LINEWIDTH MEASUREMENT SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 61/542,061, filed September 30, 2011, the disclosure of which is incorporated by reference in its entirety herein.

TECHNICAL FIELD

[0002] The present disclosure relates to material inspection systems, such as computerized systems for the inspection of moving webs of material.

BACKGROUND

[0003] Many different industries utilize processes for making micro-scale patterns on a surface of a substrate. These micro-scale patterns include an array of surface features, such as elongate grooves extending below the surface or raised ribs extending above the surface. During manufacture of a substrate including such an array of surface features, microscope imaging has been used to measure the dimensions of one or more features in the array. However, microscope imaging has a small depth of field and a narrow field of view, which has restricted its use to off-line analysis of the surface features on the substrate.

SUMMARY

[0004] An inspection technique is needed to provide real-time measurement of the dimensions of the surface features on a surface of a material as the material is being manufactured. In general, the present disclosure is directed to an apparatus and a method for measuring the dimensions of a selected surface feature in a material by processing an image of a Fraunhofer diffraction pattern of the surface feature. This measurement technique can be used to monitor the dimensions of the selected feature off-line or on-line as the material is being manufactured.

[0005] In one embodiment, the present disclosure is directed to a method including passing an interrogating light beam through a Fourier transform lens and onto the surface of a material to form a Fraunhofer diffraction pattern of one or more surface features of the material; forming an image of the diffraction pattern; and processing the image of the diffraction pattern to determine the dimensions of the feature, wherein the dimension of the feature is determined from a distance between a central order beam and a first diffraction minimum in the diffraction pattern.

[0006] In another embodiment, the present disclosure is directed to an apparatus including a light source that emits an interrogating beam into a Fourier transform lens and onto a surface

to form a Fraunhofer diffraction pattern of a feature on the surface, wherein the lens and the surface are arranged in a reverse Fourier transform mode; an image acquisition device that captures an image of the Fraunhofer diffraction pattern of the feature on the surface; and a processor to determine the diffraction pattern size and calculate a dimension of the feature on the surface, wherein the dimension of the feature is determined from a distance between a central order beam and a first diffraction minimum in the diffraction pattern.

[0007] In yet another embodiment, the present disclosure is directed to a system for monitoring a dimension of a selected feature on a surface of a material, including a light source positioned proximal to the surface, wherein the light source emits an interrogating beam through a Fourier transform lens and onto the surface to form a Fraunhofer diffraction pattern of one or more features on the surface, wherein the surface is between the Fourier transform lens and the focus thereof; an image acquisition device to capture an image of the Fraunhofer diffraction pattern of the features on the surface; and a processor to measure the size of the Fraunhofer diffraction pattern to determine a dimension of a seletected feature in the array, wherein the dimension of the selected feature is determined from a distance between a central order beam and a first diffraction minimum in the Fraunhofer diffraction pattern.

[0008] In yet another embodiment, the present disclosure is directed to a method, including positioning a light source proximal to a surface of a non-stationary web of a flexible material, wherein the web includes an arrangement of features in a surface thereof, and wherein the light source emits an interrogating beam through a Fourier transform lens and onto the surface of the web, and wherein the surface of the web and the Fourier transform lens are positioned in a reverse Fourier Transform mode; scanning the interrogating beam over the surface of the web to form a Fraunhofer diffraction pattern of one of more of the features as the beam seams; projecting an image of the diffraction pattern onto a screen or a lens; capturing with a camera the image of the diffraction pattern on the screen or lens; and measuring the diffraction pattern size to determine a dimension of a selected feature, wherein the dimension of the selected feature is determined from a distance between a central order beam and a first diffraction minimum in the Fraunhofer diffraction pattern.

[0009] In another embodiment, the present disclosure is directed to a method for inspecting web material in real time and computing a dimension of a selected feature on a surface of the web material as the web material is manufactured, including positioning a light source proximal to the surface of a the web material, wherein the light source emits an interrogating beam through a

Fourier transform lens and onto the surface of the web material, and wherein the surface of the web and the Fourier transform lens are arranged in a reverse Fourier Transform mode; scanning the interrogating beam over the surface of the web material to form a Fraunhofer diffraction pattern of one or more features on the surface; projecting an image of the diffraction pattern onto a screen or lens; imaging the diffraction pattern with a camera, wherein the camera measures the diffraction pattern size; and computing the dimension of the selected feature based on the diffraction pattern size, wherein the dimension of the feature is determined from a distance between a central order beam and a first diffraction minimum in the Fraunhofer diffraction pattern.

[0010] In yet another embodiment, the present disclosure is directed to an online computerized inspection system for inspecting web material in real time, the system including a light source positioned proximal to the surface of a the web material, wherein the light source emits an interrogating beam through a Fourier transform lens and onto the surface of the web material, and wherein the surface of the web and the Fourier transform lens are positioned in a reverse Fourier Transform mode; a scanner to scan the light interrogating beam over the surface of the web material to form a Fraunhofer diffraction pattern of one or more features in the web material; a camera to capture an image of the diffraction pattern , wherein the camera measures a diffraction pattern size; ~~and~~ a computer executing software to determine the dimensions of a selected feature based on the measured diffraction pattern size; and a memory to store a web inspection model, wherein the computer executes software to compare the dimensions of the selected feature to the model and compute a severity of a non-uniformity defect in the web material.

[0011] In yet another embodiment, the present disclosure is directed to a non-transitory computer readable medium comprising software instructions to cause a computer processor to: receive, with an online computerized inspection system, an image of a Fraunhofer diffraction pattern of one or more features on a surface of a web material during the manufacture thereof, wherein the inspection system measures a diffraction pattern size; determine the dimensions of a selected feature based on the measured diffraction pattern size; and compute the severity of a non-uniformity defect in the web material based on the calculated dimensions of the selected feature.

[0012] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0013] FIG. 1 is a schematic plan view of an embodiment of an apparatus for measuring the dimensions of a surface feature of a material by imaging a reflected Fraunhofer diffraction pattern of the surface feature.

[0014] FIG. 2 is an example of an interference pattern characteristic of an array of surface features as modulated by a sine-squared envelope function.

[0015] FIG. 3 is a schematic plan view of an embodiment of an apparatus for measuring the dimensions of a surface feature of a material by imaging a transmitted Fraunhofer diffraction pattern of the surface feature.

CLAIMS:

1. A method, comprising:

passing an interrogating light beam through a Fourier transform lens and onto the surface of a material to form a Fraunhofer diffraction pattern of one or more surface features of the material;

forming an image of the diffraction pattern; and

processing the image of the diffraction pattern to determine the dimensions of the feature, wherein the dimension of the feature is determined from a distance between a central order beam and a first diffraction minimum in the diffraction pattern.

~~2. The method of claim 1, wherein the dimension of the feature is determined from a distance between a central order beam and a first diffraction minimum in the diffraction pattern.~~

32. The method of claim 1, wherein the image of the diffraction pattern captured by a CCD camera.

43. The method of claim 1, wherein the image of the diffraction pattern is formed by reflecting the interrogating beam off the surface of the material and onto a screen or a lens.

54. The method of claim 1, wherein the image of the diffraction pattern is formed by transmitting the interrogating beam through the surface of the material and onto a screen or a lens.

65. The method of claim 43, wherein the image of the diffraction pattern is formed by reflecting the interrogating beam onto a screen.

76. The method of claim 1, wherein the interrogating light beam is collimated.

87. The method of claim 1, wherein the surface is between the Fourier transform lens and a focus of the Fourier transform lens.

98. The method of claim 1, wherein the surface of the material is flexible.

~~10~~9. The method of claim 9, wherein the surface of the material is non-stationary.

~~11~~10. An apparatus, comprising:

a light source that emits an interrogating beam into a Fourier transform lens and onto a surface to form a Fraunhofer diffraction pattern of a feature on the surface, wherein the lens and the surface are arranged in a reverse Fourier transform mode;

an image acquisition device that captures an image of the Fraunhofer diffraction pattern of the feature on the surface; and

a processor to determine the diffraction pattern size and calculate a dimension of the feature on the surface, wherein the dimension of the feature is determined from a distance between a central order beam and a first diffraction minimum in the diffraction pattern.

~~12~~11. The apparatus of claim ~~11~~10, wherein the image acquisition device comprises a CCD camera.

~~13~~12. The apparatus of claim ~~11~~10, wherein the processor is within the image acquisition device.

~~14~~13. The apparatus of claim ~~11~~10, wherein the light source is collimated.

~~15~~14. The apparatus of claim ~~12~~11, wherein the light source is a laser.

~~16~~15. The apparatus of claim ~~11~~10, further comprising a beam expander between the light source and the Fourier transform lens.

~~17~~16. The apparatus of claim ~~11~~10, wherein the interrogating beam is reflected off the surface and onto a screen or a lens.

~~18~~17. The apparatus of claim ~~11~~10, wherein the interrogating beam is transmitted through the surface and onto a screen or a lens.

~~19~~18. A system for monitoring a dimension of a selected feature on a surface of a material, comprising:

a light source positioned proximal to the surface, wherein the light source emits an interrogating beam through a Fourier transform lens and onto the surface to form a

Fraunhofer diffraction pattern of one or more features on the surface, wherein the surface is between the Fourier transform lens and the focus thereof;

an image acquisition device to capture an image of the Fraunhofer diffraction pattern of the features on the surface; and

a processor to measure the size of the Fraunhofer diffraction pattern to determine a dimension of a selected feature in the array, wherein the dimension of the selected feature is determined from a distance between a central order beam and a first diffraction minimum in the Fraunhofer diffraction pattern.

~~20~~19. The system of claim ~~19~~18, wherein the surface of the material is non-stationary.

~~21~~20. The system of claim ~~19~~18, wherein the light source is scanned over the surface of the material.

~~22~~21. The system of claim ~~19~~18, wherein the light source is a laser.

~~23~~22. The system of claim ~~19~~18, wherein the image of the Fraunhofer diffraction pattern is taken in reflection off the surface of the material.

~~24~~23. The system of claim ~~19~~18, wherein the image of the Fraunhofer diffraction pattern is taken via transmission through the surface of the material.

~~25~~24. The system of claim ~~19~~18, wherein the light source is above the surface of the material.

~~26~~25. A method, comprising:

positioning a light source proximal to a surface of a non-stationary web of a flexible material, wherein the web comprises an arrangement of features in a surface thereof, and wherein the light source emits an interrogating beam through a Fourier transform lens and onto the surface of the web, and wherein the surface of the web and the Fourier transform lens are positioned in a reverse Fourier Transform mode;

scanning the interrogating beam over the surface of the web to form Fraunhofer diffraction patterns of one or more features as the beam scans;

projecting an image of the diffraction pattern onto a screen or a lens;

capturing with a camera the image of the diffraction pattern on the screen or lens; and

measuring the diffraction pattern size to determine a dimension of a selected feature, wherein the dimension of the selected feature is determined from a distance between a central order beam and a first diffraction minimum in the Fraunhofer diffraction pattern.

~~27~~26. The method of claim ~~26~~25, wherein the light source is continuously scanned over the surface of the material.

~~28~~27. The method of claim ~~26~~25, wherein the image of the Fraunhofer diffraction pattern is taken in reflection off the surface of the material.

~~29~~28. The method of claim ~~26~~25, wherein the image of the Fraunhofer diffraction pattern is taken via transmission through the surface of the material.

~~30~~29. The method of claim ~~26~~25, wherein the light source is above the surface of the material.

~~31~~30. A method for inspecting web material in real time and computing a dimension of a selected feature in a surface of the web material as the web material is manufactured, comprising:

positioning a light source proximal to the surface of a the web material, wherein the light source emits an interrogating beam through a Fourier transform lens and onto the surface of the web material, and wherein the surface of the web and the Fourier transform lens are arranged in a reverse Fourier Transform mode;

scanning the interrogating beam over the surface of the web material to form a Fraunhofer diffraction pattern of one or more features on the surface;

projecting an image the diffraction pattern onto a screen or a lens;

imaging the the diffraction pattern with a camera, wherein the camera measures the diffraction pattern size; and

computing the dimension of the selected surface feature based on the diffraction pattern size, wherein the dimension of the feature is determined from a distance between a central order beam and a first diffraction minimum in the Fraunhofer diffraction pattern.

~~32~~31. The method of claim ~~31~~30, further comprising presenting a user interface to output the dimension of the selected feature to a user.

~~33~~32. The method of claim ~~32~~31, further comprising updating a process control parameter for the manufactured web material in response to the output.

~~34~~33. An online computerized inspection system for inspecting web material in real time, the system comprising:

a light source positioned proximal to the surface of a the web material, wherein the light source emits an interrogating beam through a Fourier transform lens and onto the surface of the web material, and wherein the surface of the web and the Fourier transform lens are positioned in a reverse Fourier Transform mode;

a scanner to scan the light interrogating beam over the surface of the web material to form a Fraunhofer diffraction pattern of one or more features in the surface web material;

a camera to capture an image of the diffraction pattern, wherein the camera measures a diffraction pattern size; ~~and~~

a computer executing software to determine the dimensions of a selected surface feature based on the measured diffraction pattern size; and

a memory to store a web inspection model, wherein the computer executes software to compare the dimensions of the selected feature to the model and compute a severity of a non-uniformity defect in the web material.

~~35. The system of claim 34, further comprising a memory to store a web inspection model, wherein the computer executes software to compare the dimensions of the selected feature to the model and compute a severity of a non-uniformity defect in the web material.~~

~~36~~34. The system of claim ~~34~~33, further comprising a user interface to output the severity of the defect to a user.

~~37~~35. A non-transitory computer readable medium comprising software instructions to cause a computer processor to:

receive, with an online computerized inspection system, an image of a Fraunhofer diffraction pattern of one or more features on a surface of a web material during the manufacture thereof, wherein the inspection system measures a diffraction pattern size;

determine the dimensions of a selected feature in the array based on the measured diffraction pattern size; and

compute the severity of a non-uniformity defect in the web material based on the calculated dimension of the selected feature.