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(54) **INFORMATION PROCESSING DEVICE, INFORMATION PROCESSING METHOD, AND RECORDING MEDIUM RECORDED WITH INFORMATION PROCESSING PROGRAM**

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(57) **ABSTRACT**

An information processing device acquires an image captured by a transmission electron microscope. The information processing device, for each partial region in the image, executes a two-dimensional Fourier transform on an image of the partial region. The information processing device, based on results obtained by executing the two-dimensional Fourier transform on each of the partial regions, performs clustering of frequency strengths obtained from the results of the two-dimensional Fourier transform. The information processing device determines regions of different crystallinity in the image, based on results of the clustering.

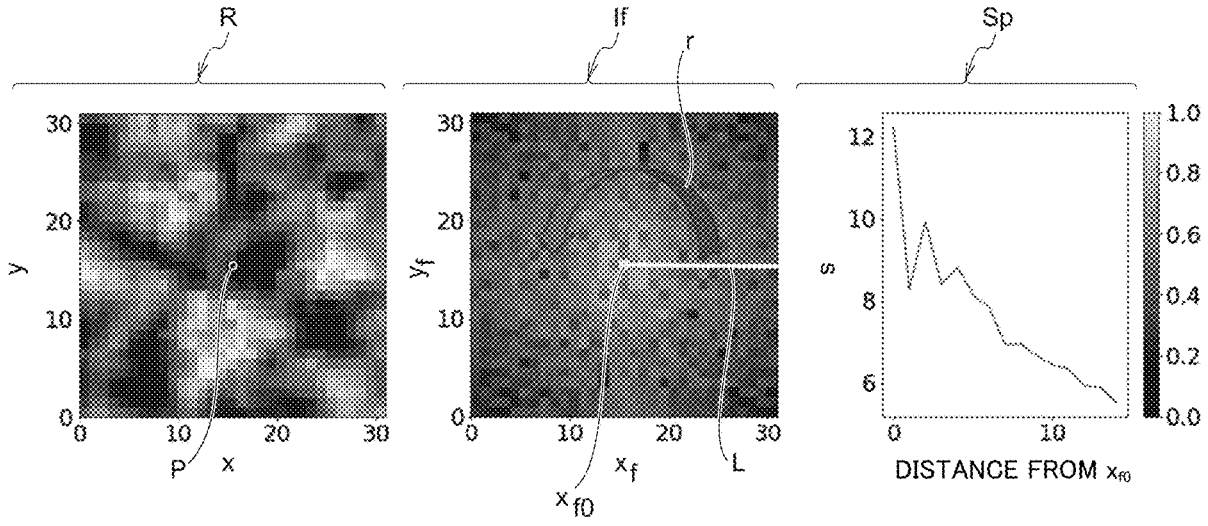


FIG.1

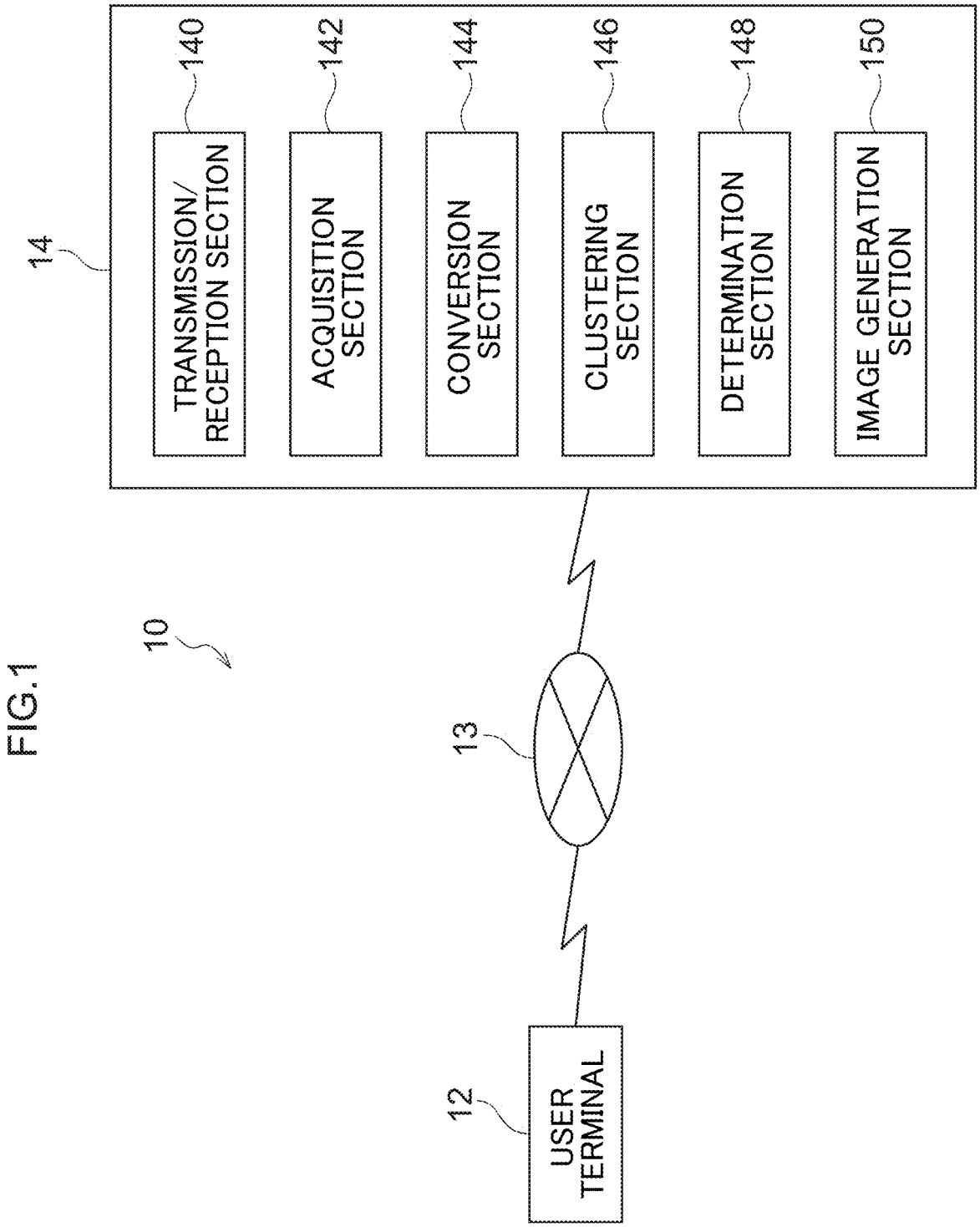

10
14
140
TRANSMISSION/ RECEPTION SECTION
142
ACQUISITION SECTION
144
CONVERSION SECTION
146
CLUSTERING SECTION
148
DETERMINATION SECTION
150
IMAGE GENERATION SECTION
13
12
USER TERMINAL

FIG.2

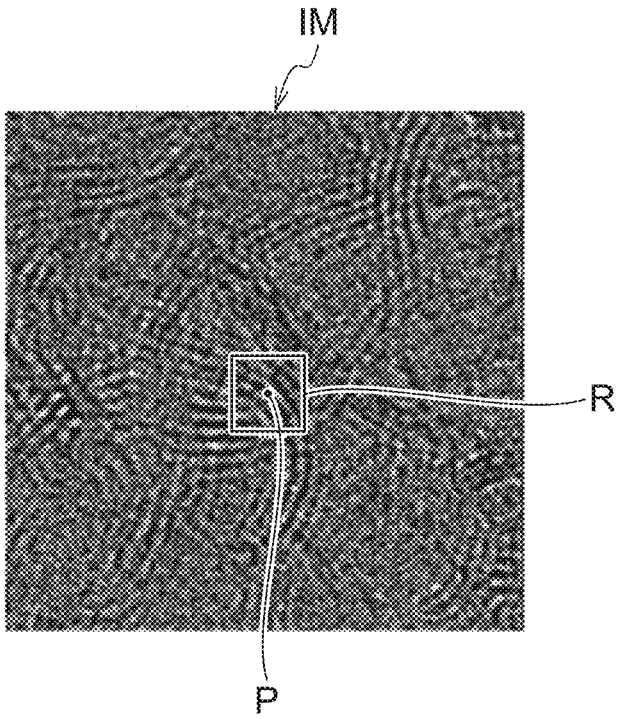


FIG.3

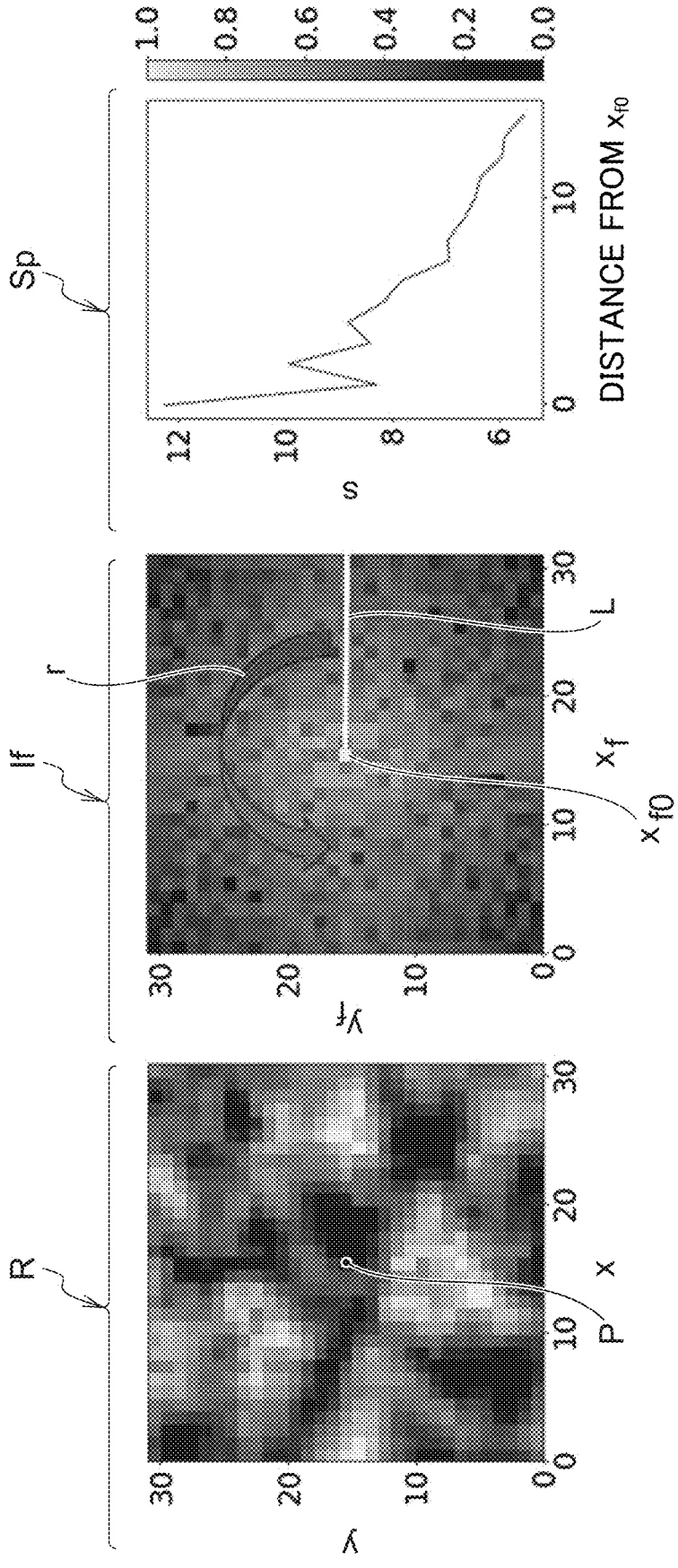


FIG.4

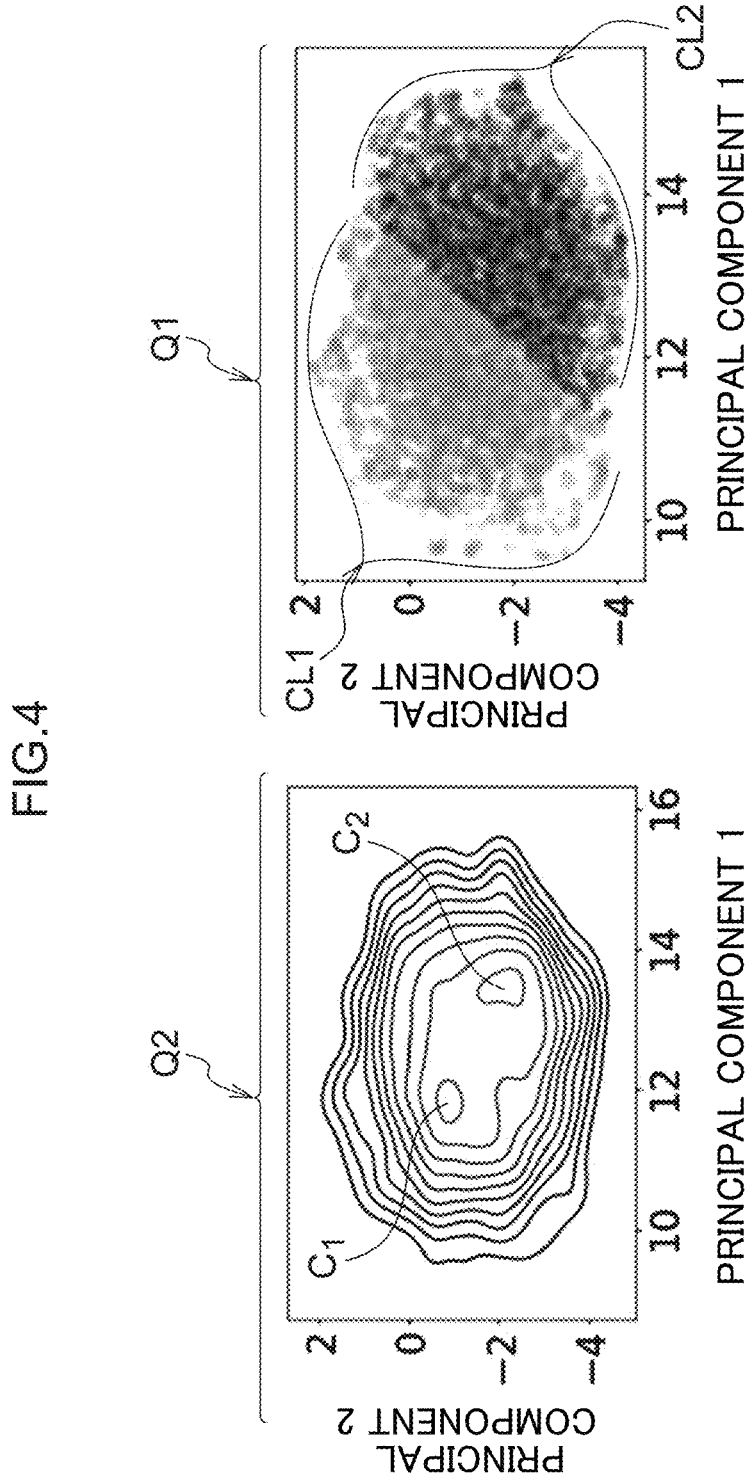

Q1
CL1
CL2
PRINCIPAL COMPONENT 2
2
0
−2
−4
10
12
14
PRINCIPAL COMPONENT 1
Q2
C1
C2
PRINCIPAL COMPONENT 2
2
0
−2
−4
10
12
14
16
PRINCIPAL COMPONENT 1

FIG.5

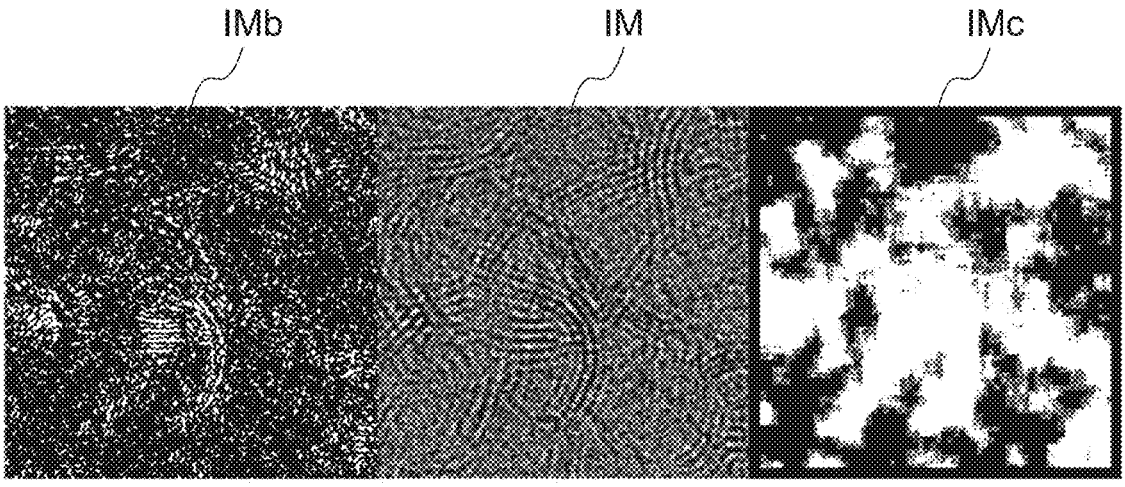

IMb
IM
IMc

FIG.6

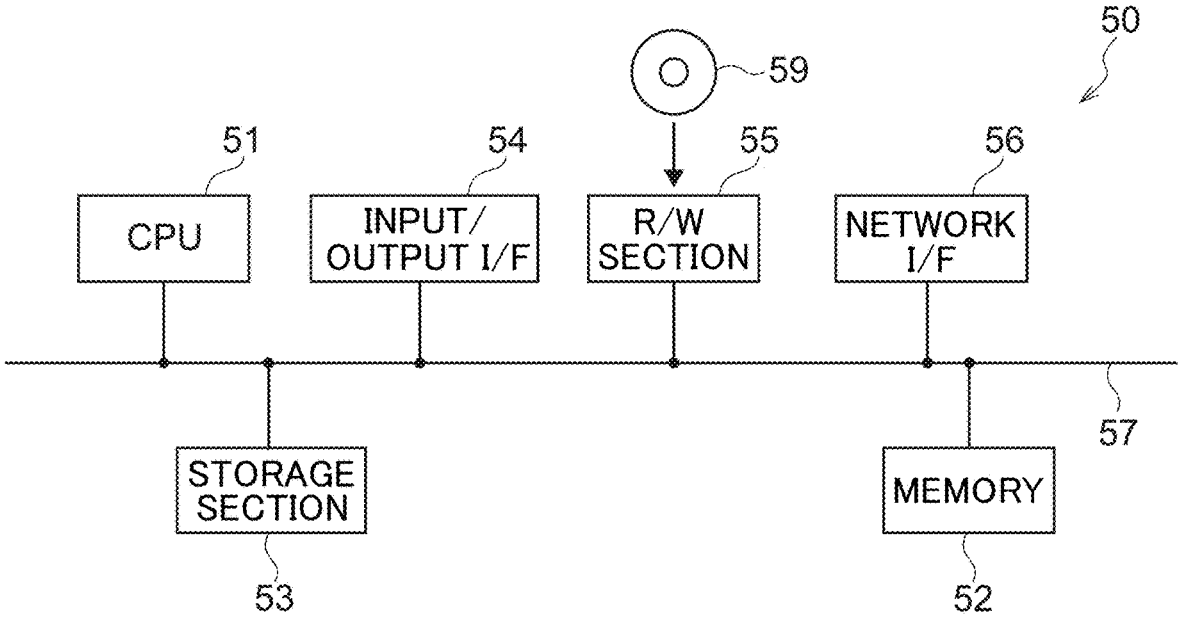

50
59
51
54
55
56
CPU
INPUT/
OUTPUT I/F
R/W
SECTION
NETWORK
I/F
57
STORAGE
SECTION
MEMORY
53
52

FIG.7

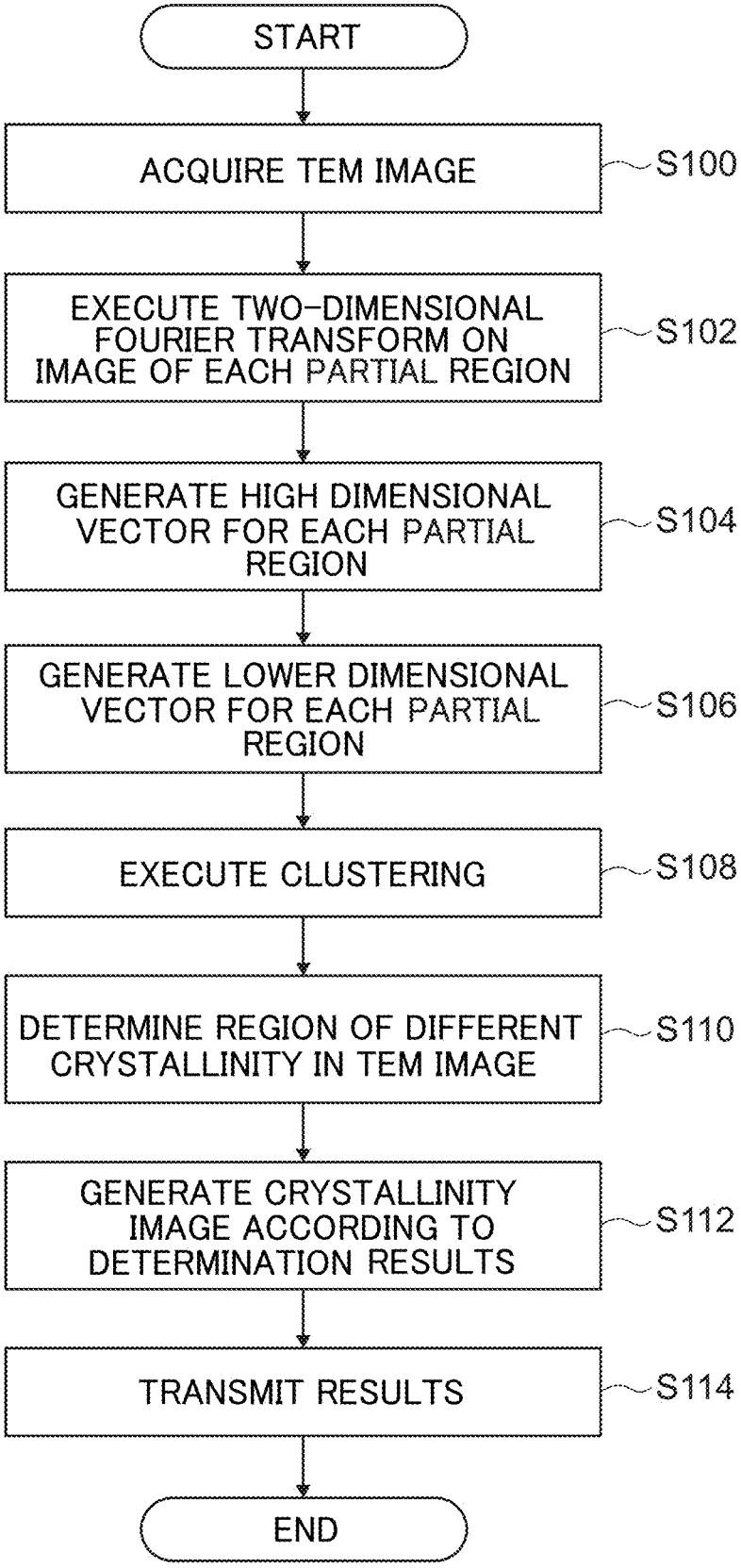

START
ACQUIRE TEM IMAGE
S100
EXECUTE TWO-DIMENSIONAL FOURIER TRANSFORM ON IMAGE OF EACH PARTIAL REGION
S102
GENERATE HIGH DIMENSIONAL VECTOR FOR EACH PARTIAL REGION
S104
GENERATE LOWER DIMENSIONAL VECTOR FOR EACH PARTIAL REGION
S106
EXECUTE CLUSTERING
S108
DETERMINE REGION OF DIFFERENT CRYSTALLINITY IN TEM IMAGE
S110
GENERATE CRYSTALLINITY IMAGE ACCORDING TO DETERMINATION RESULTS
S112
TRANSMIT RESULTS
S114
END

FIG.8

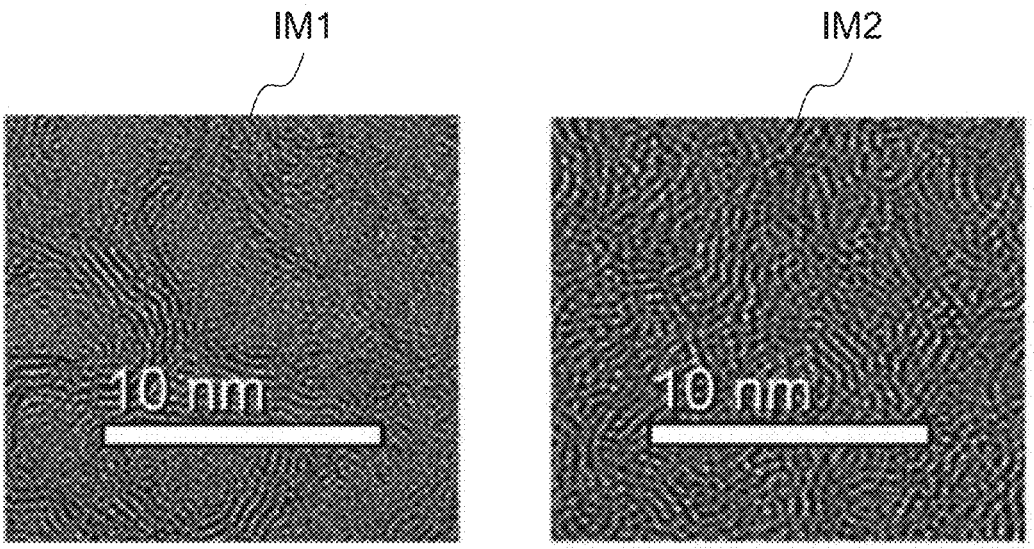
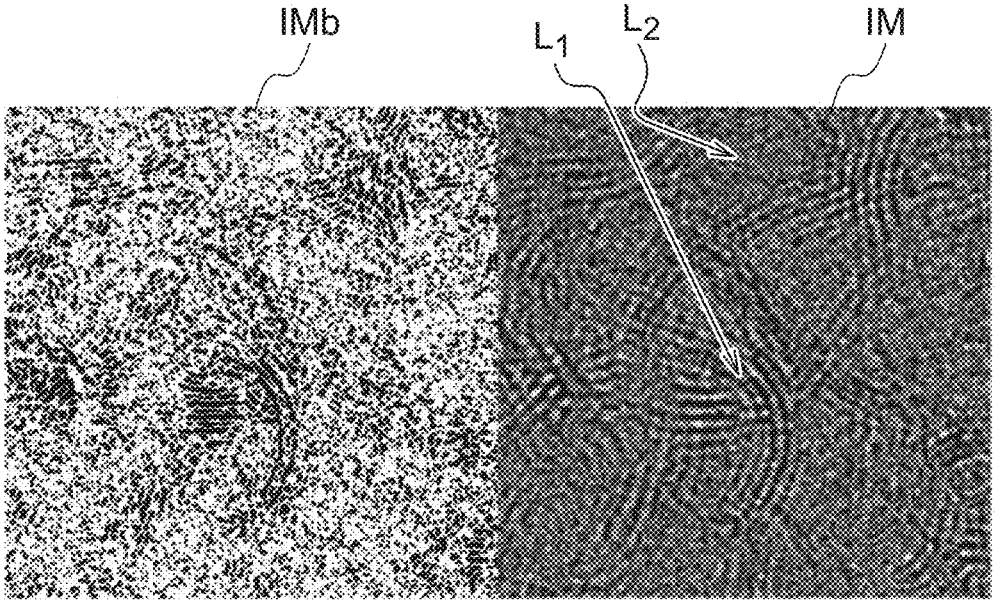


FIG.9



INFORMATION PROCESSING DEVICE, INFORMATION PROCESSING METHOD, AND RECORDING MEDIUM RECORDED WITH INFORMATION PROCESSING PROGRAM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is based on and claims priority under 35 USC 119 from Japanese Patent Application No. 2020-161482 filed on Sep. 25, 2020, the disclosure of which is incorporated by reference herein.

TECHNICAL FIELD

[0002] The present disclosure relates to an information processing device, an information processing method, and a recording medium recorded with an information processing program.

RELATED ART

[0003] Technology relating to analysis of images captured using a transmission electron microscope (TEM) (such images are referred to hereafter as TEM images) is known. For example, "GPA for Digital Micrograph" (HREM Research Inc., see https://www.hremresearch.com/Eng/download/documents/gpa4dm.pdf) discloses general image analysis technology for TEM images.

[0004] Furthermore, "A Deep Learning Approach to Identify Local Structures in Atomic-Resolution Transmission Electron Microscopy Images" (Jacob Madsen et al, see https://onlinelibrary.wiley.com/doi/abs/10.1002/adts.201800037@10.1002/(ISSN)25130390. Machine Learning) discloses technology for using a deep neural network to analyze local structures of substances depicted in TEM images.

[0005] In some cases, it is desirable to evaluate the crystallinity of a material depicted in a TEM image. FIG. **8** illustrates an example of TEM images. For example, as illustrated in FIG. **8**, locations exhibiting patterns such as those depicted in the TEM images IM**1**, IM**2** include locations that are locations of high crystallinity and locations that are locations of low crystallinity.

[0006] A conceivable approach when attempting to evaluate the crystallinity of the TEM images IM**1**, IM**2** illustrated in FIG. **8** might be, for example, to evaluate the crystallinity based on brightness values of the images as illustrated in FIG. **9**.

[0007] However, there are many high crystallinity locations L_1 and low crystallinity locations L_2 that are locations having substantially the same brightness in a TEM image IM such as that illustrated in FIG. **9**, and so crystallinity is not able to be evaluated simply by image brightness values. An image such as the image IMb in FIG. **9** is generated in cases in which thresholding is performed simply on brightness values of the TEM image IM. In the image IMb in FIG. **9**, although portions having high brightness values are simply extracted at a pixel unit level, portions of different crystallinity are not extractable at a region unit level.

[0008] Accordingly, for example, image analysis such as disclosed in "GPA for Digital Micrograph" (HREM Research Inc.) is unable on its own to determine regions of different crystallinity in the material depicted in the TEM image.

[0009] Furthermore, an attempt to evaluate the crystallinity of the material depicted in a TEM image by employing a neural network or the like, such as that disclosed in "A Deep Learning Approach to Identify Local Structures in Atomic-Resolution Transmission Electron Microscopy Images" (Jacob Madsen et al), would need a large volume of labeled training data to be prepared. The precision of a trained model such as a neural network or the like is dependent on the quality and quantity of such training data. Any attempt to generate a trained model offering high precision relies on the preparation of a large volume of training data, and the preparation thereof takes considerable effort.

[0010] As discussed above, the related art in "GPA for Digital Micrograph" (HREM Research Inc., see https://www.hremresearch.com/Eng/download/documents/gpa4dm.pdf) and "A Deep Learning Approach to Identify Local Structures in Atomic-Resolution Transmission Electron Microscopy Images" (Jacob Madsen et al) is unable to easily determine the crystallinity of a material depicted in a TEM image.

[0011] In consideration of the above circumstances, the present disclosure provides simple determination of the crystallinity of a material depicted in a TEM image.

SUMMARY

[0012] An information processing device of a first aspect is an information processing device including: an acquisition section configured to acquire an image captured by a transmission electron microscope; a conversion section configured to execute a two-dimensional Fourier transform on an image of a partial region for each partial region in the image acquired by the acquisition section; a clustering section configured to perform clustering of frequency strengths obtained from results of the two-dimensional Fourier transform based on results obtained by the conversion section executing the two-dimensional Fourier transform on each of the partial regions; and a determination section configured to determine regions of different crystallinity in the image based on results of the clustering by the clustering section.

[0013] In an information processing device of a second aspect, the clustering section is configured to cluster plural of the partial regions into a first cluster representing regions of high crystallinity and a second cluster representing regions of low crystallinity. This enables determination as to whether each of the partial regions is a region of high crystallinity or a region of low crystallinity.

[0014] In an information processing device of a third aspect, the conversion section is configured to execute the two-dimensional Fourier transform on each of the partial regions, each of the partial regions representing an image within a predetermined range centered on a center pixel. The determination section is configured to determine whether or not each of the partial regions is a region of high crystallinity by determining whether or not the center pixel of each of the partial regions is a high crystallinity pixel from results of the clustering by the clustering section based on results of the two-dimensional Fourier transform calculated for each of the partial regions. This enables determination as to whether each of the pixels in the image is in a region of high crystallinity or a region of low crystallinity.

[0015] An information processing device of a fourth aspect further includes an image generation section configured to generate a crystallinity image expressing degrees of

crystallinity by, based on results of determination for each of the center pixels by the determination section, applying a first pixel value to pixels at positions corresponding to the center pixel in cases in which high crystallinity has been determined and applying a second pixel value to pixels at positions corresponding to the center pixel in cases in which low crystallinity has been determined. This enables regions of different crystallinity in the material depicted in the TEM image to be made visible.

[0016] In an information processing device of a fifth aspect, the clustering section is further configured to integrate frequency strengths obtained from the results of the two-dimensional Fourier transform and to cluster values obtained by the integration. This enables regions of different crystallinity to be determined by taking the frequency strengths in the partial regions into consideration.

[0017] In an information processing device of a sixth aspect, the clustering section is further configured to employ a predetermined vector compression method to compress higher dimensional vectors that are values obtained by the integration into lower dimensional vectors that are vectors with fewer dimensions than the higher dimensional vectors, and to cluster the compressed lower dimensional vectors. This reduces the amount of information, enabling the amount of processing required to determine the crystallinity to be reduced.

[0018] An information processing method of a seventh aspect is an information processing method in which a computer executes processing, the processing including: acquiring an image captured by a transmission electron microscope; for each partial region in the acquired image, executing a two-dimensional Fourier transform on an image of the partial region; based on results obtained by executing the two-dimensional Fourier transform on each of the partial regions, performing clustering of frequency strengths obtained from the results of the two-dimensional Fourier transform; and determining regions of different crystallinity in the image based on results of the clustering.

[0019] An information processing program of an eighth aspect is an information processing program for causing a computer to execute processing, the processing including: acquiring an image captured by a transmission electron microscope; for each partial region in the acquired image, executing a two-dimensional Fourier transform on an image of the partial region; based on results obtained by executing the two-dimensional Fourier transform on each of the partial regions, performing clustering of frequency strengths obtained from the results of the two-dimensional Fourier transform; and determining regions of different crystallinity in the image based on results of the clustering.

[0020] As described above, the present disclosure exhibits an advantageous effect of enabling simple determination of the crystallinity of a material depicted in a TEM image.

BRIEF DESCRIPTION OF DRAWINGS

[0021] FIG. **1** is a schematic block diagram illustrating an information processing system according to an exemplary embodiment;

[0022] FIG. **2** is a diagram to explain a partial region in a TEM image;

[0023] FIG. **3** is a diagram to explain a method for obtaining frequency strength from results of a two-dimensional Fourier transform;

[0024] FIG. **4** is a diagram to explain clustering;

[0025] FIG. **5** is a diagram illustrating an example of crystallinity images;

[0026] FIG. **6** is a diagram illustrating an example of a configuration of a computer of a user terminal and of a server according to an exemplary embodiment;

[0027] FIG. **7** is a flowchart illustrating an example of information processing performed by a server according to an exemplary embodiment;

[0028] FIG. **8** is a diagram illustrating examples of TEM images; and

[0029] FIG. **9** is a diagram illustrating an example of an image obtained by performing thresholding on a TEM image.

DESCRIPTION OF EMBODIMENTS

Exemplary Embodiment

[0030] FIG. **1** is a block diagram illustrating an example of a functional configuration of an information processing system **10** according to an exemplary embodiment. As illustrated in FIG. **1**, the information processing system **10** includes a user terminal **12** and a server **14** serving as an example of an information processing device. The user terminal **12** and the server **14** are, for example, connected together over a network **13** such as the internet.

[0031] The information processing system **10** according to the present exemplary embodiment is configured to analyze a TEM image, namely an image captured by a transmission electron microscope, and to determine the crystallinity of a material depicted in the TEM image. Specifically, the server **14** of the information processing system **10** executes a Fourier transform on each partial region in a TEM image transmitted from the user terminal **12** in order to obtain frequency strengths for each of the partial regions. The server **14** performs clustering according to the frequency strengths of each of the partial regions in the TEM image in order to determine regions of different crystallinity in the TEM image. This enables simple determination of the crystallinity of a material depicted in the TEM image.

[0032] Specific explanation follows regarding the above.

[0033] User Terminal

[0034] A user inputs a TEM image of an analysis subject material into the user-operated user terminal **12**. The TEM image is an image of the material captured using a transmission electron microscope.

[0035] The user terminal **12** transmits the TEM image input by the user to the server **14** over the network **13**. The TEM image transmitted from the user terminal **12** is analyzed by the server **14**, described later.

[0036] Server

[0037] As illustrated in FIG. **1**, the server **14** includes a transmission/reception section **140**, an acquisition section **142**, a conversion section **144**, a clustering section **146**, a determination section **148**, and an image generation section **150**.

[0038] The transmission/reception section **140** receives the TEM image transmitted from the user terminal **12**.

[0039] The acquisition section **142** acquires the TEM image received by the transmission/reception section **140**.

[0040] For each of the partial regions in the TEM image acquired by the acquisition section **142**, the conversion section **144** executes a two-dimensional Fourier transform on an image of the partial region. FIG. **2** is a diagram to explain the partial regions in a TEM image.

[0041] Specifically, as illustrated in FIG. **2**, the conversion section **144** sets plural partial regions R in a TEM image IM, with each partial region R representing an image within a predetermined range centered on a center pixel P. For example, the conversion section **144** sequentially sets each of the partial regions R by setting each pixel configuring the TEM image IM as the center pixel P. The conversion section **144** then executes the two-dimensional Fourier transform on each of the partial regions.

[0042] Based on results obtained by the conversion section **144** executing the two-dimensional Fourier transform on each of the partial regions, the clustering section **146** applies known technology to perform clustering of frequency strengths obtained from the results of the two-dimensional Fourier transform into two or more clusters. Note that the frequency strengths configure a power spectrum.

[0043] FIG. **3** illustrates a diagram to explain a method for obtaining the frequency strengths from the results of the two-dimensional Fourier transform. Suppose that a two-dimensional Fourier transform result If has been obtained for a single partial region R, as illustrated in FIG. **3**. Each pixel value of the two-dimensional Fourier transform result If corresponds to a frequency strength. In this case, as illustrated in FIG. **3**, the clustering section **146** sets a straight line L from a center x_{f0} of the two-dimensional Fourier transform result If toward the outside, and acquires each of the frequency strengths at positions on the straight line L. The clustering section **146** then generates a vector with the frequency strength at each position on the straight line L as components.

[0044] Next, the clustering section **146** rotates the straight line L illustrated in FIG. **3** by a small amount in the direction of arrow r. The clustering section **146** then acquires a vector with the frequency strength at each position on this new straight line L as components. In this manner, the clustering section **146** acquires vectors representing frequency strengths in respective directions of the two-dimensional Fourier transform result If, and integrates these vectors to obtain a higher dimensional vector representing integrated values as illustrated in the graph Sp in FIG. **3**. Note that the horizontal axis of the graph Sp represents a distance from the center x_{f0} of the two-dimensional Fourier transform result If, and the vertical axis of the graph Sp represents the frequency strength S. The respective values in the graph Sp correspond to values of the respective components of the higher dimensional vector. A single higher dimensional vector is accordingly obtained for each single partial region.

[0045] Next, the clustering section **146** employs principal component analysis, this being an example of a predetermined vector compression method, to compress the higher dimensional vector into a lower dimensional vector. The lower dimensional vector is a vector with fewer dimensions than the higher dimensional vector. Accordingly, each single partial region corresponds to a single lower dimensional vector.

[0046] FIG. **4** is a diagram to explain clustering. In cases in which the lower dimensional vector is a two-dimensional vector, a single two-dimensional vector corresponds to a single partial region, and a distribution such as that labeled Q**1** in FIG. **4** is formed thereby.

[0047] For example, in cases in which the lower dimensional vectors obtained by compression are clustered into two clusters, the clustering section **146** cluster the lower dimensional vectors into a first cluster representing regions of high crystallinity, and a second cluster representing regions of low crystallinity.

[0048] For example, in cases in which a two-dimensional vector distribution such as that labeled Q**1** in FIG. **4** is clustered into two clusters, a first cluster CL**1** and a second cluster CL**2** are obtained as clustering results according to the two-dimensional vector distribution.

[0049] The diagram labeled Q**2** in FIG. **4** represents the density of the two-dimensional vector distribution, and the densities are indicated by contour lines. For example, C**1** therein indicates the center of a first cluster corresponding to partial regions with a high degree of crystallinity, and C**2** therein indicates the center of a second cluster corresponding to partial regions with a low degree of crystallinity.

[0050] The determination section **148** determines regions of different crystallinity in the TEM image based on results of the clustering by the clustering section **146**. Specifically, the determination section **148** determines whether or not the center pixel of each of the partial regions is a pixel where there is high crystallinity based on the clustering results. Determination is accordingly made as to whether or not each of the plural partial regions is a region of high crystallinity.

[0051] For example, the determination section **148** determines the center pixel of the partial region belonging to the first cluster to be a high crystallinity pixel. On the other hand, the determination section **148** determines the center pixel of the partial region belonging to the second cluster to be a low crystallinity pixel.

[0052] In cases in which the center pixel has been determined to be high crystallinity based on the determination results for each of the center pixels by the determination section **148**, the image generation section **150** applies a first pixel value (for example a pixel value expressing white) to the pixel at the position corresponding to the center pixel. In cases in which the center pixel has been determined to be low crystallinity based on the determination results for each of the center pixels by the determination section **148**, the image generation section **150** applies a second pixel value (for example a pixel value expressing black) to the pixel at the position corresponding to the center pixel. In this manner, the image generation section **150** generates a crystallinity image expressing the degree of crystallinity.

[0053] FIG. **5** illustrates an example of the TEM image IM, a crystallinity image IMb generated using related technology, and a crystallinity image IMc generated by the processing of the server **14** of the present exemplary embodiment. The crystallinity image IMb generated using related technology is an image obtained by thresholding brightness values of an image to evaluate crystallinity.

[0054] In the crystallinity image IMc generated by the processing of the server **14** of the present exemplary embodiment, white is applied in cases in which the center pixel is determined to belong in the first cluster and to have high crystallinity, and black is applied in cases in which the center pixel is determined to belong in the second cluster and to have low crystallinity. As illustrated in FIG. **5**, the crystallinity image IMb obtained using a related method is an image obtained by thresholding based simply on pixel values, and although locations of high crystallinity are extractable at a pixel unit level, locations are not extractable at a region unit level. By contrast, it can be seen that in the crystallinity image IMc locations of high crystallinity are extractable with good precision at the region unit level.

[0055] The transmission/reception section **140** transmits the crystallinity image generated by the image generation section **150** to the user terminal **12**.

[0056] The user terminal **12** receives the crystallinity image transmitted from the server **14**. The user then checks the crystallinity image displayed on a display section of the user terminal **12**.

[0057] The user terminal **12** and the server **14** may be implemented by a computer **50** such as that illustrated in FIG. **6**. The computer **50** implementing the user terminal **12** and the server **14** includes a CPU **51**, memory **52** serving as a temporarily storage region, and a non-volatile storage section **53**. The computer further includes an input/output interface (I/F) **54** to which an input/output device or the like (not illustrated in the drawings) is connected, and a read/write (R/W) section **55** that controls reading and writing of data with respect to a recording medium **59**. The computer further includes a network I/F **56** connected to a network such as the internet. The CPU **51**, the memory **52**, the storage section **53**, the input/output I/F **54**, the R/W section **55**, and the network I/F **56** are connected together through a bus **57**.

[0058] The storage section **53** may be implemented by a hard disk drive (HDD), a solid state drive (SSD), flash memory, or the like. The storage section **53** that serves as a storage medium is stored with a program to cause a computer to function. The CPU **51** reads the program from the storage section **53** and expands the program in the memory **52**, and processes of the program are executed in sequence.

[0059] Next, explanation follows regarding operation of the information processing system **10** of the present exemplary embodiment.

[0060] On input of a TEM image to the user terminal **12**, the user terminal **12** transmits the TEM image to the server **14**. On receipt of the TEM image by the server **14**, the server **14** executes the information processing routine illustrated in FIG. **7**

[0061] At step S**100**, the CPU **51** functions as the acquisition section **142** to acquire the TEM image received by the transmission/reception section **140**.

[0062] At step S**102**, the CPU **51** functions as the conversion section **144** to set partial regions centered on center pixels in the TEM image acquired at step S**100**. Plural of the partial regions are set. The CPU **51** also functions as the conversion section **144** to execute a two-dimensional Fourier transform on an image of each of the plural partial regions.

[0063] At step S**104**, based on the results of the two-dimensional Fourier transform on each of the partial regions obtained at step S**102**, the CPU **51** functions as the clustering section **146** to generate a higher dimensional vector with the frequency strengths obtained from the results of the two-dimensional Fourier transform as components. Specifically, the clustering section **146** integrates the vectors representing the frequency strengths within each of the partial regions in order to obtain a higher dimensional vector expressing integrated values, such as that illustrated by the graph Sp in FIG. **3** described previously. A higher dimensional vector is obtained for each of the partial regions.

[0064] At step S**106**, the CPU **51** functions as the clustering section **146** and employs principal component analysis to compress the higher dimensional vector obtained for each of the partial regions at step S**104** into a lower dimensional vector, so as to generate a lower dimensional vector for each of the partial regions.

[0065] At step S**108**, the CPU **51** functions as the clustering section **146** to perform clustering on the lower dimensional vectors obtained for each of the partial regions at step S**106**.

[0066] At step S**110**, the CPU **51** functions as the determination section **148** to determine regions of different crystallinity in the TEM image based on the clustering results obtained at step S**108**.

[0067] At step S**112**, the CPU **51** functions as the image generation section **150** to apply the first pixel value (for example a pixel value expressing white) to pixels at positions corresponding to the center pixels in cases in which the center pixels have been determined to be high crystallinity based on the determination results obtained at step S**110**. The CPU **51** also functions as the image generation section **150** to apply the second pixel value (for example a pixel value expressing black) to pixels at positions corresponding to the center pixels in cases in which the center pixels have been determined to be low crystallinity based on the determination results obtained at step S**110**. A crystallinity image expressing the degree of crystallinity is generated in this manner.

[0068] At step S**114**, the CPU **51** functions as the transmission/reception section **140** to transmit the crystallinity image generated as a result of step S**112** to the user terminal **12** as results.

[0069] As described above, the server **14** of the information processing system **10** according to the present exemplary embodiment executes a two-dimensional Fourier transform on an image of a partial region for each of the partial regions in the TEM image, this being an image captured by a transmission electron microscope. The server **14** performs clustering according to the frequency strengths obtained from the results of the two-dimensional Fourier transform, based on the results obtained by executing the two-dimensional Fourier transform on each of the plural partial regions. The server **14** also determines regions of different crystallinity in the TEM image based on the clustering results. This enables simple determination of the crystallinity of a material depicted in the TEM image. More specifically, this enables simple determination of regions of different crystallinity in the material depicted in the TEM image.

[0070] Since a trained model such as a neural network is not required, the crystallinity of the respective partial regions in a TEM image can be determined without preparing labeled training data. Moreover, the crystallinity of respective partial regions in a TEM image can be determined without setting threshold values.

[0071] Note that although explanation has been given regarding an example in which the processing performed by the respective devices of the exemplary embodiment described above is software processing performed by executing a program, this processing may be performed by hardware. Alternatively, the processing may performed by a combination of software and hardware. The program stored in the ROM may be distributed in a format stored on various storage media.

[0072] The present disclosure is not limited to the above explanation, and obviously various other modifications may be implemented within a range not departing from the spirit of the present disclosure.

[0073] For example, although in the exemplary embodiment described above, explanation has been given regarding an example of a case in which the plural partial regions in a TEM image are clustered into the first cluster representing regions of high crystallinity and the second cluster representing regions of low crystallinity, there is no limitation thereto. Any number of clusters may be employed for determination of regions of different crystallinity in a TEM image.

[0074] Moreover, although in the exemplary embodiment described above, explanation has been given regarding an example of a case in which principal component analysis is employed as a predetermined vector compression method, there is no limitation thereto. Other compression methods may be employed. For example, uniform manifold approximation and projection (UMAP), this being a known compression method, may be employed.

[0075] Moreover, although in the exemplary embodiment described above, explanation has been given regarding an example of a case in which a higher dimensional vector is compressed to a two-dimensional vector, there is no limitation thereto. The higher dimensional vector may be compressed into a vector of three or more dimensions. Alternatively, clustering may be performed on higher dimensional vectors in an uncompressed state.

[0076] All publications, patent applications, and technical standards mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent application, or technical standard was specifically and individually indicated to be incorporated by reference.

1. An information processing device comprising:

a memory; and

a processor coupled to the memory, the processor being configured to:

acquire an image captured by a transmission electron microscope;

for each partial region in the image, execute a two-dimensional Fourier transform on an image of the partial region;

based on results obtained by executing the two-dimensional Fourier transform on each of the partial regions, perform clustering of frequency strengths obtained from the results of the two-dimensional Fourier transform; and

determine regions of different crystallinity in the image, based on results of the clustering.

2. The information processing device of claim **1**, wherein, in a case of performing the clustering, the processor is further configured to cluster a plurality of the partial regions into a first cluster representing regions of high crystallinity and a second cluster representing regions of low crystallinity.

3. The information processing device of claim **1**, wherein:

in a case of executing the two-dimensional Fourier transform, the processor is further configured to execute the two-dimensional Fourier transform on each of the partial regions, each of the partial regions representing an image within a predetermined range centered on a center pixel; and

in a case of determining the regions of different crystallinity in the image, the processor is further configured to determine whether or not each of the partial regions is a region of high crystallinity by determining whether or not the center pixel of each of the partial regions is a high crystallinity pixel from results of the clustering based on results of the two-dimensional Fourier transform calculated for each of the partial regions.

4. The information processing device of claim **3**, wherein the processor is further configured to generate a crystallinity image expressing degrees of crystallinity by, based on results of determination for each center pixel, applying a first pixel value to a pixel at a position corresponding to the center pixel in a case in which high crystallinity has been determined and applying a second pixel value to a pixel at the position corresponding to the center pixel in a case in which low crystallinity has been determined.

5. The information processing device of claim **1**, wherein, in a case of performing the clustering, the processor is further configured to integrate frequency strengths obtained from the results of the two-dimensional Fourier transform and to cluster values obtained by the integration.

6. The information processing device of claim **5**, wherein, in a case of performing the clustering, the processor is further configured to use a predetermined vector compression method to compress higher dimensional vectors, which are values obtained by the integration, into lower dimensional vectors that are vectors with fewer dimensions than the higher dimensional vectors, and to cluster the compressed lower dimensional vectors.

7. An information processing method in which a processor executes processing, the processing comprising:

acquiring an image captured by a transmission electron microscope;

for each partial region in the image, executing a two-dimensional Fourier transform on an image of the partial region;

based on results obtained by executing the two-dimensional Fourier transform on each of the partial regions, performing clustering of frequency strengths obtained from the results of the two-dimensional Fourier transform; and

determining regions of different crystallinity in the image, based on results of the clustering.

8. A recording medium recorded with an information processing program executable by a processor to perform processing, the processing comprising:

acquiring an image captured by a transmission electron microscope;

for each partial region in the image, executing a two-dimensional Fourier transform on an image of the partial region;

based on results obtained by executing the two-dimensional Fourier transform on each of the partial regions, performing clustering of frequency strengths obtained from the results of the two-dimensional Fourier transform; and

determining regions of different crystallinity in the image, based on results of the clustering.

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