By repeating the iterative process for each of the plurality of planes, a three dimensional image of the object may be obtained.

However, problems have been noted in that images produced by the method of WO 2008/142360 may be complicated by Fresnel-type fringes relating to a plane adjacent to the plane of interest, such as a plane in front (upstream) or behind (downstream) of the plane of interest. Furthermore, the method takes no account of multiple scattering effects. That is to say, it does not take into account the effect of the object on the illumination as it propagates through the object, such as due to scattering from upstream layers of the object previously traversed by the illumination.

It is an object of embodiments of the invention to at least mitigate one or more of the problems of the prior art.

Summary

According to a first aspect of the invention, there is provided a method of providing image data for constructing an image of a region of a three dimensional target object, comprising: providing, from a radiation source, incident radiation directed at a target object; detecting an intensity of radiation scattered by the target object; determining image data for each of a respective plurality of slices within the target object each indicating one or more characteristics of the target object at a respective depth within the target object, wherein the image data is determined based on the detected intensity of radiation via an iterative process wherein running estimates of the image data for each of the plurality of slices are updated step by step.

According to a second aspect of the invention, there is provided an apparatus for providing image data for generating an image of at least one region of a target object, comprising: a radiation source for providing incident radiation at a target object; at least one detector device for detecting an intensity of radiation scattered by said target object; a processor that provides the image data responsive to a detected intensity of the scattered radiation, wherein the said processor is arranged to provide image data for each of a respective plurality of slices within the target object each indicating one or more characteristics of the target object at a respective depth within the target object, wherein the image data is determined based on the detected intensity of the radiation via an iterative process wherein running estimates of the image data for each of the plurality of slices are updated step by step.

Brief Description of the Drawings

Embodiments of the invention will now be described by way of example only, with reference to the accompanying figures, in which:

Figure 1 shows an apparatus according to an embodiment of the invention;

Figure 2 shows a first method according to an embodiment of the invention;

Figure 3 shows an apparatus associated with the method of Figure 2 according to an embodiment of the invention;

Figure 4 shows a second method according to an embodiment of the invention;

Figure 5 an apparatus associated with the method of Figure 4 according to an embodiment of the invention;

Figure 6 shows an apparatus according to another embodiment of the invention;

Figure 7 shows an apparatus according to a further embodiment of the invention;

CLAIMS

1. A method of providing image data for constructing an image of a region of a three dimensional target object, comprising:

providing, from a radiation source, incident radiation directed at a target object;

detecting an intensity of radiation scattered by the target object;

determining image data for each of a respective plurality of slices within the target object each indicating one or more characteristics of the target object at a respective depth within the target object, wherein the image data is determined based on the detected intensity of radiation via an iterative process wherein running estimates of the image data for each of the plurality of slices are updated step by step with each iteration.

2. The method of claim 1, wherein the image data for each slice is determined based upon an integral of a property of the object between first and second surfaces.

3. The method of claim 2, wherein the property of the object is one of: an optical potential or an atomic potential of the object.

4. The method of any preceding claim, comprising determining a running estimate of a transmission function for each slice indicating at least one characteristic of the target object.

5. The method of claim 4 when dependent upon claim 2 or 3, wherein the transmission function is based upon the integral of the property of the object between the surfaces.

6. The method of claim 4 or 5, wherein an accuracy of the running estimates of the transmission functions is improved by re-estimating the transmission functions with each step.

7. The method of any preceding claim, comprising providing said image data responsive to at least the detected intensity of the radiation at first and second positions with respect to the target object.

8. The method of claim 7, wherein the first and second positions are formed using a softly varying transmittance function, or illumination function, movable with respect to said target object.

9. The method of any preceding claim , comprising:

determining a probe function indicative of one or more characteristics of the incident radiation incident on each of the plurality of slices;

determining an exit wave estimate for each of the slices based on the probe function and a transmission function associated with each respective slice;

determining a combined exit wave estimate by propagating each exit wave to a surface and combining each of the exit waves at that surface.

10. The method of claim 9, wherein the probe function indicates an estimate of the incident radiation propagating in free space corresponding to a depth of each slice.

11. The method of claim 9 or 10, comprising propagating the combined exit wave from the surface to the detector to determine an expected scattering pattern at the detector.

12. The method of claim 11, comprising correcting at least one characteristic of said expected scattering pattern according to the detected intensity.

13. The method of claim 12, comprising inversely propagating the corrected expected scattering pattern to provide an updated estimate of the combined exit wave at the surface.

14. The method of claim 13, comprising determining a portion of the updated estimate of the combined exit wave corresponding to each slice and inversely propagating the respective portion to each slice.

15. The method of claim 14, comprising updating the transmission function associated with each respective slice based upon the inversely propagated respective portion.

16. The method of any of claims 10 to 15, wherein the exit waves are combined at the surface by summation of the exit waves.

17. The method of claim 16 when dependent upon claim 14 or 15, wherein the portion of the combined exit wave corresponding to each slice is determined by subtracting the exit waves propagated to the surface from other slices.

18. The method of any of claims 14 to 17, comprising updating the probe function at one of the slices based upon the inversely propagated respective portion of the updated estimate of the combined exit wave.

19. The method of claim of any of claims 1 to 9, comprising:

determining a probe function indicative of one or more characteristics of the incident radiation upon a first slice;

determining a first exit wave estimate for the first slice based on the probe function and a transmission function associated with the first slice;

propagating the first exit wave to a second slice, wherein the propagated first exit wave forms a probe function for the second slice; and

determining a second exit wave estimate for the second slice based on the probe function and a transmission function associated with the second slice.

20. The method of claim 19, comprising determining probe functions and exit wave estimates for one or more further slices of the object.

21. The method of claim 19 or 20, comprising propagating an exit wave from a final slice of the object to the detector to determine an expected scattering pattern at the detector.

22. The method of claim 21, comprising correcting at least one characteristic of said expected scattering pattern according to the detected intensity.

23. The method of claim 22, comprising inversely propagating the corrected expected scattering pattern to provide an updated estimate of the exit wave from the final slice.

24. The method of claim 23, comprising updating the transmission function associated with the final slice based upon the updated estimate of the exit wave.

25. The method of claim 23 or 24, comprising updating the probe function incident on the final slice based upon the updated estimate of the exit wave.

26, The method of claim 25, comprising inversely propagating the updated probe function to a previous slice as the updated exit wave for that slice.

27. Apparatus for providing image data for generating an image of at least one region of a target object, comprising:
a radiation source for providing incident radiation at a target object;
at least one detector device for detecting an intensity of radiation scattered by said target object;
a processor that provides the image data responsive to a detected intensity of the scattered radiation, wherein the said processor is arranged to provide image data for each of a respective plurality of slices within the target object each indicating one or more characteristics of the target object at a respective depth within the target object, wherein the image data is determined based on the detected intensity of the radiation

via an iterative process wherein running estimates of the image data for each of the plurality of slices are updated step by step with each iteration.

28. The apparatus of claim 27, wherein the processor is arranged to perform the method of any of claims 2 to 26.

29. Computer software comprising computer-executable instructions which, when executed by a processing device, causes the processing device to perform the method of any of claims 1 to 26.

30. The computer software of claim 29, wherein the computer-executable instructions are stored on a computer-readable medium.

CLAIMS

1. A method of providing image data for constructing an image of a region of a three dimensional target object, comprising:

providing, from a radiation source, incident radiation directed at a target object;

detecting an intensity of radiation scattered by the target object;

determining image data for each of a respective plurality of slices within the target object each indicating one or more characteristics of the target object at a respective depth within the target object, wherein the image data is determined based on the detected intensity of radiation via an iterative process wherein running estimates of the image data for each of the plurality of slices are updated step by step.

2. The method of claim 1, wherein the image data for each slice is determined based upon an integral of a property of the object between first and second surfaces.

3. The method of claim 2, wherein the property of the object is one of: an optical potential or an atomic potential of the object.

4. The method of any preceding claim, comprising determining a running estimate of a transmission function for each slice indicating at least one characteristic of the target object.

5. The method of claim 4 when dependent upon claim 2 or 3, wherein the transmission function is based upon the integral of the property of the object between the surfaces.

6. The method of claim 4 or 5, wherein an accuracy of the running estimates of the transmission functions is improved by re-estimating the transmission functions with each step.

7. The method of any preceding claim, comprising providing said image data responsive to at least the detected intensity of the radiation at first and second positions with respect to the target object.

8. The method of claim 7, wherein the first and second positions are formed using a softly varying transmittance function, or illumination function, movable with respect to said target object.

9. The method of any preceding claim , comprising:

determining a probe function indicative of one or more characteristics of the incident radiation incident on each of the plurality of slices;

determining an exit wave estimate for each of the slices based on the probe function and a transmission function associated with each respective slice;

determining a combined exit wave estimate by propagating each exit wave to a surface and combining each of the exit waves at that surface.

10. The method of claim 9, wherein the probe function indicates an estimate of the incident radiation propagating in free space corresponding to a depth of each slice.

11. The method of claim 9 or 10, comprising propagating the combined exit wave from the surface to the detector to determine an expected scattering pattern at the detector.

12. The method of claim 11, comprising correcting at least one characteristic of said expected scattering pattern according to the detected intensity.

13. The method of claim 12, comprising inversely propagating the corrected expected scattering pattern to provide an updated estimate of the combined exit wave at the surface.

14. The method of claim 13, comprising determining a portion of the updated estimate of the combined exit wave corresponding to each slice and inversely propagating the respective portion to each slice.

15. The method of claim 14, comprising updating the transmission function associated with each respective slice based upon the inversely propagated respective portion.

16. The method of any of claims 10 to 15, wherein the exit waves are combined at the surface by summation of the exit waves.

17. The method of claim 16 when dependent upon claim 14 or 15, wherein the portion of the combined exit wave corresponding to each slice is determined by subtracting the exit waves propagated to the surface from other slices.

18. The method of any of claims 14 to 17, comprising updating the probe function at one of the slices based upon the inversely propagated respective portion of the updated estimate of the combined exit wave.

19. The method of claim of any of claims 1 to 9, comprising:

determining a probe function indicative of one or more characteristics of the incident radiation upon a first slice;

determining a first exit wave estimate for the first slice based on the probe function and a transmission function associated with the first slice;

propagating the first exit wave to a second slice, wherein the propagated first exit wave forms a probe function for the second slice; and

determining a second exit wave estimate for the second slice based on the probe function and a transmission function associated with the second slice.

20. The method of claim 19, comprising determining probe functions and exit wave estimates for one or more further slices of the object.

21. The method of claim 19 or 20, comprising propagating an exit wave from a final slice of the object to the detector to determine an expected scattering pattern at the detector.

22. The method of claim 21, comprising correcting at least one characteristic of said expected scattering pattern according to the detected intensity.

23. The method of claim 22, comprising inversely propagating the corrected expected scattering pattern to provide an updated estimate of the exit wave from the final slice.

24. The method of claim 23, comprising updating the transmission function associated with the final slice based upon the updated estimate of the exit wave.

25. The method of claim 23 or 24, comprising updating the probe function incident on the final slice based upon the updated estimate of the exit wave.

26, The method of claim 25, comprising inversely propagating the updated probe function to a previous slice as the updated exit wave for that slice.

27. Apparatus for providing image data for generating an image of at least one region of a target object, comprising:

a radiation source for providing incident radiation at a target object;

at least one detector device for detecting an intensity of radiation scattered by said target object;

a processor that provides the image data responsive to a detected intensity of the scattered radiation, wherein the said processor is arranged to provide image data for each of a respective plurality of slices within the target object each indicating one or more characteristics of the target object at a respective depth within the target object, wherein the image data is determined based on the detected intensity of the radiation

via an iterative process wherein running estimates of the image data for each of the plurality of slices are updated step by step.

28. The apparatus of claim 27, wherein the processor is arranged to perform the method of any of claims 2 to 26.

29. Computer software comprising computer-executable instructions which, when executed by a processing device, causes the processing device to perform the method of any of claims 1 to 26.

30. The computer software of claim 29, wherein the computer-executable instructions are stored on a computer-readable medium.