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MONITORING REMOVAL OF THIN FILM LAYERS

Technical Field

This invention relates to a method for
5 monitoring a progressive removal of a thin film layer.

Illustratively, such removal occurs during
etching of the thin film in the manufacture of semi-
conductor devices. There is a need for detecting a point
which can be used for determining when the film is
10 removed. Changes of thickness can also be used to detect
the rate of removal of the thin film material. The rate
can be then used to determine the processing time
required to remove a film of a given thickness. This
expedient is useful to account for variations in etching
15 rates that arise due to minor changes in processing
conditions.

Background of the Invention

A variety of optical techniques has been proposed
for monitoring an etching process. The
20 detection of the removal of a thin layer during an etching
process is commonly referred to as "end point" detection.
This may be the point in time at which the layer underlying
the layer being etched first becomes exposed. Often, how-
ever, etching is continued beyond the point of first expo-
25 sure to allow etching of the entire area that is to be
removed. In these cases the so-called "end point" is
actually an indicator of a point in the etching operation
28 after the "clearing point" at which the layer beneath

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first becomes exposed. A consequence of this can be a more accurate etching process since detecting the process of the etching process allows for anticipation of the conclusion of the process and there is no error due to continued etching while the process is being
5 turned off as would be the case when the ultimate end of the process is detected. Observing changes in reflectivity of the layer being etched is described in U.S. Patent No. 4,198,261. A technique using interference effects is described in Chapter 2, page 213, of Fine Line Lithography, North Holland Publishing Company (1980). These
10 methods and other optical methods share the common requirement of directing the light used for the measurement onto the layer being processed. In modern semiconductor processing that layer may comprise one or more features of a very small size. Difficulty is then encountered in focusing the analysing beam to the size of the
15 feature and/or addressing that feature.

Techniques for monitoring thin layer removal largely have been visual and empirical. However, as line width requirements for semiconductor integrated circuit fabrication become more stringent, the need for more precise photoresist masks increases. More
20 accurate monitoring is essential to avoid overetching and consequent loss of definition. Operator judgement is sometimes unreliable.

Summary of the Invention

With the invention as set out in the claims the area which is illuminated by the light beam and from which the reflected light is
25 monitored includes both first and second material. The problem of focusing and/or addressing very small features is thus avoided.

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The end point of an etching operation is detected in a preferred example of the invention by directing a beam of electromagnetic radiation, typically light, onto regions of the assembly being processed. The regions on which the analyzing radiation is incident exhibit at least two rates of change, under the conditions of the process. Additionally, the materials are sufficiently transparent to the analyzing radiation to provide reflections of the radiation from the surface underlying the layer being processed, which corresponds approximately to the lower surface of the layer being processed, as well as reflections from the top surface of the layer. These two reflections combine in the reflected beam to provide an interference effect that changes in accordance with certain characteristics of the layer. The main effect of interest is the physical thickness of the layer. Other effects, e.g. changes in refractive index, or polarization, may be detected as well.

The fluctuation in the dual interference effects are used in accordance with the invention to determine the change in the single property of interest by relative measurement of the rapidly varying signal.

In the preferred example, the surface of a photoresist coating on a semiconductor body undergoing development is subjected to a beam of intense monochromatic light. The light illuminates portions of both exposed and unexposed photoresist which are being eroded at distinctly different rates. Light reflected from the surface of the semiconductor body interferes with light reflected from the surface of both the rapid eroding and the slow eroding photoresist surfaces. The intensity of this reflected light has an oscillatory character as a function of time. The faster eroding surface gives rise to a faster oscillation than that exhibited by the more slowly eroding unexposed photoresist portion. The occurrence of the clearing point, corresponding to the removal of the bulk of the exposed resist, is signaled by the cessation of the fast oscillations in the presence of the continuing

slower oscillations.

The detection of this cessation is accomplished by logic circuit means which compute in analog fashion the first, second, and third time derivatives of the reflected light signal. The circuit is designed so that the fast oscillations are detected selectively in the presence of the slower oscillations. Since the second and third analog derivatives of an oscillating signal of suitable frequency are out of phase with one another, they will be zero simultaneously, within some voltage range, δ , only when the fast oscillations cease. The clearing point is indicated by the circuit with a logical "true" signal. Thus, a control computer is programmed to monitor a digital line and note when the output indicates "true" signaling the clearing point of the development process.

Brief Description of the Drawings

The preferred example of the invention will now be described with reference to the accompanying drawings, in which:

FIG. 1 and 2 are graphs of reflected light intensity versus time illustrating the development process,

FIG. 3 and 4 are graphs of second and third derivatives of the light signals with time, and

FIGS. 5, 6 and 7 are circuit schematics of an arrangement for processing the light signals and indicating the end-point by a logic output.

Detailed Description

Apparatus for the practice of the exemplary method consists basically in a source of monochromatic light of sufficient intensity to provide sufficiently strong reflectivity from the photoresist-coated surface of a semiconductor wafer to produce distinct signals. Although not shown, such apparatus may comprise a laser light source and a standard photosensitive diode or diodes. To provide an averaging effect, a plurality of photo-detectors which scan a greater portion of the surface may be used.

Procedurally, once the photoresist-coated wafer

has been exposed, it is immersed in a developer solution and while therein, is subjected to the monochromatic light beam, and the photodetector pickup is transformed into an electrical signal having the general form as shown in

5 FIG. 1, which is a plot of reflected light intensity versus time. It is known that the intensity of the reflected light from a photoresist-coated surface during development exhibits time oscillations because reflections from the surface of the photoresist interfere constructively or

10 destructively with those from the underlying substrate, depending on the thickness of the developing photoresist layer. Since both the exposed and unexposed portions of the photoresist are eroded by the developer solution at different rates, two distinct oscillations are observed, as

15 shown in the curves of FIG. 1. In this curve, the fast oscillations, at the left, which result from the thinning of the exposed resist, are superimposed on a set of much slower oscillations which are indicative of the erosion of unexposed resist. The occurrence of the clearing point,

20 which is the instant at which a sufficient area of the semiconductor surface is bared of photoresist to cause the disappearance of one set of reflective interferences and correspondingly denotes removal of the bulk of the exposed photoresist, is indicated by the cessation of the

25 fast oscillations in the presence of the slow. Circuit means for detecting this event are illustrated in FIG. 5, 6 and 7.

The circuit of FIG. 5 includes the photodetector 11 upon which the light reflected from the photoresist surface impinges. The element 12 is a

30 preamplifier stage which is connected to the element 13 which functions as an AC noise filter and provides further amplification.

The amplified signal from the output of the circuit of FIG. 5 is fed to the input 20 of the circuit of

35 FIG. 6. This circuit comprises the first differentiation stage comprising the element 21 coupled to the second differentiation stage comprising the element 22.

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Elements 23 and 24 are the third differentiation stage and a final low-pass filter, respectively. Elements 25 and 26 are a ten-to-one amplifier and a low-pass filter in this particular embodiment.

5 The circuit of FIG. 7 comprises two window comparators, the outputs of which are fed to an AND gate. As previously stated, since the second and third analog derivatives are out of phase with one another, they will be simultaneously zero, within some voltage range, δ , only
10 when the fast oscillations cease. Accordingly, the comparators composed of stages 61 and 62 serve to determine

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the vanishing of the derivatives to within δ , and their outputs are fed to AND gate 72 and NOR gates 73 which indicate the clearing point by the occurrence of an output.

In a specific embodiment, the circuits in accordance with FIG. 5, 6, and 7 included the following elements: (1) Western Electric 559C Operational Amplifier; (2) Western Electric 41FP AND gates; (3) Western Electric NOR 41EE.

Resistors - Value In Ohms

10	14-1 MEG	39-100K	67-5K
	15-100K	40-100K	68-200
	16-250K	43-10K	69-5K
	27-4.75K	44-100K	70-200
	29-402K	45-100K	71-5K
15	31-4.75K	46-100K	
	33-100K	64-200	
	35-10K	65-5K	
	37-402K	66-200	

Capacitors - Value In Microfarads

20	17 - 0.01
	28 - 4
	30 - 0.022
	32 - 4
	34 - 0.022
25	36 - 4
	38 - 0.04
	41 - 1
	42 - 1
	47 - 1
30	48 - 1

FIG. 2 shows a typical raw reflected light signal in curve I in which the fast oscillations are superimposed on an irregular baseline. The rectilinear graph II is the logical signal produced by the circuit means just described, with the occurrence of the TRUE indication represented by the change in level at 11.44 seconds elapsed time.

In general, low frequency oscillations, which arise from the erosion of the unexposed photoresist and constitute a formidable baseline in the raw signal, do not interfere with the determination of the clearing point.

5 FIG. 3 shows the second derivative signal and FIG. 4 the third derivative signal, each from light reflected from different locations on the same wafer showing that both signals indicate substantially the same time to reach the clearing point.

10 After the clearing point has been detected, the end-point is determined by a factor determined largely by factors relating to the character and geometry of the resist pattern. Typically, the total development time to end-point would be 1-2 times the time to the clearing
15 point.

Accordingly, there is provided an arrangement for accurately and automatically detecting the end-point of the photoresist development process, thereby avoiding particularly overetching which tends to degrade the
20 definition of photoresist masks.

It is expected that the processes described herein will find use as important parts of a device technology and will become economically significant additions to manufacturing operations. Thus the invention
25 as claimed herein is not regarded as a testing procedure per se but as an important step in a manufacturing process in the same way that etching, implantation, chemical deposition and other processes are important steps in manufacturing microminiature devices.

30 The references herein to different materials is meant to describe materials that are either chemically or physically different. Such materials may be different as the result of selectively induced changes in layers initially of the same material, as in the examples given
35 above.

CLAIMS

1. A method for manufacture of microminiature device which includes the steps of forming a patterned layer by removing a thin film portion of a first material from an underlying support body in the presence of an adjacent region of a second material on the support body which second material is not removed or is progressively removed at a much slower rate than the rate of the first material, and monitoring the removal of the first material by illuminating with a light beam a contiguous area including first material and second material and monitoring the light reflected from the said area to detect a change in the reflected light, the said reflected light comprising light reflected from the exposed surface of the first material, the exposed surface of the second material and the underlying surface of the support body.
2. A method as claimed in claim 1, wherein the beam is monochromatic light and the change that is detected is change in the interference between light reflected from the support body and light reflected from the film of first material.
3. A method as claimed in claim 2, wherein the said interference creates first oscillations in a detector signal, and the process causing the removal of the first material is terminated at a time fixed from the time at which the first oscillations terminate.
4. A method as claimed in claim 3, wherein the second and third derivatives with respect to time of the detector signal are derived.
5. A method as claimed in claim 4, wherein the termination of the first oscillations is determined by the simultaneous presence of the second and third derivatives within a predetermined range from zero.
6. A method as claimed in claim 5, wherein the reflected light is detected by a photodetector, the second and third derivatives are derived by electrical circuits coupled to the photodetector and the simultaneous presence of the second and third derivatives within the said range is determined by an AND circuit



coupled to the electrical circuits.

7. A method as claimed in any of claims 3 to 6 wherein the process causing the removal of the first material is terminated at a time equal to a factor between 1 and 2 multiplied by the time taken to reach the termination of the first oscillations.

8. A method as claimed in any of the preceding claims wherein the body is a semiconductor substrate, and the first and second material are parts of a photoresist film which has been selectively exposed and is developed to etch selectively the first material.

9. A method of manufacture of a microminiature device, substantially as hereinbefore described.

