtaining an instantaneous film thickness during the etching processing.

[0082] FIG. **5** shows a result in the case where a minimum film thickness of the standard differential pattern used for the pattern matching processing is set to 20 nm. From the figure, it can be seen that the abrupt film thickness reduction can be avoided in the etching processing time period from about 25 to about 30 seconds in which plasma fluctuation is caused. Further, as a result of the pattern matching processing at the time when plasma fluctuation is caused, the pattern matching deviation is 0.05 or more, and there is no film thickness at which the standard differential pattern and the actual differential pattern match with each other. Thus, the film thickness at the time is set to the initial film thickness when the standard differential pattern is created. As for the setting of the standard differential pattern with respect to the film thickness used for the film thickness measurement, when a target residual film thickness value is set in step **600** in the flow chart shown in FIG. **2**, a minimum film thickness of the standard differential pattern is defined on the basis of this value, and the standard differential pattern not less than the minimum film thickness is adopted.

[0083] Next, there is shown a further embodiment for avoiding plasma fluctuation. Here, there is utilized the fact that when plasma fluctuation is caused, the pattern matching deviation is increased. Generally, during a period of several seconds from the start of the differential processing for film thickness determination after the start of the etching processing, the interference waveform is slightly disturbed due to the influence of plasma ignition, so that the pattern matching deviation value σ deteriorates. On the basis of the pattern matching (set) deviation value $\sigma\mathbf{0}$ at this time point, the pattern matching deviation value σ after the time point is calculated. When the pattern matching deviation value σ is larger than the pattern matching (set) deviation value $\sigma\mathbf{0}$, it is determined that the pattern matching with the standard differential pattern is not enough. Then, the instantaneous film thickness Zi is not obtained from the standard differential pattern, but set, for example, to the initial film thickness of the database (standard differential patterns). Thus, the instantaneous film thickness data set as the initial film thickness at this time point is not used for the regression straight line approximate analysis for obtaining the calculated film thickness F.

Embodiment 2

[0084] As a second embodiment, FIG. **6** shows a result obtained in such a manner that an instantaneous film thickness Zi at a time point i during etching processing is obtained by using a pattern matching deviation value $\sigma\mathbf{0}$=0.04 during a period of 2 seconds after the start of the differential processing, and that a calculated film thickness F at the time point i is calculated by the regression straight line approximation on the basis of the time series data of the instantaneous film thickness Zi before the time point i. From the figure, it can be seen that the obtained film thickness transition can be stabilized without being influenced by plasma fluctuation, and the film thickness determination can be sufficiently performed. Here, the pattern matching deviation value $\sigma\mathbf{0}$ is obtained in a period of several seconds after the start of the time differential processing for each wafer processing, and the pattern matching determination is performed. However, it may also be adapted such that a plurality of wafers are processed and an average value of respective pattern matching deviation values $\sigma\mathbf{0}$ is set in step **600** in the flow chart shown in FIG. **2**.

[0085] In the process of mass production adapted to process a semiconductor wafer by using plasma in order to produce a semiconductor device from the semiconductor wafer, a plasma processing apparatus such as the device according to the present invention is continuously operated, to cause fluctuation in conditions in the processing chamber, due to adherence and deposition of products onto the surface of member inside the processing chamber in accordance with the increase in the number of pieces of materials to be processed, and the like. This causes the state of plasma generated in the processing chamber to fluctuate, and causes the surface shape obtained as a result of the processing to be changed. Therefore, it is necessary to manage the process so as to control the fluctuation in the result of processing of the material to be processed in the above described mass production. In the case where such mass production management is performed in the present embodiment, the number of times when the pattern matching deviation value exceeds a predetermined value is monitored in the processing for each wafer as a material to be processed, and the number of times is counted by a recorder, a counter (both not shown), or the like. Such counting may also be performed by the pattern matching deviation comparator **115**.

[0086] Further, it is possible to grasp a device status and a wafer etching status by comparing transition of the number of times with a predetermined value (for example, a predeter-

mined value about a value of the number of times and an increasing rate). That is, when the number of times is gradually increased, a predetermined value of the number of times is used as a measure to start maintenance work, such as the wet cleaning, in the plasma processing apparatus. When the number of times is abruptly increased and the increasing rate becomes larger than a predetermined value, the need for measures, such as conveying the wafer to be processed to the wafer inspection step, is informed to a user, or a warning is issued to the user. Such notification and warning are displayed, for example, in the indicator **17** shown in FIG. **1** and the like, in accordance with a command from the pattern matching deviation comparator **115**.

Embodiment 3

[0087] Next, a third embodiment for avoiding plasma fluctuation is explained. Here, instead of stabilizing the instantaneous film thickness transition by the above described pattern matching deviation comparison, the instantaneous film thickness Zi at a time point i during etching processing is obtained. In the case where a calculated film thickness F at the time point i is calculated by the regression straight line approximation on the basis of the time series data of the instantaneous film thickness Zi before the time point i, and where the difference (absolute value) between the calculated film thickness F and the instantaneous film thickness Zi is not less than a film thickness allowable value set beforehand, it is determined that the instantaneous film thickness Zi at the time point i is not an accurate film thickness. FIG. **7** shows a result obtained by a method in which the instantaneous film thickness Zi is determined to be not accurate in this manner is not used for the calculation of the calculated film thickness based on the regression straight line approximation after the time point i. From FIG. **7**, it can be seen that even with this method, it is also possible to similarly avoid the abrupt change during the etching processing period from about 25 seconds to about 30 seconds in which plasma fluctuation is caused as shown in FIG. **4**. Here, a value of 20 nm is used as the film thickness allowable value. The setting of the film thickness allowable value can be determined on the basis of the change in the interference waveform appearing during the etching processing. For example, when poly-silicon of the initial film thickness of 200 nm is etched as a material to be etched, since the interference waveform at the wavelength of 500 nm continues for about ½ periods, the interference waveform within ¼ periods (in which the sign of differential value is changed) may be accurately determined, and the film thickness is set to about 20 nm.

Embodiment 4

[0088] Next, there is explained a fourth embodiment which relates to avoiding erroneous determination in the film thickness measurement, and which utilizes the fact that the etching rate during the mass production processing is almost constant and the fluctuation of the etching rate is in a range of at most ±10%. From the instantaneous film thickness transition shown in FIG. **3**, it can be seen that the inclination of the change of the instantaneous film thickness Zi during the normal etching processing (from 32 to 60 seconds) is constant, and the etching rate obtained from the inclination is about 123 nm/min. On the other hand, it can be seen that the inclination of the change of the instantaneous film thickness during the period (from 25 to 31 seconds) in which plasma fluctuation is caused as shown in FIG. **4** is smaller than the inclination during the normal etching processing. When the etching rate becomes twice or half in the mass production processing, the etching processing is abnormal, and hence it is necessary to return the etching device to the normal state by performing processing such as the wet cleaning of the etching device. FIG. **8** shows a constitution of a plasma processing apparatus provided with a film thickness determining device according to a fourth embodiment. Further, FIG. **9** shows a flow chart of the film thickness determination.

[0089] As shown in FIG. **8**, the fourth embodiment has a feature that an residual film thickness comparator **20** and an etching rate comparator **21** are added between the regression analyzer **19** and the end point determining device **230** of the etching amount measuring device **10** in the plasma processing apparatus shown in FIG. **1**.

[0090] First, as shown in FIG. **9**, there are set a target etching amount (target residual film thickness value), differential patterns (residual film thickness standard differential patterns) PSj whose wavelength regions (at least three wavelength regions) are extracted from the differential waveform pattern database, a pattern matching (set) deviation value σ**0**, a film thickness allowable value Z**0**, and an etching rate allowable value R**0** (step **1600**).

[0091] In the subsequent step, the sampling of interference light (for example, every 0.25 to 0.5 seconds) is started (step **1601**). That is, a sampling start instruction is issued in correspondence with the start of etching processing. The emission intensity of multiple wavelengths which is changed in accordance with the progress of etching is detected by the photodetector as a photodetection signal of a voltage corresponding to the emission intensity. The photodetection signal of the spectroscope **11** is digitally converted, so that the sampling signals yi,j are acquired.

[0092] Next, the multiple wavelength output signals yi,j from the spectroscope **11** are smoothed by the first stage digital filter **12**, and the smoothed time series data Yi,j are calculated (step **1602**). That is, a noise is reduced by the first stage digital filter, so that the smoothed time series data Yi,j are obtained.

[0093] Next, the differential coefficients di,j are calculated by the S-G method in the differentiator **13** (step **1603**). That is, (first-order or second-order) differential coefficients di of the signal waveforms are obtained by the differential processing (the S-G method). Further, the smoothed differential coefficient time series data Di,j are calculated by the second stage digital filter **14** (step **1604**). Then, in the differential waveform comparator **15**, the pattern matching (minimum) deviation value $\sigma s=\sqrt{(\Sigma(Di,j-PSj)2/j)}$ is calculated to obtain a minimum value σ which is the smallest pattern matching (minimum) deviation value σs with respect to a film thickness s (step **1605**).

[0094] Next, in the pattern matching deviation comparator **115**, the determination whether $\sigma \leqq \sigma 0$ is performed for comparing the calculated matching pattern deviation value (minimum value) σ and the matching pattern (set) deviation value σ**0** with each other (step **1606**). When $\sigma \leqq \sigma 0$, it is determined that the film thickness of the material to be processed is made into the film thickness s, and an instantaneous film thickness Zi at a time point is stored in the residual film thickness time series data recorder **18** (step **1607**). Except when $\sigma \leqq \sigma 0$, the instantaneous film thickness Zi at the time point i cannot be obtained from the standard differential pattern database, and

the instantaneous film thickness is not stored in the residual film thickness time series data recorder **18** (step **1608**).

[0095] As for the etching rate during the processing, the calculated film thickness F and the inclination Xa thereof are obtained by the first-order regression straight line approximation in the regression analyzer **19** on the basis of the data in the residual film thickness time series data recorder **18** (**1609**). Next, in the residual film thickness comparator **20**, it is determined whether or not the instantaneous film thickness Zi is a film thickness limited by the calculated film thickness F and the film thickness allowable value z**0** (F−z**0**≦Zi≦F+z**0**), or in the etching rate comparator **21**, it is determined whether or not the inclination of the straight line Xa obtained by the regression approximation is an etching rate limited by the etching rate R at the time of creating the standard differential pattern and the etching rate allowable value R**0** (R−R**0**≦Xa≦R+R**0**). In the case where (F−z**0**≦Zi≦F+z**0**) or where (R−R**0**≦Xa≦R+R**0**), the instantaneous film thickness Zi is stored in the residual film thickness time series data recorder **18** (step **1612**). In the other cases, the instantaneous film thickness Zi is not stored in the residual film thickness time series data recorder **18** (step **1611**).

[0096] Subsequently, the film thickness determination is performed on the basis of the calculated film thickness F. When the calculated film thickness F is not more than the target residual film thickness value, it is determined that the etching amount of the material to be processed has reached the predetermined value, and the result is displayed in the indicator **17** (step **1613**). The state of the film thickness change during etching can be displayed by displaying the calculated film thickness F. When the calculated film thickness F is not less than the target residual film thickness value, the process returns to step **1602** and these steps are repeated. Finally, the setting of the end of the sampling is performed (step **1614**).

[0097] FIG. **10** shows a result of the calculated film thickness transition in the fourth embodiment, when the allowable film thickness range value is set to 20 nm, the etching rate allowable value is set to 50% (etching rate: 117 nm/min), and the minimum film thickness is set to 1 nm (target residual film thickness value: 50 nm). From the figure, it can be seen that the transition of the calculated film thickness F is stabilized without being influenced by plasma fluctuation, so that the target film thickness of 50 nm can be accurately determined. Here, the target film thickness is a film thickness set as a target to be obtained by the etching processing, and the minimum film thickness is a minimum value of the film thickness which can be determined when the minimum value is determined. In the present embodiment, since the film thickness allowable range value is 20 nm, the remaining film thickness may be in the range of the target film thickness 50 nm±20 nm. In the case where the minimum film thickness value of 30 nm can be detected, even when a film thickness not more than the minimum film thickness value is suddenly detected, the detected value can be ignored.

[0098] When the etching processing is normally performed, the number of data of the instantaneous film thickness which have not been stored in the residual film thickness time series data recorder **18**, is almost zero. When the etching characteristic of the etching device is changed due to the time-based change of the device, the matching of the interference differential pattern deteriorates so as to increase the number of data which are not stored. Further, when the specification of the wafer to be processed is changed, the pattern matching deteriorates so as to increase the number of data. Therefore, in the mass production process, it is possible to perform the device management of the etching device and the production management of processed wafers, by displaying in the indicator **17** the number of data of the instantaneous film thickness which have not been stored in the residual film thickness time series data recorder **18**.

Embodiment 5

[0099] Next, there is explained a fifth embodiment in which the film thickness determination is performed by correcting the interference light and reference light, which are observed when plasma fluctuation is caused. The interference light is changed by a steep change in plasma emission caused by plasma fluctuation (abnormality), which may make it difficult to obtain an accurate film thickness, as shown, for example, in FIG. **4** and FIG. **5**. Further, since the digital filter processing and the polynomial fitting smoothing differential processing are used to improve the S/N ratio of observed optical signals, the steep change in the light emission is moderated by these processings to cause the effect of the steep change to appear for a long period of time. As a method for avoiding this effect, there is a method adapted such that when there is a steep change in plasma emission, the digital filter processing and the polynomial fitting smoothing differential processing are temporarily interrupted. However, when these processings are interrupted, the instantaneous film thickness cannot be obtained to make it impossible to perform the film thickness determination.

[0100] Thus, there is explained a method for obtaining a film thickness in a manner of detecting a steep change in plasma, obtaining a change quantity for each wavelength used for measurement, correcting an optical signal of each wavelength in accordance with the change quantity of each wavelength, and performing processings such as the digital filter processing and the polynomial fitting smoothing differential processing to the corrected optical signals.

[0101] When collecting the standard pattern data as a database for film thickness determination, a change quantity (difference during a period between time points i and i−1) at a sampling point of the time point i, of the emission data obtained by measuring the time change of the interference light and the reference light, is checked for each wavelength, so that maximum change amounts during etching processing are obtained for the interference light and the reference light. A noise threshold value is set on the basis of the maximum changes per one sampling, so that a steep change in plasma is detected by using the noise threshold value.

[0102] Next, when there is a change quantity exceeding the noise threshold value, each correction coefficient for each wavelength (intensity ratio: Si,j=yi−1,j/yi,j) is obtained, to correct the optical signals yi,j on the basis of a formula: y'i,j=Si,j*yi,j. The instantaneous film thickness Zi is obtained by performing processings such as the digital filter processing and the polynomial fitting smoothing differential processing for the corrected optical signals y'i, j, and the determination is performed.

[0103] With reference to FIG. **11**, there is explained a constitution of a plasma processing apparatus which is capable of avoiding the plasma fluctuation in this manner and is provided with a film thickness determining device according to a sixth embodiment, in which the film thickness determination was performed. An etching device (plasma processing apparatus) **1** is provided with a vacuum container **2**. An etching gas

introduced into the inside of the vacuum container **2** is decomposed by microwave power or the like into a state of plasma, so that a material to be processed **4** such as a semiconductor wafer on a sample stage **5**, is etched by the plasma **3**. An emitted light of multiple wavelengths from a measuring light source (for example, halogen light source) provided in a spectroscope **11** of an etching amount measuring device **10** (a residual film thickness or an etching depth) is introduced into the vacuum container **2** by an optical fibre **8** and made incident at the vertical incident angle onto the material to be processed **4**. An interference light from the material to be processed is introduced to the spectroscope **11** of the etching amount measuring device **10** via the optical fibre **8**. On the basis of the state of the interference light, a measurement of an etching film thickness of silicon and a processing for determining an end point of etching are performed.

[0104] The etching amount measuring device **10** includes the spectroscope **11**, a sampling data comparator **110**, a noise value setting device **111** for setting a noise threshold value, a correction coefficient recorder and indicator **113**, a sampling data corrector **112**, a first digital filter circuit **12**, a differentiator **13**, a second digital filter circuit **14**, a differential waveform comparator **15**, a differential waveform pattern database **16**, a pattern matching deviation comparator **115**, a deviation value setting device **116**, a residual film thickness time series data recorder **18**, a regression analyzer **19**, an end point determining device **230**, and an indicator **17** for displaying a result from the end point determining device **230**.

[0105] The emission intensities of multiple wavelengths received by the spectroscope **11** are made into current detecting signals, each of which corresponds to emission intensity for each specific wavelength, and converted to voltage signals. The signals of a plurality of specific wavelengths (j pieces) outputted as sampling signals by the spectroscope **11** are compared, in the sampling data comparator **110**, with values set beforehand in the noise value setting device **111**. When the change value of the signals exceeds the noise value, the time series data yi,j are corrected in the sampling data corrector **112**, so as to prevent the signals from being changed. The correction coefficients at this time are stored in the correction coefficient recorder and indicator **113**. In this way, the time series data y'i,j obtained by being corrected on the basis of the instantaneously changed signals are stored in a storage devices such as a RAM. Next, the time series data y'i,j at a time point i are smoothed by the first digital filter circuit **12**, and stored in a storage device such as a RAM, as a smoothed time series data Yi,j. On the basis of the smoothed time series data Yi,j, time series data di,j of differential coefficient values (first-order differential values or second-order differential values) are calculated by the differentiator **13**, and stored in a storage devices such as a RAM. The time series data di,j of the differential coefficient value are subjected to a smoothing processing by the second digital filter circuit **14**, and stored as smoothed differential coefficient time series data Di,j in a storage device such as a RAM. Thus, an actual pattern (with wavelength taken as a parameter) which shows the wavelength dependence of the differential value of interference light intensity can be obtained from the smoothed differential coefficient time series data Di,j.

[0106] On the other hand, in the differential waveform pattern database **16**, there are set beforehand differential waveform pattern data values PSj of the interference light intensity with respect to respective wavelengths, each of which value corresponds to a film thickness s of the material to be processed, as an object of the etching amount measurement. In the differential waveform comparator **15**, an actual pattern and the differential waveform pattern data value PSj of the film thickness s are compared with each other. In the pattern matching deviation comparator **115**, a pattern matching (minimum) deviation value σs at which a pattern matching deviation ($\sigma s=\sqrt{(\Sigma j(Di,j-PSj)\times(Di,j-PSj)/j)}$) is minimized, is obtained and compared with a deviation value σ**0** set beforehand in the deviation value setting device **116**. When the pattern matching (minimum) deviation value σs is not more than the pattern matching (set) deviation value σ**0**, the film thickness value s is stored as an instantaneous film thickness at the time point i in the film thickness time series data recorder **18**. When the pattern matching (minimum) deviation value as is not less than the pattern matching (set) deviation value σ**0**, the instantaneous film thickness at the time point i is not stored. In the regression analyzer **19**, a calculated film thickness F at the time point i is obtained on the basis of the regression straight line approximation using the instantaneous film thickness data Zi before the time point i. Whether or not the calculated film thickness F is not more than the target film thickness set beforehand is determined by the end point determining device **230**. The resultant etching amount of the material to be processed, which is obtained by the above described processing, is displayed by the result indicator **17**.

(Modification)

[0107] In the block diagram shown in FIG. **11**, there is described the processing means of the interference light. However, in a modification of the fifth embodiment as shown in FIG. **12**, plasma light measuring means **1001** provided in the side wall of the etching processing container **2**, a spectroscope **1003**, a sampling data comparator **1110**, and a noise value setting device **1111** are provided not for the interference light measurement based on the light from the external light source, but as the processing means of the interference light measurement utilizing plasma light. Further, as plasma light measuring means, plasma light measuring means **1002** provided in the bottom of the etching processing container **2**, the spectroscope **1003**, the sampling data comparator **1110**, and the noise value setting device **1111** may also be provided as shown in FIG. **13**. These devices operate similarly to the spectroscope **103**, the sampling data comparator **110**, and the noise value setting device **111** which are shown in FIG. **11**. The output of the sampling data comparator **1110** is outputted to the first digital filter **12** via the sampling data corrector **112**, similarly to the output of the sampling data comparator **110** in FIG. **11**.

[0108] Next, with reference to a flow chart shown in FIG. **14**, there is explained a procedure for obtaining an etching amount of a material to be processed, when the etching processing is performed by the etching amount measuring device **10** shown in FIG. **11**.

[0109] First, there are set a target etching amount (target residual film thickness value), differential patterns PSj whose wavelength regions (at least three wavelength regions) are extracted from the standard differential pattern database, a deviation value σ**0**, and a noise value N (step **2600**). That is, a standard differential pattern corresponding to an etching amount s needed in accordance with processing conditions of a material to be processed, is set beforehand in the differential waveform pattern databases **15** and **25**.

[0110] In the subsequent step, the sampling of the interference light (for example, every 0.25 to 0.5 seconds) is started (step **2601**). That is, a sampling start instruction is issued in correspondence with the start of the etching processing. The emission intensity of multiple wavelengths which is changed in accordance with the progress of etching is detected by a photodetector as a photodetection signal of a voltage corresponding to the emission intensity. The photodetection signals of the spectroscope **11** are digitally converted, so that the sampling signal yi,j are acquired.

[0111] Next, differences between the multiple wavelength output signals yi,j and signals yi−1,j at a time point i−1 are obtained (step **2604**). It is determined whether or not the differences (yi,j−yi−1,j) are larger than the value N set beforehand in the noise value setting device **111**, by using the sampling data comparator **110** (step **2620**). In the cases of the embodiments shown in FIG. **12** and FIG. **13**, whether or not output signals relating to plasma emission at the time point i−1 and the time point are larger than a value set beforehand in the noise value setting device **1111** is determined by using the sampling data comparator **1110**. When the output signals are larger than the preset value, change rates, that is, correction coefficients are obtained by a formula: Si,j yi−1,j/yi,j (step **2621**). When the output signals are smaller than the preset value, the correction coefficients are set as Si,j=1 (step **2622**). The multiple wavelength output signals yi,j from the spectroscope are corrected by these correction coefficients in a manner that y'i,j=Si,j×yi,j (step **2623**). Note that these correction coefficient values are stored or displayed in the correction coefficient recorder and indicator **113**, and are used for the mass production management of the etching process. The signals y'i,j corrected in this way are transmitted to and smoothed by the first stage digital filter **12**, so that the time series data Yi,j are calculated (step **2602**). That is, the noise is reduced by the first stage digital filter, so that the smoothed time series data Yi,j are obtained.

[0112] Next, the differential coefficients di,j are calculated by the S-G method in the differentiator **13** (step **2603**). That is, the (first-order or second-order) differential coefficients di of the signal waveforms are obtained by the differential processing (the S-G method). Further, the smoothed differential coefficient time series data Di,j are calculated by the second stage digital filter **14** (step **2604**). Then, in the differential waveform comparator **15**, the value $\sigma s=\sqrt{(\Sigma(Di,j-PSj)2/j)}$ is calculated, to obtain a minimum value σ of the pattern matching (minimum) deviation value σs with respect to the film thickness s (step **2605**). Next, in the pattern matching deviation comparator **115**, the determination (σs: matching pattern (minimum) deviation value σ, and σ**0**: matching pattern (set) deviation value) is performed (step **2606**). When $\sigma s \leqq \sigma 0$, it is determined that the film thickness of the material to be processed is made into the film thickness s, and an instantaneous film thickness at the time point i is stored in the residual film thickness time series data recorder **18** (step **2607**). Except when $\sigma s \leqq \sigma 0$, the instantaneous film thickness at the time point i cannot be obtained from the standard differential pattern database, and the instantaneous film thickness is not stored in the residual film thickness time series data recorder **18** (step **2608**). The smoothed differential coefficient time series data Di,j and differential patterns PZj set beforehand in the differential waveform comparator **15** are compared with each other, so that a residual film value Zi at that time point is calculated (step **2615**). Next, by the use of the stored past time series data Zi, a first-order regression straight line Y=Xa×t+Xb (Y: residual film amount, t: etching time, absolute value of Xa: etching rate, Xb: initial film thickness) is obtained by the regression analyzer **19**, so that a calculated residual film amount F at the time point i (present time) is calculated on the basis of the regression straight line (step **2609**). Next, in the end point determining device **230**, the calculated residual film amount F and the target residual film thickness value are compared with each other. When the calculated residual film amount F is not more than the target residual film thickness value, it is determined that the etching amount of the material to be processed is made into the predetermined value, and the comparison result is displayed in the indicator **17** (step **2609**). When the calculated residual film amount F is not less than the target residual film thickness value, the process returns to step **2604** and these steps are repeated. Finally, the setting of the end of the sampling is performed (step **2611**).

[0113] Next, there is explained the interference light measurement when discharge fluctuation is caused as shown in FIG. **4**, in relation to specific embodiment according to the present invention. The maximum change quantities per one sampling of the time changes in the interference light and the reference light of the standard pattern data for film thickness determination, which are used here, are determined as follows. In the above described etching processing of polysilicon (during a period between time points 5 seconds and 55 seconds from the start of etching), the maximum change quantity of the interference light of the standard pattern data is 50 counts and the maximum change quantity of the reference light of the standard pattern data is 20 counts. Therefore, the noise threshold values for detecting a steep change in plasma are set to 100 counts and 50 counts which are predetermined values defined in accordance with the specification that the noise threshold value be set to a value between two and three times of the maximum change quantity.

[0114] FIG. **15** shows a result obtained by correcting a steep change in plasma by performing the above described processing. As shown in FIG. **15**, it can be seen that the fluctuation of the light emission generated at the time point of about 25 seconds after the start of etching as shown in FIG. **4** is corrected, and abnormal changes in the interference light waveform and the reference light waveform are reduced. In this example, since the noise (abnormal light emission) of the interference waveform is small, any change larger than the noise threshold value is not caused. However, since the noise (abnormal light emission) of the reference light is large, the change in plasma can be sufficiently detected, and the correction is performed to the reference light and the interference light at the time point when the change in plasma is detected. This makes it possible to correct a slight change in the interference light. It can be seen that it is possible to stabilize the transition of the instantaneous film thickness which can be obtained during etching, by the above described processings.

[0115] In this example, the reference light is used as means for detecting a steep change in plasma, but it may be adapted such that values of reflection power and a matching point of electric power for generating plasma, or values of reflection power and a matching point of bias applied to the wafer are monitored, and a change in the values are used as means for detecting the steep change in plasma.

[0116] Further, here, the correction coefficients are obtained by Si,j=yi−1,j/yi,j, but an average value of a plurality of waveform data before the time point i−1 may also be used as the correction coefficient. Further, the approximate value at the time point i−1 based on a smooth curve obtained from the

past time series data by using an interpolation method, such as the Lagrange interpolation method and a spline interpolation method, may also be used as the correction coefficient. In addition, the emission data at the time point i may be further modified by applying the Lagrange interpolation method and the spline interpolation method to the emission data at the time point i which are modified by the correction coefficient. Further, in the embodiments shown in FIG. **12** and FIG. **13**, similarly to the case where the interference light from the sample surface is used, the sampling data of the interference light may be corrected by using the correction coefficient obtained on the basis of the result of comparison relating to plasma light emission performed by the sampling data comparator **1110**. Further, when it is detected at an arbitrary time point that the noise threshold value is exceeded, it may be adapted such that the film thickness is detected by an arithmetic operation using the above described regression analysis at least at one time point corresponding to a predetermined number of times when the noise threshold value is exceeded, and that when it is detected that the noise threshold value is exceeded at a time point after the one time point, the film thickness is detected by using the correction coefficient.

[0117] When the etching processing is normally performed, the number of times when the noise threshold value is exceeded is zero. However, when the etching characteristic of the etching device is changed due to the time-based change of the device and the plasma state deteriorates, the number of times when the noise threshold value is exceeded is increased. Therefore, in the mass production process, it is possible to perform the device management of the etching device by displaying in the indicator **17** the number of times when the noise threshold value is exceeded.

Embodiment 6

[0118] Next, with reference to FIG. **16** to FIG. **18**, there is explained a sixth embodiment in which the film thickness measurement is performed by correcting a result of matching with the differential waveform pattern database when there is plasma fluctuation at an initial period from the start of etching. FIG. **16** shows a device constitution of the sixth embodiment. The sixth embodiment has a feature that an etching rate comparator **21**, a film thickness corrector **201**, and a noise determining device **202** are added between the residual film thickness time series data recorder **18** and the regression analyzer **19** of the etching amount measuring device **10** in the plasma processing apparatus shown in FIG. **1**.

[0119] First, as shown in FIG. **17**, there are set a target etching amount, differential patterns (residual film thickness standard differential patterns) PSj whose wavelength regions (at least three wavelength regions) are extracted from the differential waveform pattern database, an etching rate allowable value R**0**, a film thickness value at the start of etching, and an etching rate R at the time of creating the standard differential pattern (step **3600**).

[0120] In the subsequent step, the sampling of the interference light (for example, every 0.25 to 0.5 seconds) is started (step **3601**). That is, a sampling start instruction is issued in correspondence with the start of the etching processing. The emission intensity of multiple wavelengths which is changed in accordance with the progress of etching is detected as a photodetection signal of a voltage corresponding to the emission intensity by the photodetector. The photodetection signal of the spectroscope **11** is digitally converted, so that the sampling signals yi,j are acquired.

[0121] Next, the multiple wavelength output signals yi,j from the spectroscope **11** are smoothed by the first stage digital filter **12**, and the smoothed time series data Yi,j are calculated (step **3602**). That is, a noise is reduced by the first stage digital filter, so that the smoothed time series data Yi,j are obtained.

[0122] Next, the differential coefficients di,j are calculated by the S-G method in the differentiator **13** (step **3603**). That is, the (first-order or second-order) differential coefficients di of the signal waveforms are obtained by the differential processing (the S-G method). Further, the smoothed differential coefficient time series data Di,j are calculated by the second stage digital filter **14** (step **3604**). Then, in the differential waveform comparator **15**, the pattern matching (minimum) deviation value $\sigma s=\sqrt{(\Sigma(Di,j-PSj)2/j)}$ is calculated to obtain the instantaneous film thickness data Zi from a minimum value σ of the pattern matching (minimum) deviation value σs with respect to the film thickness s (step **3605**). The instantaneous film thickness data Zi is stored in the residual film thickness time series data recorder **18**.

[0123] As for the etching rate during the processing, an inclination Xa is obtained by the etching rate comparator **21** from a regression straight line **1** on the basis of the instantaneous residual film time series data Zi (step **3606**). Next, it is determined whether or not the current inclination Xa is an etching rate limited by the etching rate R at the creation time of the standard differential pattern, and the etching rate allowable value R**0** (R−R**0**≦Xa≦R+R**0**) (step **3607**). In the case where (R−R**0**≦Xa≦R+R**0**), the instantaneous film thickness Zi is stored in the residual film thickness time series data recorder **18** (step **3608**). In other cases, the instantaneous film thickness Zi is not stored in the residual film thickness time series data recorder **18** (step **3609**). When the instantaneous film thickness Zi is not stored, correction instantaneous film thickness data Fei and correction instantaneous film thickness auxiliary data Fepi and Femi which are respectively values of Fei ±10%, are obtained from the etching rate R at the creation time of the standard differential pattern, and stored in the residual film thickness time series data recorder **18** instead of the current instantaneous film thickness data Zi (step **3610**). Here, the reason for using the values of Fei ±10% is based on the fact that the fluctuation of the etching rate is at most about ±10%, but other values may also be set depending upon the kind of wafer and the state of etching.

[0124] Next, in the noise determining device **202**, the instantaneous film thickness time series data Zi, the correction instantaneous film thickness data Fei, the correction instantaneous film thickness auxiliary data Fepi and Femi which are respectively the values of Fei ±10%, are compared with the regression straight line **1** calculated in step **3606**, so that the instantaneous film thickness data Zi having a difference not less than a fixed value (for example, not less than 10 nm) from the regression straight line **1** is set as noise data (step **3611**). FIG. **18** shows an instantaneous film thickness correcting function based on the correction instantaneous film thickness data Fei, the correction instantaneous film thickness auxiliary data Fepi and Femi. When the etching rate Xa is outside the allowable range, the instantaneous film thickness data Zi is not adopted. Instead, the correction instantaneous film thickness data Fei and the correction instantaneous film thickness auxiliary data Fepi and Femi are adopted. Thereby, the film thickness transition in the early stage of etching is stabilized. At the initial timing from the start of etching, plasma is not stable in many cases, and hence a mismatch

easily occurs in the matching operation with the database. Further, the amount of the past residual film thickness time series data Zi for obtaining the regression straight line is small, so that the calculated film thickness value obtained by the regression straight line **2** is liable to have low reliability and to be abnormal. Thus, the correction instantaneous film thickness data Fei and the correction instantaneous film thickness auxiliary data Fepi and Femi are adopted instead of Zi determined as the noise data. The adoption of the correction instantaneous film thickness auxiliary data Fepi and Femi is to increase the number of data at the time of obtaining the calculated film thickness value by the regression straight line **2**, and to improve the reliability of the calculated film thickness value. Further, when the correction instantaneous film thickness data Fei and the correction instantaneous film thickness auxiliary data Fepi and Femi are determined as the noise by the noise determining device **202**, the data are excluded from the object data of the regression straight line **2** for calculating the calculated film thickness value.

[0125] The calculated film thickness F at the time point i is obtained by the regression straight line **2** in the regression analyzer **19** by using the data of the instantaneous film thickness time series data Zi, the correction instantaneous film thickness data Fei and the correction instantaneous film thickness auxiliary data Fepi and Femi, which data are not determined as the noise by the noise determining device **202** (step **3612**). It is determined in the end point determining device **230** whether or not the calculated film thickness F is not more than the target residual film thickness value set beforehand (step **3613**). Finally, when the calculated residual film amount F is not more than the target residual film thickness value in step **3613**, the setting of the end of the sampling is performed (step **3614**). The result of etching amount of the material to be processed obtained by the above processing is displayed in the result indicator **17**.

[0126] In the sixth embodiment, the transition of the calculated film thickness value in the unstable region of plasma during the early stage of etching is stabilized by the film thickness correcting function. In a thin film wafer, the etching time period is short, and the calculated film thickness value stabilized from the early stage of etching is important. When the calculated film thickness value is unstable, the etching processing is ended at a film thickness not less than the target film thickness, which results in a production failure.

[0127] In the case where the mass production management is performed in the present embodiment, the totals of the number of data determined as the noise and the data deviation amount (noise amount) are monitored by the processing for each wafer, and the totals of the number of data determined as the noise and the data deviation amount are counted by a recorder, a counter or the like (not shown). Such counting operation may also be performed by the film thickness corrector **201**. Further, it is possible to grasp the state of the device and the etching state of the wafer, by comparing the transition of the totals of the number of data determined as the noise and the data deviation amount with predetermined values (for example, predetermined values relating to a value of the number of data and the increasing rate). That is, in the case where the above described number of data is gradually increased, the predetermined values for the totals of the number of data and the data deviation amount are used as measures for starting the maintenance work, such as the wet cleaning, in the plasma processing apparatus. When the totals of the number of data and the data deviation amount are abruptly increased and the increasing rate of the totals exceeds the predetermined value, the need for a measure such as that of conveying the wafer to the inspection process of the wafer to be processed, is informed to a user, and a warning is issued. Such information and warning are displayed, for example, in the indicator **17** shown in FIG. **16** and the like, in response to a command from the film thickness corrector **201**.

[0128] According to the present invention, it is possible to provide a film thickness measuring method in which an etching amount of a material to be processed can be accurately measured online in plasma processing, especially in plasma etching processing, and to provide a process end point determining method using the film thickness measuring method.

[0129] Further, it is possible to provide an etching process in which a layer to be etched of a semiconductor device can be highly precisely controlled online, so as to be etched by a predetermined etching amount. Further, it is possible to provide an etching amount measuring device of a material to be processed, in which an actual etching amount of a layer to be processed accurately measured online.

What is claimed is:

1. A plasma processing apparatus adapted to perform etching processing of a film on the surface of a sample in a vacuum container by using plasma formed in the vacuum container, comprising:

a detector adapted to detect interference light of a plurality of wavelengths from the sample surface during the processing;

pattern comparing means adapted to compare actual deviation pattern data relating to the interference light obtained at an arbitrary time point during the processing of the sample, with a plurality of standard deviation patterns which are data of interference light of the plurality of wavelengths, relating to processing of another sample obtained before the processing of the sample, and which correspond to a plurality of thicknesses of the film, and adapted to calculate a deviation between the actual deviation pattern data and the plurality of standard deviation patterns;

deviation comparing means adapted to compare the deviation between the actual deviation pattern data and the plurality of standard deviation patterns with a deviation set beforehand, and to output data relating to a film thickness of the sample at the arbitrary time point;

residual film thickness time series data recording means adapted to record the data relating to the film thickness from the deviation comparison means as time series data; and

an end point determining device adapted to determine that an etching of a predetermined amount is ended, by using the data on the film thickness from the deviation comparison means.

2. The plasma processing apparatus according to claim **1**, wherein when a minimum value of the deviation is larger than a predetermined value, the determining device determines the reaching of the film thickness estimated from the value of the film thickness determined before the arbitrary time point.

3. The plasma processing apparatus according to claim **1**, wherein the determining device is means adapted, when a minimum value of the deviation is larger than a predetermined value, to determine the reaching of the film thickness estimated from the value of the film thickness determined before the arbitrary time point, and to determine a value obtained by interpolation using film thick-

ness values at each time point within a predetermined time period before the arbitrary time point, as a film thickness at the arbitrary time point.

4. The plasma processing apparatus according to claim **1**, wherein the determining device is means adapted, when a minimum value of the deviation is larger than a predetermined value, to determine the reaching of the film thickness estimated from the value of the film thickness determined before the arbitrary time point, and to use a value obtained by performing interpolation using film thickness values at respective time points within a predetermined time period before the arbitrary time point, for determining the film thickness at a time point after the arbitrary time point.

5. The plasma processing apparatus according to claim **1**, wherein the determining device is means adapted, when a minimum value of the deviation is larger than a predetermined value, to determine the reaching of the film thickness estimated from the value of the film thickness determined before the arbitrary time point, and to determine a value obtained by performing extrapolation using film thickness values at respective time points within a predetermined time period before the arbitrary time point, as the film thickness at a time point after the arbitrary time point.

6. A plasma processing apparatus adapted to perform etching processing of a film on the surface of a sample in a vacuum container by using plasma formed in the vacuum container, comprising:

a detector adapted to detect interference light of a plurality of wavelengths from the sample surface during the processing;

a differentiator adapted to obtain an actual differential pattern constituted by a time series of actual differential waveforms by differentiating changes in intensity of the detected interference light;

a differential waveform pattern database which is a differential waveform obtained by differentiating a change in intensity of interference light of the plurality of wavelengths relating to processing of another sample obtained before the processing of the sample, and which is constituted by a plurality of standard differential waveforms respectively corresponding to a plurality of thicknesses of the film;

a differential waveform comparator adapted to compare a real time differential waveform formed by differentiating a change in intensity of interference light obtained at an arbitrary time point from the start of the processing of the sample, with a pattern of standard differential waveforms stored in the differential waveform pattern database, and to output a pattern matching deviation value between the real time differential waveform and the pattern of standard differential waveforms;

a deviation value setting device in which a minimum value of the pattern matching deviation value is set; and

a determining device adapted to determine reaching of a film thickness corresponding to a pattern of the data for which the pattern matching deviation value is minimized,

wherein when a difference between the determined film thickness value and a film thickness value determined at a time point just before the arbitrary time point is larger than a predetermined value, the determining device determines reaching of a film thickness estimated from the film thickness determined before the arbitrary time point.

7. The plasma processing apparatus according to claim **6**, comprising the determining device which determines a value obtained by performing interpolation using film thickness values at respective time points within a predetermined time period before the arbitrary time point, as a film thickness at the arbitrary time point.

8. The plasma processing apparatus according to claim **6**, further comprising

the value obtained by performing interpolation as the determination value used for the film thickness determination at the arbitrary time point and at a time point subsequent to the arbitrary time point.

9. The plasma processing apparatus according to claim **6** or claim **7**, further comprising

a determining device adapted to use a value obtained by performing extrapolation.

10. A plasma processing apparatus adapted to perform etching processing of a film on the surface of a sample in a vacuum container by using plasma formed in the vacuum container, comprising:

a detector adapted to detect interference light from the sample surface in the vacuum container; and

a determining device adapted to compare data relating to the interference light obtained by differentiating an output obtained from the detector at an arbitrary time point during the processing, with a plurality of patterns of data which are interference light data of a plurality of wavelengths obtained by differentiating the outputs from the detector in processing of another sample obtained before the processing of the sample, and which respectively correspond to a plurality of thicknesses of the film, and to determine reaching of a film thickness at which the difference between the data and the plurality of patterns is minimized,

wherein when a ratio (difference) between the output value of the detector at the arbitrary time point and an output value of the detector at a time point just before the arbitrary time point is larger than a predetermined value, the output value at the arbitrary time point is corrected to make the ratio at the arbitrary time point equal to the ratio at the time point just before the arbitrary time point (to eliminate the difference therebetween).

11. A plasma processing apparatus adapted to perform etching processing of a film on the surface of a sample in a vacuum container by using plasma formed in the vacuum container, comprising:

a first detector adapted to detect light emission of plasma in the vacuum container;

a second detector adapted to detect interference light from the sample surface in the vacuum container; and

a determining device adapted to compare data relating to the interference light obtained by differentiating an output obtained from the second detector at an arbitrary time point during the processing, with a plurality of patterns of data which are interference light data of a plurality of wavelengths obtained by differentiating outputs obtained from the second detector in processing of another sample obtained before the processing of the sample, and which respectively correspond to a plurality of thicknesses of the film, and to determine reaching of

a film thickness at which the difference between the data and the plurality of patterns is minimized,

wherein when a ratio (difference) between an output value of the first detector at the arbitrary time point and an output value of the first detector at a time point just before the arbitrary time point is larger than a predetermined value, a coefficient obtained to make the output value at the arbitrary time point equal to the output value at the time point just before the arbitrary time point (to eliminate the difference therebetween) is multiplied to the output of the second detector at the arbitrary time point.

12. A plasma processing apparatus adapted to perform etching processing of a film on the surface of a sample in a vacuum container by using plasma formed in the vacuum container, comprising:

a detector adapted to detect interference light of a plurality of wavelengths from the sample surface during the processing;

a differentiator adapted to obtain an actual differential pattern constituted by a time series of actual differential waveforms obtained by differentiating changes in intensity of the detected interference light;

a differential waveform pattern database which is a differential waveform obtained by differentiating a change in intensity of interference light of the plurality of wavelengths relating to processing of another sample obtained before the processing of the sample, and which is constituted by a plurality of standard differential waveforms respectively corresponding to a plurality of thicknesses of the film;

a differential waveform comparator adapted to compare a real time differential waveform at an arbitrary time point formed by differentiating a change in intensity of the interference light obtained at the arbitrary time point from the start of the processing of the sample, with a pattern of a standard differential waveform stored in the differential waveform pattern database, and to output a pattern matching deviation value between the real time differential waveform and the pattern of the standard differential waveform;

an etching rate comparator adapted to compare a current etching rate calculated on the basis of an instantaneous film thickness value obtained by the differential waveform comparator, with an etching rate of the differential waveform pattern database;

a film thickness corrector adapted, when the current etching rate is abnormal, to correct the current etching rate to the etching rate of the differential waveform pattern database; and

an end point determining device adapted to determine that the etching of a predetermined amount is ended, by using film thickness data from the film thickness corrector.

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