Title: DUAL BEAM AUTOMATIC FOCUS SYSTEM

Abstract

The invention relates to a method and means for automatic focusing and has particular use in semiconductor metrology. The invention concerns the use of two beam sources and a single detector. One of said beam sources is projected forwardly of an image plane of an object to be viewed and the second of said beam sources is projected rearwardly of an image plane of an object to be viewed. The reflections from each of said beams are then passed through a vignetting aperture and onto a single focus detector. Using this arrangement it is possible to efficiently and accurately determine the point of focus.
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DUAL BEAM AUTOMATIC FOCUS SYSTEM

Field of Invention

The invention relates to a method of automatic focusing; a system including such a method and an apparatus for performing such a method.

It is known in a number of applications that there is a need for automatic focusing. For example, many microscopes and cameras are provided with a means for automatic focusing and also many compact disc players are similarly provided with such a means. Microscopes are deployed in automated wafer handling systems for use in the semiconductor industry and in particular for use in semiconductor metrology. The automated wafer handling systems must move the wafer to a measurement site and then focus on that site before an image can be acquired and then overlay measurement performed. In order to reduce the time taken by this process is it necessary to acquire the focus position very rapidly, or maintain a lock-on focus throughout the wafer's motion. Conventionally, there are a number of techniques for achieving automatic focusing.

One technique involves vignetting, or partial obscuration, of a reflected image as illustrated in Figure 1a. Typically, an image 1x is illuminated and a reflected image is projected onto a knife edge 2x. The degree to which the knife edge partially obscures the reflected image is detected by a beam detector, ideally a split detector. Focus is determined when partial obscuration equals half of the reflected image. Clearly, as one moves in and out of focus more than or greater than half of the reflected light will pass
beyond the knife edge and be detected by the beam detector. It is often preferred to use a split detector because it provides for signed, ie positive and negative, focus response, with the null at focus. Figure 2a is a graph showing illumination of a split detector comprising detectors D1 and D2 as one moves through focus. It can be seen that there is a rapid variation in the region of focus ie at the steepest part of the curve and thus there is a large sensitivity to focus errors. The long range of defocusing over which the signal can be discerned from zero involves a large acquisition range of the servo system. As mentioned, the position of the knife edge determines the balance of the light fluxes of the two detectors when the scanning point is in focus and a small displacement of the edge from its middle position will be interpreted as a defocusing and subsequently "corrected" by the servo system. It is known, in order to decrease the positional sensitivity of the method to use a prism instead of a knife edge. Unfortunately, this technique is of limited application especially when required to focus on rectilinear detail, or highly topographical and varied contrast material.

A second technique involves deflection of an angled beam as illustrated in Figure 1b. A source of light is made to illuminate an object at a given angle and the reflected light is detected by a detector array. As a source of light moves into and out of focus the deflected light will strike different parts of the detector array, thus focus can be determined having regard to the parts of the detector array that are activated.

A third technique involves analysis of picture content using objective 7x for high frequency spatial components as shown in Figure 1c. In other words, the image detail is assessed. When the image is in focus 8x more detail will be provided then when out of focus 9x.
Although image analysis is a good way of focusing because it uses the whole of a field of view i.e., the region surrounding and including the focus site, it unfortunately takes considerably time to scan through focus and acquire and analyse images. Moreover, the signal is not signed and it does not provide an "in focus" null condition. In addition, the signal variation is small close to focus, thus there is a relatively small sensitivity to focus errors.

A fourth technique involves reflected spot size analysis as shown in Figures 1d and 2b. Measurement of a single reflected spot size is achieved by sampling the image via an aperture to ascertain the image intensity.

Since this fourth technique represents the closest prior art in respect of the invention it will be described in greater detail. The image or signal intensity will be at its greatest at the point of focus. This is shown in the accompanying Figure 2b which shows a graph of signal intensity as one moves through focus. Clearly, signal intensity is greatest when the image plane is in focus. Travelling in and out of focus, and thus to either side of the focus point on the X axis, signal intensity declines symmetrically. The series of dotted lines represent the graphs obtained for essentially the same system except in that the reflectivity of the surface at the image plane has been varied. Thus it can be seen that the reflectivity affects signal intensity.

However, the point of focus is constant. In addition, it can be seen that at the point of focus the curve is flattest thus indicating that there is low signal variation near focus. This means it is difficult to determine the centre point of the curve and thus the point at which focus is actually achieved.

Unfortunately this technique cannot be used with high contrast objects because it is affected by reflectivity nor does it have a signed or null focus
response. In addition, low signal variation is exhibited near to the beam focus.

It can be seen therefore that although there are at least four different techniques used in automatic focusing, each technique has associated disadvantages.

We believe that the closest prior art is described in EP 0 044 074. This document describes a method of automatic focusing which seeks to maintain the focus of a diffraction limited spot at the centre of the field of view of an objective. Focus servomechanisms are then able to track the topography of the recording medium. Thus, spot focusing is used. As previously mentioned, this means of focusing is not suitable for use with high contrast objects such as highly topographical and patterned surfaces. Furthermore, detail at the centre of the field of view is frequently out of focus with respect to the surrounding detail. Also, intensity variations within the patterning will cause false interpretations of beam intensities, and this can lead to false readings of the focus positions. In short, an automatic focusing technique for use with highly topographical and patterned surfaces requires a global as opposed to a local auto-focus mechanism.

Whilst, in principal, the design disclosed in EP 0 044 074 could be scaled up so that the relevant beam foci illuminate and utilise a much larger portion of the field of view, certain aspects of the design still remain undesirable. These aspects mainly concern noise performance and signal processing. Given the use of the design in EP 0 044 074 as a global auto-focus mechanism it follows that with a very low reflectivity target, such as a photo-resist coated semi-conductor wafer, only a small fraction of the beam will be reflected
onto the detectors. The signal strength may be only slightly greater than the noise generated within the detector. Whilst this is true of all auto-focus systems, the noise problem is increased by the presence of more than one detector, as independent noise sources, and the halving of signal strength through beam splitting. Moreover, to generate a reflectivity dependent offset from the detected signals requires their difference be divided by their sum. If a modulated signal is used to improve the signal to noise performance, then the difference and sum signals must be filtered and their amplitudes extracted before division can take place. In a computer controlled system it is also necessary to convert the resulting analogue voltage into a digital value. Though this may be done at an earlier stage and digital signal processing used, the digital resolution required would be quite large (> 12 bit). Each processing stage (difference, sum, filter, demodulation, division, A to D conversion) is a potential source of noise and offset error.

To summarise therefore, the signal beam/dual detector system described in EP 0 044 074 suffers from the following disadvantages:

1. Signal strength is halved by splitting the beam, halving the signal to noise ratio;

2. Noise from each detector is independent and is therefore summed in the combined signal;

3. Difference and sum signals must be filtered and demodulated independently, doubling filtration noise.

4. Signals must be differenced, summed and divided electronically, each
5. In a computer controlled system, signals must be converted to digital format.

It can therefore be seen that even if the design of EP 0 044 074 was adapted in order to provide for a global auto-focus mechanism it would still suffer from the above disadvantages.

In order, therefore, to provide a global auto-focus mechanism we have gone against the conventional teaching described in EP 0 044 074 and we have in fact reversed the optical configuration of EP 0 044 074 as will be described in greater detail hereinafter. Briefly, we have used two different sources and a single detector. The beams from our sources are combined via a beam splitter and are therefore co-linear. Furthermore, the beams are arranged so that they are both equally defocused on the target, when it is at the focal plane of the objective, and therefore illuminate and use exactly the same region of the target. Each of the two sources is independently modulated, ideally one with a sine wave, ideally the other with a co-sine wave of the same frequency, generated by dividing and analogue filtering a much higher digital clock frequency. This means that only a single detector is necessary because the signals can be separated electronically. However, signal separation is redundant, because the sum of the combined signals contains the desired focus information in the form of sinusoidal phase. Furthermore, this phase can be converted to a digital output by the simple expedient of counting clock pulses between the crossing points of the modulation signal and the detected signal. The digital resolution of this reading is determined by the length of counter, and the clock frequency, but is ultimately limited
by phase noise generated by the detector.

With only a single signal of fixed frequency to process, filtration and amplification is relatively straightforward. The only requirement is that any amplifier induced phase shift should be thermally stable, and should not vary with signal amplitude.

We have found that the following advantages are associated with our global auto-focus mechanism.

1. Signal to noise ratio is improved because only one detector is used.

2. Only one electronic signal is to be processed, so there is no need for matched circuits.

3. There is no need for high resolution RMS amplitude detection.

4. There is no need for electronic division of the difference signal by the sum signal.

5. Output digitisation is simplified.

Our novel technique of automatic focusing has, we believe, particular, but not exclusive, application in the semiconductor industry. During the manufacture of semiconductors, multiple layers of material are deposited on a wafer substrate. The alignment of these layers is critical to the functioning of the resultant chip and therefore it is necessary to measure wafer alignment. To this end, individual layers are provided with markers and as each layer is
deposited suitable markers are aligned. Automatic focusing is therefore required in order to assess this alignment procedure as each layer is deposited. Thus, in semiconductor metrology the automated wafer handling system must move the wafer to the measurement site and then focus on that site before an image can be acquired and an overlay measurement performed. Rapid wafer handling dictates that the focus position is very rapidly acquired, or a lock is maintained on focus throughout a wafer’s motion.

The highly topographical and variable contrast nature of a semiconductor wafer makes it a poor target for most auto-focus techniques because they tend to focus on a very small region of the wafer, or a region far away from the measurement site. In addition, many of the markers tend to be rectilinear and therefore existing knife edge or vignetting auto-focus techniques cannot be used.

It is therefore an object of the invention to provide a method, system and apparatus for automatic focusing which operates on the full field of view; provides an almost instantaneous measure of focus offset; is not susceptible to topographical and contrast variations; has a highly sensitive and signed focus response; and has maximum signal variation through focus.

In other words, it is an object of the invention to provide an automatic focusing method, system and apparatus which overcomes many of the problems associated with the prior art and which is suitable for use particularly, but not exclusively, in the semiconductor industry.

According to a first aspect of the invention there is therefore provided a method of automatic focusing comprising;
projecting at least one first beam so that it is focused forwardly of an image plane of an object to be viewed;

projecting at least one second, different beam so that it is focused rearwardly of an image plane of an object to be viewed;

projecting the reflection of said first and second beams through a vignetting aperture and onto a single focus detector.

The offset from the focus is measured in terms of the difference or ratio between the two beam signals with the desired focus position occurring when both signals have the same intensity.

In yet a preferred embodiment of the invention the signal or beam intensity can be sampled as a ratio, as opposed to a difference. This method is preferred because it is independent of reflectivity of the image plane.

It will be apparent to those skilled in the art that by utilising the correct beam displacement the point of focus may be determined when maximum signal variations with substrate position is achieved.

In a preferred embodiment of the invention the said two beams are of identical intensity and convergence.

Preferably the said second beam differs from the said first beam by a predetermined parameter which may be, for example, either optical or electronic. For example, where an optical parameter is used the two beams may differ in terms of polarisation and/or wave length. Where an electronic
parameter is used the two beams may differ in terms of modulation, for example, this modulation may be temporal i.e. the beams are on at different times, frequency i.e. the beams have different frequency modulations, or phase i.e. the beams are of the same frequency but sine and cosine wave forms are used. In the latter instance, a sine wave and cosine wave of the same frequency are used and ideally generated by dividing and analogue filtering a much higher digital clock frequency so that the signals can be separated electronically.

The above examples of how two beams can be distinguished are provided for the purpose of exemplification only. It is not intended that the above examples should be exhaustive, rather any other known means may be used in order to distinguish said first and second beams.

Ideally the method further comprises a sampling technique in order to determine the intensity of the two beams. In this technique the two beams are combined and their components measured before reflection. Thus signal beam ratios for the beams are taken before and after reflection in order to eliminate any difference between the beam intensities.

Where this preferred sampling technique is used it is preferable to differ the said first and second beams by way of phase modulation because the phase of the signals from the combined beams is a direct function of the relative beam intensity, this means that the focus offset is simply related to the phase difference between the two signals from the two beam detectors.

According to a second aspect of the invention there is provided an automatic focusing system employing the aforementioned method of the invention.
According to a yet further aspect of the invention there is provided an apparatus for automatic focusing comprising:

at least one first beam source and associated projection means adapted to project said first beam so that it focuses foremost of an image plane of an object to be viewed; at least one second, different beam source and associated projection means adapted to project said second beam rearward of an image plane of an object to be viewed; and reflection means adapted to project said reflected images of said first and second beams through a vignetting aperture and onto a single focus detector.

In a preferred embodiment of the invention said associated projection means for either or both said first and second beams comprises a beam combiner whereby said first and second beams are combined during projection and prior to focusing as above described.

More preferably still said reflection means comprises a beam splitter and ideally a lens whereby the reflected image of said first and second beams is made to change direction and pass through said lens prior to entering said vignetting aperture and then falling on said focus detector.

More preferably still means are provided so that said first and second beams are of substantially similar or identical intensity and convergence.

More preferably still means are provided for distinguishing said two beams, for example, said means may be either optical or electronic. For example, where optical means are provided said means may select for given polarisation and/or wave length properties so that beams of different
polarisation and/or wave length are provided.

In the instance where electronic means are provided means are selected so that modulation may occur, this modulation may be temporal such that the beams are on at different times, or alternatively such modulation may involve frequency whereby beams of different frequencies are provided, or alternatively, said modulation may involve phase modulation whereby beams of the same frequency are provided but having different sine and cosine waveforms. In the latter instance a sine wave and cosine wave of the same frequency are generated by dividing and analogue filtering a much higher digital clock frequency.

An embodiment of the invention will now be described by way of example only; with reference to the following figures wherein:

Figure 2c is a graph exemplifying the nature of the invention;

Figure 3 is a diagrammatic illustration of the method, system and apparatus of the invention; and

Figure 4 is a diagrammatic illustration of the means by which auto-focus modulation is achieved to provide beams of the same frequency but having different sine and cosine waveforms.

As previously mentioned, spot-size analysis represents the closest prior art for this invention. With reference to Figure 2b it has been shown how reflectivity can affect signal intensity and thus a determination of a point of focus and in addition how signal variation falls off towards the point of focus
thus making it difficult to determine this point.

With reference to Figures 2c and 3 we will disclose the method and apparatus of the invention.

Referring firstly to Figure 2c there is shown a graph of signal intensity as one moves through focus. A first beam $x$ is made to focus forwardly of said image plane and a second, different, beam $y$ is made to focus rearwardly of said image plane. Thus graphs $x$ and $y$ are produced in Figure 2c. Graphs $x_1$, $x_2$ etc and $y_1$ and $y_2$ etc show the variations that are produced in the signal provided by first and second beams as the reflectivity of the surface of the image plane changes. Such changes in reflectivity are common in semiconductor metrology because of the highly topographical nature of the wafer and/or the nature of the materials used.

Figure 2c thus shows two intersecting graphs. The point of intersection represents the point of focus and it is important to note that the point of intersection is an absolute parameter and since this represents the point of focus it can be seen that an absolute point of focus is determined. Moreover, it can also be seen that the signal variation is relatively high at the point of focus ie both curves $x$ and $y$ are relatively steep, thus again, the accuracy of a determination of a point of focus is improved.

Thus the method depicted in Figure 2c is advantageous because it provides an almost instantaneous measure of focus offset; has a highly sensitive and signed focus response and has maximum signal variation through focus.

In addition, it is possible to compensate for topographical and contrast
variations. This is achieved as follows.

In order to compensate for reflectivity we consider it advisable to determine focus as a measure of a ratio of signal intensity. Thus as a ratio of $x$ over $y$. As will be apparent to those skilled in the art the use of a ratio is preferred because the constant error introduced into the system by way of reflectivity is removed. Thus a ratio of $x:y$, $x_1:y_1$, or $x_2:y_2$ will be constant and thus a determination of a point of focus will be constant.

Figure 2c thus describes the concept underlying the invention and we will now refer to Figure 3 in order to describe just one example of an embodiment of the invention.

In the first instance, an illuminating beam, source 2, is selected and arranged to project so that its focus is displaced forwardly of a desired wafer position. This means that a large area of the wafer contributes the signal, reducing wafer detail effects. It also means that the largest signal variation occurs through the desired wafer position, and produces a directional focus offset. However, the correct wafer position now corresponds not to a null or turning point, but to a particular signal intensity which is a function of the beam intensity and the wafer reflectivity.

In order to create a null measurement method a second beam, source 1, of identical intensity and convergence, is arranged to focus rearwardly of the desired wafer position. Ideally the point of focus of each of the two beams from sources 1 and 2 is the same distance from the wafer position or image plane. This arrangement is favoured because it provides for best linearity. Given that the two beams emanating from sources 1 and 2 can be
distinguished then the wafer offset can be measured in terms of the difference between these two beams, with the desired wafer position or focus occurring when both signals have the same intensity. If their ratio is measured instead of their difference, the measured offset is also independent of the wafer reflectivity.

In practice, the beam signals may be distinguished by various techniques, both optical and electronic. The following list of techniques is not intended to be exhaustive but rather to exemplify the invention. Any known technique may be used which allows for the distinguishing of beams. Optically, polarisation and wave length may be used to physically combine and separate the beam. Electronically, the beams sources may be differently modulated in such a way that their combined signals may be separated. This modulation separation may be in time (being on at different times), frequency, (different modulation frequencies) or phase (same frequency but sine and cosine wave forms).

Phase modulation is achieved ideally having regard to the information provided in Figure 4. A first beam source is provided by emitter 26 and a second beam source is provided by emitter 28. A single detector is represented at reference 30. The auto-focus modulation, phase counting, and control signals are all derived from the same crystal controlled oscillator 10. To generate the sinusoidal modulation signals the oscillator output is divided down, using clock divider 12, to produce a square wave 14 which is then low pass filtered, using filter 16, to remove all but the fundamental harmonic. Modulation signals with ¼ wave phase difference can be generated either by integrating this sine wave, or by generating and filtering a second phase shifted square wave 18 using filter 20. The modulation signals drive the
LED sources through ballast resistors to a negative bias voltage, so that they are always forward biased and generating light. This bias voltage may be switched to turn the LEDs off when the auto-focus is not required.

The light received by the single detector carries a proportion of each of the output modulation signals, with the amplitude ratio determined by the focus offset of the targets. Since both signals are sinusoids of the same frequency, their sum is likewise a sinusoid of that frequency, with a phase determined by their amplitude ratio. Therefore the signal from the detector is proportional to the sum of the signal intensities, as a phase determined by the focus offset of the target.

A very narrow band filter is used to select only the frequency of interest and reduce the noise level, and any DC offset. The filtered signal is then converted back to a square wave by a comparator. A timer 22, counting at the original oscillator frequency, is triggered by the modulated square wave, and stopped by the regenerated detection square wave. The resulting count, which represents a phase offset, is then output to a latch buffer 24 to be read by the controlling computer.

It therefore follows that the use of beams that are reflected forwardly and rearwardly of an image plane provide a means of determining focus. This is because signals from the two beams will have the same intensity at the point of focus.

The advantage of the invention is that it involves no complex calculation and therefore the results of the focus detector can be fed simply to a servo motor and thus almost instantaneous focusing can be achieved.
We therefore have devised a novel technique for enabling automatic focusing, which technique includes highly desirable parameters such as a signed focus response with a null at the desired focus and maximum signal variation through focus. In addition, the technique is robust in that it is not susceptible to topographical and contrast variation and moreover it can operate on a full field of view.
CLAIMS

1. A method of automatic focusing comprising;

projecting at least one first beam so that it is focused forwardly of an image plane of an object to be viewed;

projecting at least one second, different beam, so that it is focused rearwardly of an image plane of an object to be viewed;

projecting the reflection of said first and second beams through a vignetting aperture and onto a single focus detector.

2. A method according to claim 1 which further comprises determining the intensity of the said two beam signals with a view to establishing focus when both signal intensities are equal.

3. A method according to claim 1 or 2 which further comprises determining the ratio of the two beam signal intensities.

4. A method according to any preceding claim wherein said two beams are of identical intensity.

5. A method according to any preceding claim wherein said two beams are of identical convergence.

6. A method according to any preceding claim wherein said second beam differs from said first beam by a predetermined parameter.
7. A method according to claim 6 wherein said parameter is optical.

8. A method according to claim 7 wherein said parameter is polarisation and/or wavelength.

9. A method according to claim 6 wherein said parameter is electronic.

10. A method according to claim 9 wherein said parameter is modulation.

11. A method according to claim 10 wherein said modulation is temporal.

12. A method according to claim 9 wherein said parameter is frequency.

13. A method according to claim 12 wherein a sine beam and cosine beam are produced.

14. A method according to claim 13 wherein said sine beam and cosine beam are of the same frequency.

15. A method according to any preceding claim wherein a sampling technique comprising a measurement of one, or both, beams before and after reflection by the object to be viewed is undertaken in order to eliminate any difference between the intensity of the two beams.

16. An apparatus for automatic focusing comprising:

at least one first beam source and associated projection means adapted to project said first beam foremost of an image plane of an object to
be viewed;

at least one second, different beam source and associated projection means adapted to project said second beam rearward of an image plane of an object to be viewed; and

a reflection means adapted to project said reflected images of said first and second beams through a vignetting aperture and onto a single focus detector.

17. An apparatus according to claim 16 wherein associated projection means for either or both of said first and second beams comprises a beam combiner whereby said first and second beams are combined during projection and prior to focusing.

18. An apparatus according to claims 16 or 17 wherein said reflection means comprises a beam splitter.

19. An apparatus according to claim 16 wherein said reflection means further comprises a lens whereby the reflected images of said first and second beams are made to change direction and pass through said lens prior to enter said vignetting aperture and falling on said focus detector.

20. An apparatus according to claims 16 to 19 wherein said apparatus further comprises means to ensure that said first and second beams are of substantially similar or identical intensity.
21. An apparatus according to claims 16 to 20 wherein said apparatus further comprises means so as to ensure that said first and second beams are of substantially similar or identical convergence.

22. An apparatus according to claims 16 to 21 wherein said apparatus further comprises means which enables said two beams to be distinguished.

23. Apparatus according to claim 10 wherein said means enables the polarisation and/or wavelength of one beam to be varied having regard to said remaining beam.

24. Apparatus according to claim 22 wherein said means comprises electronic means which enables one of said beams to be modulated with respect to said remaining beam.
FIGURE 1

METHODS OF AUTOMATIC FOCUS
FIGURE 2a

FIGURE 2b

FIGURE 2c

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INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B7/32 G03F9/00 G02B21/24 G02B7/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B G03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>DE 27 19 214 A (AGFA GEVAERT AG) 9 November 1978</td>
<td>1-6, 9-12, 15-22,24</td>
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<td>see page 10, line 1 - page 12, line 13; claims 1,2,4; figure 1</td>
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<td>DE 34 46 727 A (ZEISS CARL FA) 3 July 1986</td>
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<td>EP 0 608 448 A (IBM) 3 August 1994</td>
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Patent family members are listed in annex.

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Date of the actual completion of the international search
26 March 1997

Date of mailing of the international search report
16.04.97

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