DESCRIPTION

Title of Invention: TRAINING METHOD, INFERENCE MODEL, NOISE REDUCTION METHOD, NOISE REDUCTION SYSTEM, AND NOISE REDUCTION PROGRAM

Technical Field

[0001] The present invention relates to a learning method for generating an inference model used to reduce flickering due to noise from an image, the generated inference model, and a noise reduction method, a noise reduction system, and a noise reduction program for reducing flickering due to noise from an image by using the generated inference model.

Background Art

[0002] Patent Literature 1 discloses that noise is reduced from an image by an inference model generated by machine learning.

Citation List

Patent Literature

[0003] [Patent Literature 1] Japanese Unexamined Patent Publication No. 2023-139782

Summary of Invention

Technical Problem

[0004] Analysis images used for failure analysis of semiconductor devices, such as emission images, include random noise. In failure analysis of semiconductor devices, a pattern image of a semiconductor device and an analysis image may be superimposed and displayed. However, when superimposing and displaying a pattern image of a semiconductor device and an analysis image, there were cases where the

pattern image of the semiconductor device was difficult to visually recognize due to flickering caused by random noise. Therefore, when performing failure analysis using analysis images, it is required to reduce flickering of random noise.

[0005] Related art inference models, including those shown in Patent Literature 1 above, are not specialized for reducing flickering due to random noise from analysis images, and there was a concern that flickering due to random noise may not necessarily be appropriately reduced.

[0006] One embodiment of the present invention has been made in view of the above, and it is an object thereof to provide a learning method, an inference model, a noise reduction method, a noise reduction system, and a noise reduction program capable of appropriately reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices.

Solution to Problem

[0007] In order to achieve the aforementioned object, a learning method according to one embodiment of the present invention is a learning method for generating an inference model used to reduce flickering due to random noise from analysis images used for failure analysis of semiconductor devices, and includes: a learning acquisition step of acquiring an analysis image for learning that includes a target signal related to a semiconductor device and includes random noise, and a noise image for learning that does not include the target signal and includes random noise; a noise addition step of reducing contrast of the analysis image for learning acquired in the learning acquisition step, adding the

random noise of the noise image for learning to the analysis image for learning with reduced contrast, and generating a noise-added image for learning; and a training step of performing machine learning training of the inference model using the noise-added image for learning generated in the noise addition step.

[0008] In the learning method according to one embodiment of the present invention, the random noise of the noise image for learning is added to the analysis image for learning with the reduced contrast, and a noise-added image for learning is generated. An inference model generated using such a noise-added image for learning is capable of appropriately reducing flickering due to random noise from an analysis image. Therefore, according to the learning method according to one embodiment of the present invention, flickering due to random noise can be appropriately reduced from an analysis image.

[0009] In the training step, the machine learning training of the inference model may be performed by treating the analysis image for learning with the reduced contrast as an image not including the random noise and treating the noise-added image for learning as an image including the random noise. According to this configuration, the machine learning training of the inference model can be performed more appropriately, and a more appropriate inference model can be generated. As a result, flickering due to random noise can be more appropriately reduced from an analysis image.

[0010] In the noise addition step, a pixel value corresponding to the noise image for learning may be subtracted from a pixel value of each pixel of the analysis image for learning, the pixel value of each pixel

after the subtraction may be multiplied by a coefficient less than 1 set in advance, the subtracted pixel value may be added to the pixel value of each pixel after the multiplication, and the analysis image for learning with the reduced contrast may be generated. According to this configuration, a more appropriate analysis image for learning with the reduced contrast can be generated. As a result, flickering due to random noise can be more appropriately reduced from an analysis image.

[0011] In the noise addition step, a plurality of analysis images for learning with the reduced contrast may be generated using a plurality of mutually different coefficients, and a plurality of noise-added images for learning may be generated. According to this configuration, a plurality of analysis images for learning with the reduced contrast can be generated from one analysis image for learning, and the variation of images used for the machine learning training of the inference model can be increased. This allows the machine learning training of the inference model to be performed more appropriately, and a more appropriate inference model can be generated. As a result, flickering due to random noise can be more appropriately reduced from an analysis image.

[0012] In the learning acquisition step, an original image that includes a portion that can serve as the analysis image for learning and is larger in size than the analysis image for learning may be acquired, a part of the acquired original image may be cropped, a value based on a pixel value of the cropped image may be compared with a value corresponding to a pixel value of the noise image for learning, and the cropped image may be used as the analysis image for learning according to the comparison result. Furthermore, in the learning acquisition step, a value based on

the pixel value of the cropped image may be compared with an average or a variation value of the pixel values of the noise image for learning, and the cropped image may be used as the analysis image for learning according to the comparison result. According to these configurations, the analysis image for learning can be acquired simply and appropriately.

[0013] The inference model itself generated by the learning method according to one embodiment of the present invention is also an invention having a novel configuration. That is, the inference model according to one embodiment of the present invention is an inference model for causing a computer to function to receive information based on an analysis image used for failure analysis of a semiconductor device, perform a calculation according to the input, and output information, and the inference model is generated by the learning method described above.

[0014] In order to achieve the aforementioned object, a noise reduction method according to one embodiment of the present invention is a noise reduction method for reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices, and includes: a reduction acquisition step of acquiring an analysis image for noise reduction that includes a target signal related to a semiconductor device and includes random noise; and an image generation step of generating an inference image in which flickering due to random noise is reduced from the analysis image for noise reduction acquired in the reduction acquisition step, by using an inference model generated in advance by machine learning training.

[0015] According to the noise reduction method according to one

embodiment of the present invention, flickering due to random noise can be appropriately reduced from an analysis image.

[0016] The inference model may be the inference model generated by the learning method described above. According to this configuration, flickering due to random noise can be appropriately reduced from an analysis image.

[0017] In the reduction acquisition step, a pattern image of the semiconductor device corresponding to the analysis image for noise reduction may also be acquired, and in the image generation step, a composite image obtained by superimposing the generated inference image and the pattern image acquired in the reduction acquisition step may be generated. According to this configuration, a composite image obtained by superimposing the inference image, in which flickering due to random noise has been appropriately reduced, and the pattern image can be obtained.

[0018] One embodiment of the present invention can be described not only as an invention of the noise reduction method as described above but also as inventions of a noise reduction system and a noise reduction program as follows. These differ only in category, but are substantially the same invention and have similar functions and effects.

[0019] That is, a noise reduction system according to one embodiment of the present invention is a noise reduction system for reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices, and includes: a reduction acquisition means for acquiring an analysis image for noise reduction that includes a target signal related to a semiconductor device and includes random

noise; and an image generation means for generating an inference image in which flickering due to random noise is reduced from the analysis image for noise reduction acquired by the reduction acquisition means, by using an inference model generated in advance by machine learning training. The inference model may be the inference model generated by the learning method described above.

[0020] In addition, a noise reduction program according to one embodiment of the present invention is a noise reduction program for reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices, and causes a computer to execute: a reduction acquisition process of acquiring an analysis image for noise reduction that includes a target signal related to a semiconductor device and includes random noise; and an image generation process of generating an inference image in which flickering due to random noise is reduced from the analysis image for noise reduction acquired by the reduction acquisition process, by using an inference model generated in advance by machine learning training. The inference model may be the inference model generated by the learning method described above.

Advantageous Effects of Invention

[0021] According to one embodiment of the present invention, flickering due to random noise can be appropriately reduced from analysis images used for failure analysis of semiconductor devices.

Brief Description of Drawings

[0022] FIG. 1 is a diagram showing the configurations of a learning system and a noise reduction system according to an embodiment of the

present invention.

FIG. 2 is a diagram showing an inference model generated and used in the embodiment together with examples of images input to and output from the inference model.

FIG. 3 is a diagram showing images used in the embodiment.

FIG. 4 is a graph showing images used in the embodiment.

FIG. 5 is a diagram showing an overview of machine learning training of the inference model in the embodiment.

FIG. 6 is a flowchart showing a learning method that is a process performed by the learning system according to the embodiment of the present invention.

FIG. 7 is a flowchart showing a noise reduction method that is a process performed by the noise reduction system according to the embodiment of the present invention.

FIG. 8 is an example of flickering reduction due to noise performed by the embodiment.

FIG. 9 is an example of flickering reduction due to noise performed by the embodiment.

FIG. 10 is an example of a composite image (superimposed image) generated by the embodiment.

FIG. 11 is a diagram showing the configurations of a learning program and a noise reduction program according to the embodiment of the present invention, together with a recording medium.

Description of Embodiments

[0023] Hereinafter, embodiments of a learning method, an inference model, a noise reduction method, a noise reduction system, and a noise

reduction program according to the present invention will be described in detail with reference to the drawings. In addition, in the description of the drawings, the same elements are denoted by the same reference numerals, and repeated description thereof will be omitted.

[0024] FIG. 1(a) shows a learning system 10 that executes the learning method according to the present embodiment. FIG. 1(b) shows a noise reduction system 20 that executes the noise reduction method according to the present embodiment. The learning system 10 is a system (apparatus) that generates an inference model used to reduce (remove) flickering due to random noise from analysis images used for failure analysis of semiconductor devices. The noise reduction system 20 is a system (apparatus) that reduces flickering due to random noise from analysis images by using the inference model generated by the learning system 10.

[0025] The analysis image subject to reduction of flickering due to random noise is, for example, an emission image used for emission analysis. The emission image is obtained, for example, by imaging a semiconductor device that is a target of failure analysis with an imaging device such as an InGaAs camera. The emission image captures the emission at locations corresponding to the presence or absence of failure, the location of failure, and the like of the semiconductor device. In the emission image, areas other than the emission location of the semiconductor device can be regarded as background.

[0026] By analyzing the emission in the emission image, analysis (failure analysis) such as the presence or absence of failure of the semiconductor device or the location of failure can be performed.

Failure analysis of semiconductor devices using noise-reduced emission images may be performed in the same manner as conventionally. Failure analysis of semiconductor devices is performed, for example, in the inspection of semiconductor devices manufactured on a manufacturing line. In addition, failure analysis of semiconductor devices is performed on semiconductor devices that are known to be defective or to operate abnormally through another inspection. Semiconductor devices subject to failure analysis include integrated circuits such as microcontrollers, logic ICs (Integrated Circuits), analog ICs, or hybrid ICs, memory devices such as volatile memories or non-volatile memories, power semiconductor devices, optical semiconductor devices, or discrete devices. In addition, the analysis image subject to reduction of flickering due to random noise may be other than an emission image as long as it is used for failure analysis of semiconductor devices. For example, the analysis image may be one obtained by imaging with a thermal camera (thermal image), one obtained by imaging with an SI-CCD camera, or one obtained by OBIRCH (Optical Beam Induced Resistance CHange) analysis, OBIC (Optical Beam Induced Current) analysis, EOFM (Electro Optical Frequency Mapping) analysis, or the like.

[0027] The analysis image includes random noise that is the target of reduction in the present embodiment. Random noise is, for example, noise that occurs irregularly both temporally and spatially depending on the imaging conditions and the imaging device. In particular, because random noise occurs with spatial flickering, the analysis image appears to flicker throughout due to random noise. Therefore, visibility when the analysis image is superimposed and displayed with other images

such as a pattern image of a semiconductor device is reduced, and the accuracy of failure analysis is reduced. An analysis image with reduced flickering of random noise has improved visibility when superimposed and displayed with other images. Therefore, by using an analysis image with reduced flickering of random noise, the accuracy of failure analysis can be improved. When the analysis image is an emission image, emission analysis performance can be improved.

[0028] FIG. 2 shows an example of an emission image 31 including the random noise and an example of an emission image 32 (denoised image) with reduced random noise obtained by using an inference model.

[0029] The learning system 10 and the noise reduction system 20 include a conventional computer including hardware such as a processor, a memory, and a communication module. The processor is, for example, a CPU (Central Processing Unit) or a GPU (Graphics Processing Unit).

[0030] In addition, the learning system 10 and the noise reduction system 20 may include an imaging device such as a camera for acquiring images used in processing. Alternatively, the learning system 10 and the noise reduction system 20 may be included in an imaging device such as a camera for acquiring images used in processing. In FIG. 1, the learning system 10 and the noise reduction system 20 are shown as separate systems (apparatuses), but may be realized by the same system (apparatus).

[0031] The computer configuring the learning system 10 and the noise reduction system 20 may be a computer system including a plurality of computers. In addition, the computer may be configured by cloud computing or edge computing. The functions of the learning system 10

and the noise reduction system 20 described later are realized by these components operating through programs and the like. For example, the functions of the learning system 10 and the noise reduction system 20 described later (in particular, the functions of the noise reduction system 20) may be realized by a dedicated application corresponding to the imaging device.

[0032] Next, the functions of the learning system 10 and the noise reduction system 20 according to the present embodiment will be described. As shown in FIG. 1, the learning system 10 includes a learning acquisition unit 11, a noise addition unit 12, and a training unit 13.

[0033] The learning system 10 generates an inference model by machine learning training. The inference model includes, for example, a neural network. The neural network may be a multilayer neural network. That is, the inference model may be generated by deep learning. In addition, the neural network may be a convolutional neural network (CNN). The format of the inference model may be the same as that of an inference model generated by conventional machine learning training (for example, Noise2Clean).

[0034] The inference model is used to reduce flickering due to random noise from analysis images. For example, the inference model receives an analysis image subject to reduction of flickering due to random noise and outputs an analysis image after reduction of flickering due to random noise. This inference model is a denoising model (noise removal model) and is a filter that improves flickering due to random noise in analysis images. In this case, the inference model is provided with neurons in the

input layer for inputting the analysis image subject to reduction of flickering due to random noise. For example, the information input to the inference model is the pixel value (luminance value) of each pixel of the analysis image subject to reduction of flickering due to random noise. In this case, as many neurons as the number of pixels of the analysis image are provided in the input layer, and the pixel value of the corresponding pixel is input to each neuron.

[0035] In addition, the inference model is provided with neurons in the output layer for outputting the analysis image after reduction of flickering due to random noise. For example, the information output from the inference model is the pixel value of each pixel of the analysis image after reduction of flickering due to random noise. In this case, as many neurons as the number of pixels of the analysis image are provided in the output layer, and the pixel value of the corresponding pixel is output from each neuron.

[0036] Alternatively, the inference model may be one that receives an analysis image subject to reduction of flickering due to random noise and outputs an image (data) of the random noise included in the analysis image. In this case, an analysis image after reduction of flickering due to random noise can be obtained by performing a process of removing the output random noise image from the analysis image subject to reduction of flickering due to random noise. In addition, the inference model may be other than those described above as long as it is for reducing flickering due to random noise from an analysis image subject to reduction of flickering due to random noise.

[0037] The inference model is for causing a computer to function to

receive information based on an analysis image, perform a calculation according to the input, and output information. The inference model is assumed to be used as a program module that is a part of artificial intelligence software. The inference model is used, for example, in a computer including a processor and a memory, and the processor of the computer operates according to instructions from the model stored in the memory. For example, according to the instruction, the processor of the computer operates to input information to the model, perform a calculation according to the model, and output a result from the model. Specifically, according to the instruction, the processor of the computer operates to input information to the input layer of the neural network, perform a calculation based on parameters such as learned weighting coefficients in the neural network, and output a result from the output layer of the neural network. In addition, the inference model may be configured other than by a neural network.

[0038] The learning acquisition unit 11 is a learning acquisition means for acquiring an analysis image for learning that includes a target signal related to a semiconductor device and includes random noise, and a noise image for learning that does not include the target signal and includes random noise. The learning acquisition unit 11 may acquire an original image that includes a portion that can serve as the analysis image for learning and is larger in size than the analysis image for learning, crop a part of the acquired original image, compare a value based on a pixel value of the cropped image with a value corresponding to a pixel value of the noise image for learning, and use the cropped image as the analysis image for learning according to the comparison result. The learning

acquisition unit 11 may compare a value based on the pixel value of the cropped image with an average or a variation value of the pixel values of the noise image for learning, and use the cropped image as the analysis image for learning according to the comparison result.

[0039] The analysis image for learning and the noise image for learning acquired by the learning acquisition unit 11 are for generating the inference model. The learning acquisition unit 11 acquires the analysis image for learning and the noise image for learning, for example, as follows. The analysis image for learning and the noise image for learning are images of the same format as the analysis image subject to reduction of flickering due to random noise. For example, the analysis image for learning and the noise image for learning are images of the same size as the analysis image subject to reduction of flickering due to random noise and are emission images similar to the analysis image subject to reduction of flickering due to random noise.

[0040] The analysis image for learning and the noise image for learning include random noise. The analysis image for learning includes a target signal related to a semiconductor device. The target signal related to a semiconductor device is a signal used for failure analysis of the semiconductor device in the analysis image. For example, when the analysis image is an emission image, the target signal is a signal related to emission. In addition, when the analysis image is a thermal image, the target signal is a signal related to heat generation (for example, heat generation due to operation of the semiconductor device). The background portion of the analysis image that is not emitting or generating heat is not related to the target signal. The noise image for

learning does not include a target signal related to a semiconductor device. For example, the noise image for learning is an image in which only the portion corresponding to the background of the analysis image for learning is captured. When the analysis image subject to reduction of flickering due to random noise is an emission image, the analysis image for learning is an image with emission related to the semiconductor device, and the noise image for learning is an image without emission related to the semiconductor device. When the analysis image subject to reduction of flickering due to random noise is a thermal image, the analysis image for learning is an image with heat generation related to the semiconductor device, and the noise image for learning is an image without heat generation related to the semiconductor device.

[0041] The analysis image for learning may be one in which the pixel value of the target signal related to the semiconductor device is relatively large (luminance is relatively high). This is to generate the inference model more appropriately.

[0042] The learning acquisition unit 11 acquires an original image that includes a portion that can serve as the analysis image for learning and is larger in size than the analysis image for learning. The original image including the analysis image for learning is, for example, an image obtained by imaging, with an imaging device, a semiconductor device for learning prepared in advance in a state where random noise occurs in the captured image. The semiconductor device for learning may be a semiconductor device of the same type as the semiconductor device related to the analysis image subject to reduction of flickering due to

random noise, or may be a semiconductor device of a different type. The original image is acquired, for example, by receiving it from the imaging device that captured the original image, or by accepting a user's input operation of the original image to the learning system 10.

[0043] As shown in FIG. 3, the learning acquisition unit 11 crops an image of a region of a preset size smaller than the original image 41 (a part of the original image) from the original image 41, and uses the cropped image as the analysis image for learning 42. The location to be cropped may be a random location or a preset location. The location to be cropped is assumed to include a target signal related to a semiconductor device. Detection of a location including a target signal related to a semiconductor device in the original image may be performed by any method as necessary. The learning acquisition unit 11 may acquire a plurality of analysis images for learning 42 from a plurality of mutually different locations in one original image 41.

[0044] For example, the analysis image for learning 42 may be cropped at a size of 10% to 20% of the original image 41 (field of view size). If the size of the original image 41 is 1000 pixels × 1000 pixels, the size of the cropped analysis image for learning 42 may be 128 pixels × 128 pixels.

[0045] The learning acquisition unit 11 acquires an original image that includes a portion that can serve as the noise image for learning and is larger in size than the noise image for learning. The original image including the noise image for learning is, for example, an image obtained by imaging with an imaging device in a state where there is no imaging target (semiconductor device) and random noise occurs in the captured

image. The original image is acquired, for example, by receiving it from the imaging device that captured the original image, or by accepting a user's input operation of the original image to the learning system 10.

[0046] As shown in FIG. 3, the learning acquisition unit 11 crops an image of a region of a preset size smaller than the original image 51 (a part of the original image) from the original image 51, and uses the cropped image as the noise image for learning 52. The location to be cropped may be a random location or a preset location. The learning acquisition unit 11 may acquire a plurality of noise images for learning 52 from a plurality of mutually different locations in one original image 51.

[0047] In addition, imaging by the imaging device for acquiring the analysis image for learning and the noise image for learning may be performed so that the analysis image for learning and the noise image for learning include random noise similar to that included in the analysis image subject to reduction of flickering due to random noise. Because these images include similar random noise, the generated inference model can more appropriately reduce flickering due to random noise from the analysis image subject to reduction of flickering due to random noise. For example, imaging by the imaging device for acquiring the analysis image for learning and the noise image for learning may be performed by the same type of imaging device as the imaging device for acquiring the analysis image subject to reduction of flickering due to random noise, under the same imaging conditions.

[0048] In addition, when the learning acquisition unit 11 crops the analysis image for learning 42 from the original image 41, it may

determine whether to adopt the cropped image as the analysis image for learning 42 based on the noise image for learning. In this case, the learning acquisition unit 11 compares a value based on the pixel value of the cropped image with a value corresponding to the pixel value of the noise image for learning, and uses the cropped image as the analysis image for learning according to the comparison result. For example, the learning acquisition unit 11 determines whether to adopt the cropped image as the analysis image for learning 42 as follows.

[0049] The learning acquisition unit 11 calculates the average of the pixel values of the noise image for learning 52. This average of pixel values corresponds to the average of the pixel values of the background in the noise image for learning 52. The learning acquisition unit 11 calculates a value obtained by multiplying the calculated average of pixel values by a coefficient greater than 1 set in advance (for example, 3). The learning acquisition unit 11 compares the calculated value with the pixel value of each pixel of the partial image cropped from the original image 41.

[0050] When the partial image cropped from the original image 41 includes a pixel having a pixel value equal to or greater than the calculated value, the learning acquisition unit 11 determines to adopt the cropped partial image as the analysis image for learning 42. This is because a pixel having a pixel value that greatly exceeds the average of the pixel values of the noise image for learning 52 (the average of the pixel values of the background) is considered to be related to the target signal related to the semiconductor device. Alternatively, when the number of pixels having a pixel value equal to or greater than the

calculated value in the partial image cropped from the original image 41 is equal to or greater than a preset threshold value, the learning acquisition unit 11 may determine to adopt the cropped partial image as the analysis image for learning 42.

[0051] In addition, the learning acquisition unit 11 may perform the above determination by the following method instead of or in addition to the above method. The learning acquisition unit 11 calculates the variation (for example, standard deviation (S.D.)) of the pixel values of the noise image for learning 52. When acquiring a plurality of noise images for learning 52, the learning acquisition unit 11 may calculate the average of the variations of the plurality of noise images for learning 52. The learning acquisition unit 11 calculates the variation of the pixel values of the partial image cropped from the original image 41. The variation of the pixel values of the partial image to be calculated is the same type as the variation of the pixel values of the noise image for learning 52 (for example, standard deviation).

[0052] The learning acquisition unit 11 compares these variations. When the variation of the pixel values of the partial image cropped from the original image 41 is greater than the variation of the pixel values of the noise image for learning 52, the learning acquisition unit 11 determines to adopt the cropped partial image as the analysis image for learning 42. This is because the variation of the pixel values of an image including a portion corresponding to the target signal related to the semiconductor device is considered to be greater than that of the pixel values of the noise image for learning 52. For example, the standard deviation of the pixel values of a partial image including a portion

corresponding to the target signal is 11.2, and the standard deviation of the pixel values of the noise image 52 is 4.7.

[0053] Alternatively, the learning acquisition unit 11 may crop a plurality (for example, 100) of partial images, and determine to adopt the partial image having the largest variation among the partial images having a variation of pixel values greater than the variation of pixel values of the noise image for learning 52 as the analysis image for learning 42. In addition, a value obtained by multiplying the variation of the pixel values of the noise image for learning 52 by a coefficient greater than 1 set in advance may be used for the above determination.

[0054] In addition, the learning acquisition unit 11 may acquire the analysis image for learning and the noise image for learning by methods other than those described above. The number of analysis images for learning and noise images for learning to be acquired is a number sufficient for the process of generating the inference model. The learning acquisition unit 11 outputs the acquired analysis image for learning and noise image for learning to the noise addition unit 12.

[0055] The noise addition unit 12 is a noise addition means for reducing contrast of the analysis image for learning acquired by the learning acquisition unit 11, adding the random noise of the noise image for learning to the analysis image for learning with reduced contrast, and generating a noise-added image for learning. The noise addition unit 12 may subtract a pixel value corresponding to the noise image for learning from the pixel value of each pixel of the analysis image for learning, multiply the pixel value of each pixel after the subtraction by a coefficient less than 1 set in advance, add the subtracted pixel value to

the pixel value of each pixel after the multiplication, and generate an analysis image for learning with the reduced contrast. The noise addition unit 12 may generate a plurality of analysis images for learning with the reduced contrast using a plurality of mutually different coefficients, and generate a plurality of noise-added images for learning.

[0056] The contrast of an image is defined, for example, by the difference between the maximum and minimum pixel values of the pixels included in the image. The analysis image for learning with the reduced contrast and the noise-added image for learning generated by the noise addition unit 12 are used for machine learning training for generating the inference model. By reducing the contrast of the analysis image for learning, flickering due to random noise included in the analysis image for learning is reduced. Although the random noise itself included in the analysis image for learning cannot be made zero, flickering due to random noise can be brought close to zero. In the present embodiment, the analysis image for learning with the reduced contrast is treated as an image not including the random noise. The noise-added image for learning is an image that includes random noise and corresponds to the analysis image for learning with the reduced contrast (image not including the random noise).

[0057] Training of the inference model in the present embodiment is performed so that when the noise-added image for learning (image including the random noise) is input to the inference model, the analysis image for learning with the reduced contrast (image not including the random noise) is output. The noise addition unit 12 generates the analysis image for learning with the reduced contrast and the noise-

added image for learning, for example, as follows.

[0058] The noise addition unit 12 receives the analysis image for learning 42 and the noise image for learning 52 from the learning acquisition unit 11. FIG. 4 shows a graph for explaining the generation of the analysis image for learning with the reduced contrast and the noise-added image for learning. The graph shown in FIG. 4 corresponds to an image. In the graph shown in FIG. 4, the horizontal axis indicates each pixel and the vertical axis indicates the pixel value of each pixel.

[0059] Graph G1 shown in FIG. 4 is a graph of the analysis image for learning 42. The peak portion in graph G1 is a portion corresponding to the target signal related to the semiconductor device. When the analysis image is an emission image, the portion is a location that is emitting light. Portions other than the peak portion in graph G1 are background portions that do not correspond to the target signal related to the semiconductor device. All portions in graph G1 include random noise.

[0060] Graph G2 shown in FIG. 4 is a graph of the noise image for learning 52. Graph G2 has no peak portion, and all portions are background portions that do not correspond to the target signal related to the semiconductor device. All portions in graph G2 include random noise.

[0061] The noise addition unit 12 calculates the average of the pixel values of the noise image for learning 52. In addition, when the average of the pixel values of the noise image for learning 52 has been calculated by the learning acquisition unit 11, the noise addition unit 12 may use that value. This average of pixel values corresponds to the average of the pixel values of the background in the noise image for learning 52.

[0062] As shown in FIG. 3, the noise addition unit 12 subtracts the calculated average of pixel values (background average) from the pixel value of each pixel of the analysis image for learning 42. Graph G3 shown in FIG. 4 is a graph of the image obtained thereby. As shown in graph G3 in FIG. 4, the image is a graph in which the average of the pixel values of the background portion is zero. In addition, in the image, the average of the pixel values of the background portion does not need to be strictly zero, and it is sufficient that the pixel values of the background portion are approximately close to zero.

[0063] Subsequently, as shown in FIG. 3, the noise addition unit 12 multiplies the pixel value of each pixel of the analysis image for learning 42 from which the background average has been subtracted by a luminance magnification, which is a coefficient less than 1 set in advance. Graph G4 shown in FIG. 4 is a graph of the image obtained thereby. By multiplying by the luminance magnification, the contrast of the image can be reduced. As a result, noise in the background portion of the image can be reduced. The luminance magnification may be, for example, randomly selected from a range of 0.01 (lower limit) or more and less than 1 (upper limit) (excluding 1). In addition, the luminance magnification may be set in advance so that the variation of the pixel values of the background portion in the obtained image is equal to or less than a certain value. For example, the luminance magnification may be set so that the standard deviation (σ value) of the pixel values of the background portion is equal to or less than 1.

[0064] In addition, the coefficient (3 in the above-described example) multiplied by the average of pixel values in order for the learning

acquisition unit 11 to determine whether to adopt the cropped partial image as the analysis image for learning 42, as described above, may be a value corresponding to the luminance magnification. For example, the coefficient may be a value such that the target signal is not buried in noise even when the lower limit value of the luminance magnification is used. In addition, from this perspective, the luminance magnification may be set to a value corresponding to the coefficient.

[0065] Subsequently, as shown in FIG. 3, the noise addition unit 12 adds the background average subtracted above to the pixel value of each pixel of the image obtained by multiplying the pixel value by the luminance magnification, that is, the image with the reduced contrast. The image obtained thereby is the analysis image for learning with the reduced contrast. Since the analysis image of a semiconductor device includes noise other than random noise, by adding the background average to the image with the reduced contrast, an analysis image for learning in which only flickering due to random noise has been reduced from the actual analysis image can be obtained. Graph G5 shown in FIG. 4 is a graph of the image obtained thereby (the analysis image for learning with the reduced contrast). The analysis image for learning with the reduced contrast obtained in this manner is an image in which the contrast of the analysis image has been reduced without changing the pixel value of the background average (with the pixel value of the background average as a reference). When the analysis image is an emission image, the image is an emission image with the reduced contrast.

[0066] The analysis image for learning with the reduced contrast has smaller pixel values in the portion corresponding to the target signal, but

as described above, flickering due to random noise in the background portion has been reduced. Therefore, as described above, the analysis image for learning with the reduced contrast can be treated as an image not including the random noise.

[0067] The noise addition unit 12 may generate a plurality of analysis images for learning with the reduced contrast having mutually different contrast reduction rates for one analysis image for learning 42 by using each of a plurality of luminance magnifications. This allows the variation of images used for the machine learning training of the inference model to be increased.

[0068] In addition, as shown in FIG. 3, the noise addition unit 12 subtracts the calculated average of the pixel values of the noise image for learning 52 (background average) from the pixel value of each pixel of the noise image for learning 52. Graph G6 shown in FIG. 4 is a graph of the image obtained thereby. As shown in graph G6 in FIG. 4, the image is a graph in which the average of pixel values is zero. In addition, in the image, the average of pixel values does not need to be strictly zero, and it is sufficient that the pixel values are approximately close to zero. The image obtained thereby is a zero-mean noise image.

[0069] Subsequently, the noise addition unit 12 adds the pixel value of each pixel of the analysis image for learning with the reduced contrast (for example, the emission image with the reduced contrast) and the pixel value of each pixel of the zero-mean noise image for each pixel at the same position. The image obtained thereby is the noise-added image for learning. Graph G7 shown in FIG. 4 is an overlay of graph G5 of the analysis image for learning with the reduced contrast and graph G6 of

the zero-mean noise image.

[0070] As described above, by adding the zero-mean noise image to the analysis image for learning with the reduced contrast, it is possible to add to the analysis image for learning with the reduced contrast only the pixel values of the random noise portion, excluding the pixel values in the case where there is no random noise in the noise image for learning.

[0071] In addition, the generated noise-added image for learning may be other than those described above as long as it can be generated by adding the random noise of the noise image for learning to the analysis image for learning with the reduced contrast and can be used for the machine learning training of the inference model. In addition, the noise addition unit 12 may generate the noise-added image for learning from the analysis image for learning 42 and the noise image for learning 52 by methods other than those described above.

[0072] The noise addition unit 12 outputs to the training unit 13 a combination of the generated analysis image for learning with the reduced contrast and the noise-added image for learning generated from the analysis image for learning with the reduced contrast.

[0073] The training unit 13 is a training means for performing machine learning training of the inference model using the noise-added image for learning generated by the noise addition unit 12. The training unit 13 may perform the machine learning training of the inference model by treating the analysis image for learning with the reduced contrast as an image not including the random noise and treating the noise-added image for learning as an image including the random noise.

[0074] The training unit 13 performs the machine learning training of

the inference model, for example, as follows. The training unit 13 receives a combination of the analysis image for learning with the reduced contrast and the noise-added image for learning. The training unit 13 trains the inference model using this combination.

[0075] The training unit 13 performs the machine learning training of the inference model by treating the analysis image for learning with the reduced contrast as an image not including the random noise and treating the noise-added image for learning as an image including the random noise. For example, when the inference model is configured to receive an analysis image including the random noise and output an image after reduction of flickering due to random noise, the training unit 13 trains the inference model to receive the noise-added image for learning and output the analysis image for learning with the reduced contrast. For example, when the analysis image is an emission image, as shown in FIG. 5, training of the inference model is performed so that when a synthesized emission image with changed emission intensity (noise-added image for learning), which is an emission image with the reduced contrast plus zero-mean noise, is input to the inference model, an emission image with changed emission intensity (analysis image for learning with the reduced contrast), which is an emission image with the reduced contrast, is output from the inference model. That is, training of the inference model is performed so that the inference model eliminates the random noise component added to the analysis image for learning with the reduced contrast. The training unit 13 performs training of the inference model by a conventional method (for example, Noise2Clean).

[0076] In this case, for example, the training unit 13 inputs the noise-

added image for learning to the inference model and obtains, as an output from the inference model, an image in which flickering due to random noise has been reduced by the inference model at that point. The training unit 13 compares the output from the inference model with the analysis image for learning with the reduced contrast, and updates the parameters of the inference model by backpropagation based on the loss (Loss) based on the comparison.

[0077] In addition, when the inference model is configured to receive an analysis image including the random noise and output an image of random noise, the training unit 13 trains the inference model to receive the noise-added image for learning and output the noise image for learning corresponding to the input image.

[0078] The training unit 13 repeatedly trains the inference model using a plurality of combinations of the analysis image for learning with the reduced contrast and the noise-added image for learning. The repetition of training of the inference model is performed, similarly to conventional machine learning training, for example, a preset number of times, or until the generation of the inference model converges based on preset conditions. When the above repetition of training of the inference model is completed, the training unit 13 outputs the generated inference model to the noise reduction system 20. The above is the function of the learning system 10.

[0079] As shown in FIG. 1, the noise reduction system 20 includes a reduction acquisition unit 21 and an image generation unit 22.

[0080] The reduction acquisition unit 21 is a reduction acquisition means for acquiring an analysis image for noise reduction that includes

a target signal related to a semiconductor device and includes random noise. The reduction acquisition unit 21 may also acquire a pattern image of the semiconductor device corresponding to the analysis image for noise reduction.

[0081] The reduction acquisition unit 21 acquires images, for example, as follows. The reduction acquisition unit 21 acquires the analysis image for noise reduction by receiving it from the imaging device that captured the analysis image for noise reduction, or by accepting a user's image input operation to the noise reduction system 20. When the size of the analysis image for noise reduction input to the inference model is, similarly to the analysis image for learning described above, a size of an image that is cropped from the original image obtained by imaging with the imaging device and is smaller than the original image, the reduction acquisition unit 21 may acquire the original image, divide the original image into images having the size of the analysis image input to the inference model, and use the divided images as the analysis images for noise reduction.

[0082] The reduction acquisition unit 21 may acquire the analysis image for noise reduction by methods other than those described above. The reduction acquisition unit 21 outputs the acquired analysis image for noise reduction to the image generation unit 22.

[0083] The reduction acquisition unit 21 may also acquire a pattern image of the semiconductor device corresponding to the analysis image for noise reduction. The pattern image is an image obtained by imaging the pattern of the semiconductor device. The pattern image is an image conventionally used for failure analysis of semiconductor devices

together with emission images. The reduction acquisition unit 21 acquires, for example, a pattern image corresponding to the analysis image for noise reduction or its original image (an image in which pixels at the same position indicate the same position of the semiconductor device). The reduction acquisition unit 21 may acquire the pattern image in the same manner as the analysis image for noise reduction. The reduction acquisition unit 21 outputs the acquired pattern image of the semiconductor device to the image generation unit 22.

[0084] The image generation unit 22 is an image generation means for generating, from the analysis image for noise reduction acquired by the reduction acquisition unit 21, an inference image in which flickering due to random noise is reduced, by using an inference model generated in advance by machine learning training. The inference model used by the image generation unit 22 may be the inference model generated by the learning system 10. The image generation unit 22 may generate a composite image obtained by superimposing the generated inference image and the pattern image acquired by the reduction acquisition unit 21.

[0085] The image generation unit 22 generates images, for example, as follows. The image generation unit 22 receives and stores the inference model generated by the learning system 10, and uses it to generate an inference image in which flickering due to random noise is reduced. In addition, the image generation unit 22 may store an inference model other than one generated by the learning system 10, and use it to generate an inference image in which flickering due to random noise is reduced.

[0086] The image generation unit 22 receives the analysis image for

noise reduction from the reduction acquisition unit 21. The image generation unit 22 inputs the received analysis image for noise reduction to the inference model and generates an inference image after reduction of flickering due to random noise. For example, when the inference model is one that outputs an inference image after reduction of flickering due to random noise, the image generation unit 22 acquires the output from the inference model as the inference image after reduction of flickering due to random noise. Alternatively, when the inference model is one that outputs an image of random noise, the image generation unit 22 obtains the inference image after reduction of flickering due to random noise by removing the random noise indicated by the random noise image obtained using the inference model from the analysis image for noise reduction. In addition, the image generation unit 22 may generate the inference image after reduction of flickering due to random noise from the analysis image for noise reduction by methods other than those described above as long as the method uses the inference model.

[0087] When a pattern image of the semiconductor device is acquired by the reduction acquisition unit 21, the image generation unit 22 receives the pattern image of the semiconductor device from the reduction acquisition unit 21. The image generation unit 22 generates a composite image (superimposed image) obtained by superimposing the generated inference image after reduction of flickering due to random noise and the pattern image. The generation of the composite image may be performed in the same manner as conventionally.

[0088] The image generated by the image generation unit 22 (the inference image after reduction of flickering due to random noise or the

composite image) is used for failure analysis of semiconductor devices. The image generation unit 22 outputs the generated image. The output of the generated image may be performed in the same manner as conventional methods according to the failure analysis of semiconductor devices to be performed. At this time, the analysis image for noise reduction (the analysis image before reduction of flickering due to random noise) and the inference image after reduction of flickering due to random noise may be selectively displayable. The above is the function of the noise reduction system 20.

[0089] Next, the processes performed by the learning system 10 and the noise reduction system 20 according to the present embodiment (operation methods performed by the learning system 10 and the noise reduction system 20) will be described using the flowcharts in FIGS. 6 and 7.

[0090] First, the learning method, which is a process performed by the learning system 10 according to the present embodiment, will be described using the flowchart in FIG. 6. In this process, the learning acquisition unit 11 acquires an analysis image for learning that includes a target signal related to a semiconductor device and includes random noise, and a noise image for learning that does not include the target signal and includes random noise (S01, learning acquisition step). Subsequently, the noise addition unit 12 reduces contrast of the analysis image for learning and generates an analysis image for learning with reduced contrast (S02, noise addition step). Subsequently, the noise addition unit 12 adds the random noise of the noise image for learning to the analysis image for learning with the reduced contrast and generates

a noise-added image for learning (S03, noise addition step).

[0091] Subsequently, the training unit 13 uses the noise-added image for learning to perform machine learning training of the inference model (S04, training step). Subsequently, the inference model generated by training is output from the learning system 10 to the noise reduction system 20 (S05). In the noise reduction system 20, the inference model is stored and used in the following noise reduction process. The above is the learning method, which is a process performed by the learning system 10 according to the present embodiment.

[0092] Subsequently, the noise reduction method, which is a process performed by the noise reduction system 20 according to the present embodiment, will be described using the flowchart in FIG. 7. In this process, the reduction acquisition unit 21 acquires an analysis image for noise reduction that includes a target signal related to a semiconductor device and includes random noise (S11, reduction acquisition step). Subsequently, the image generation unit 22 uses the inference model to generate an inference image in which flickering due to random noise is reduced from the analysis image for noise reduction (S12, image generation step). The inference image in which flickering due to random noise is reduced is output from the image generation unit 22 to a predetermined output destination (S13). When a pattern image of the semiconductor device corresponding to the analysis image for noise reduction is acquired by the reduction acquisition unit 21, the image generation unit 22 generates and outputs a composite image obtained by superimposing the inference image and the pattern image. The above is the noise reduction method, which is a process performed by the noise

reduction system 20 according to the present embodiment.

[0093] In the learning system 10 according to the present embodiment, the random noise of the noise image for learning is added to the analysis image for learning with the reduced contrast, and a noise-added image for learning is generated. An inference model generated using such a noise-added image for learning is capable of appropriately reducing flickering due to random noise from an analysis image. Therefore, according to the learning system 10 according to the present embodiment, flickering due to random noise can be appropriately reduced from an analysis image. In addition, in the present embodiment, it is not necessary to prepare in advance an analysis image not including the random noise.

[0094] As in the present embodiment, the machine learning training of the inference model may be performed by treating the analysis image for learning with the reduced contrast as an image not including the random noise and treating the noise-added image for learning as an image including the random noise. According to this configuration, the machine learning training of the inference model can be performed more appropriately, and a more appropriate inference model can be generated. As a result, flickering due to random noise can be more appropriately reduced from an analysis image. However, the machine learning training of the inference model does not necessarily need to be performed by treating the analysis image for learning with the reduced contrast and the noise-added image for learning as described above, and it is sufficient that the training is performed using the noise-added image for learning.

[0095] As in the present embodiment, a pixel value corresponding to the

noise image for learning may be subtracted from a pixel value of each pixel of the analysis image for learning, the pixel value of each pixel after the subtraction may be multiplied by a coefficient less than 1 set in advance (luminance magnification), the subtracted pixel value may be added to the pixel value of each pixel after the multiplication, and an analysis image for learning with the reduced contrast may be generated. According to this configuration, a more appropriate analysis image for learning with the reduced contrast can be generated. As a result, flickering due to random noise can be more appropriately reduced from an analysis image. However, the generation of the analysis image for learning with the reduced contrast does not necessarily need to be performed as described above, and may be performed by any method.

[0096] As in the present embodiment, a plurality of analysis images for learning with the reduced contrast may be generated using a plurality of mutually different coefficients (luminance magnifications), and a plurality of noise-added images for learning may be generated. According to this configuration, a plurality of analysis images for learning with the reduced contrast can be generated from one analysis image for learning, and the variation of images used for the machine learning training of the inference model can be increased. This allows the machine learning training of the inference model to be performed more appropriately, and a more appropriate inference model can be generated. As a result, flickering due to random noise can be more appropriately reduced from an analysis image. However, it is not necessary to use a plurality of mutually different coefficients (luminance magnifications) in generating the noise-added images for learning.

[0097] As in the present embodiment, an original image that includes a portion that can serve as the analysis image for learning and is larger in size than the analysis image for learning may be acquired, a part of the acquired original image may be cropped, a value based on a pixel value of the cropped image may be compared with a value corresponding to a pixel value of the noise image for learning, and the cropped image may be used as the analysis image for learning according to the comparison result. Specifically, a value based on the pixel value of the cropped image may be compared with an average or a variation value of the pixel values of the noise image for learning, and the cropped image may be used as the analysis image for learning according to the comparison result. According to these configurations, the analysis image for learning can be acquired simply and appropriately. As a result, flickering due to random noise can be more appropriately reduced from an analysis image. However, the acquisition of the analysis image for learning does not need to be performed as described above.

[0098] According to the noise reduction system 20 according to the present embodiment, flickering due to random noise can be appropriately reduced from an analysis image.

[0099] As in the present embodiment, a pattern image of the semiconductor device corresponding to the analysis image for noise reduction may also be acquired, and a composite image obtained by superimposing the generated inference image and the pattern image may be generated. According to this configuration, a composite image obtained by superimposing the inference image, in which flickering due to random noise has been appropriately reduced, and the pattern image

can be obtained.

[0100] Next, examples according to the present embodiment are shown. FIG. 8 shows an example of reduction of flickering due to random noise performed by the present embodiment. FIG. 8(a) is an analysis image subject to reduction of flickering due to random noise, and FIG. 8(b) is an inference image in which reduction of flickering due to random noise has been performed on the analysis image by the present embodiment. The analysis image subject to reduction of flickering due to random noise shown in FIG. 8(a) was captured under the condition of a lens magnification of 5×. In addition, the standard deviation (S.D.) of pixel values in a partial region R1 in each image in FIG. 8 is shown. The partial region R1 is a background portion that does not correspond to the target signal related to the semiconductor device. Therefore, the standard deviation of pixel values in the partial region R1 indicates that the smaller the value, the less flickering due to random noise.

[0101] FIG. 9 shows an example of reduction of flickering due to random noise performed by the present embodiment. FIG. 9(a) is an analysis image subject to reduction of flickering due to random noise, and FIG. 9(b) is an inference image in which reduction of flickering due to random noise has been performed on the analysis image by the present embodiment. The analysis image subject to reduction of flickering due to random noise shown in FIG. 9(a) was captured under the condition of a lens magnification of 20×. In addition, the standard deviation (S.D.) of pixel values in a partial region R2 in each image in FIG. 9 is shown. The partial region R2 is a background portion that does not correspond to the target signal related to the semiconductor device. Therefore, the

standard deviation of pixel values in the partial region R2 indicates that the smaller the value, the less flickering due to random noise. In both of the examples of FIGS. 8 and 9, reduction of flickering due to random noise in the analysis image has been performed appropriately.

[0102] FIG. 10 shows an example of a composite image (superimposed image) generated by the present embodiment. FIG. 10(a) is a composite image obtained by superimposing the analysis image subject to reduction of flickering due to random noise and the pattern image. FIG. 10(b) is a composite image obtained by superimposing the inference image, in which reduction of flickering due to random noise has been performed on the analysis image by the present embodiment, and the pattern image. The analysis image subject to reduction of flickering due to random noise used in the composite image of FIG. 10(a) was captured at a driving frequency of 1.2 MHz of the semiconductor device.

[0103] In addition, FIG. 10(c) and FIG. 10(d) show enlarged images of a partial region R3 in each image of FIG. 10(a) and FIG. 10(b). The partial region R2 is a portion corresponding to the target signal related to the semiconductor device. In the example of FIG. 10 as well, reduction of flickering due to random noise in the analysis image has been performed appropriately. In the example of FIG. 10, compared to the case where reduction of flickering due to random noise (denoising) has not been performed (FIGS. 10(a) and 10(c)), in the case where reduction of flickering due to random noise (denoising) has been performed (FIGS. 10(b) and 10(d)), signals with weak emission intensity can also be confirmed.

[0104] Next, a learning program and a noise reduction program for

executing the above-described series of processes by the learning system 10 and the noise reduction system 20 will be described. As shown in FIG. 11(a), a learning program 100 is stored in a program storage region 111 formed in a computer-readable recording medium 110, which is inserted into a computer and accessed or which is provided in the computer. The recording medium 110 may be a non-transitory recording medium.

[0105] The learning program 100 includes a learning acquisition module 101, a noise addition module 102, and a training module 103. The functions realized by executing the learning acquisition module 101, the noise addition module 102, and the training module 103 are the same as the functions of the learning acquisition unit 11, the noise addition unit 12, and the training unit 13 of the learning system 10 described above, respectively.

[0106] As shown in FIG. 11(b), a noise reduction program 200 is stored in a program storage region 211 formed in a computer-readable recording medium 210, which is inserted into a computer and accessed or which is provided in the computer. The recording medium 210 may be a non-transitory recording medium. In addition, when the learning program 100 and the noise reduction program 200 are executed on the same computer, the recording medium 210 may be the same as the recording medium 110.

[0107] The noise reduction program 200 includes a reduction acquisition module 201 and an image generation module 202. The functions realized by executing the reduction acquisition module 201 and the image generation module 202 are the same as the functions of

the reduction acquisition unit 21 and the image generation unit 22 of the noise reduction system 20 described above, respectively.

[0108] In addition, a part or entirety of each of the learning program 100 and the noise reduction program 200 may be transmitted through a transmission medium, such as a communication line, and received by another device and recorded (including installation). In addition, each module of the learning program 100 and the noise reduction program 200 may be installed on any of a plurality of computers instead of one computer. In this case, the above-described series of processes are performed by a computer system including the plurality of computers.

[0109] The learning method, the inference model, the noise reduction method, the noise reduction system, and the noise reduction program of the present disclosure have the following configuration.

[1] A learning method for generating an inference model used to reduce flickering due to random noise from analysis images used for failure analysis of semiconductor devices, comprising:

a learning acquisition step of acquiring an analysis image for learning that includes a target signal related to a semiconductor device and includes random noise, and a noise image for learning that does not include the target signal and includes random noise;

a noise addition step of reducing contrast of the analysis image for learning acquired in the learning acquisition step, adding the random noise of the noise image for learning to the analysis image for learning with reduced contrast, and generating a noise-added image for learning; and

a training step of performing machine learning training of the

inference model using the noise-added image for learning generated in the noise addition step.

[2] The learning method according to [1], wherein the machine learning training of the inference model is performed in the training step by treating the analysis image for learning with the reduced contrast as an image not including the random noise and treating the noise-added image for learning as an image including the random noise.

[3] The learning method according to [1] or [2], wherein in the noise addition step, a pixel value corresponding to the noise image for learning is subtracted from a pixel value of each pixel of the analysis image for learning, the pixel value of each pixel after the subtraction is multiplied by a coefficient less than 1 set in advance, the subtracted pixel value is added to the pixel value of each pixel after the multiplication, and the analysis image for learning with the reduced contrast is generated.

[4] The learning method according to [3], wherein in the noise addition step, a plurality of analysis images for learning with the reduced contrast are generated using a plurality of mutually different coefficients, and a plurality of noise-added images for learning are generated.

[5] The learning method according to any one of [1] to [4], wherein in the learning acquisition step, an original image that includes a portion that can serve as the analysis image for learning and is larger in size than the analysis image for learning is acquired, a part of the acquired original image is cropped, a value based on a pixel value of the cropped image is compared with a value corresponding to a pixel value of the noise image for learning, and the cropped image is used as the

analysis image for learning according to the comparison result.

[6] The learning method according to [5], wherein in the learning acquisition step, a value based on the pixel value of the cropped image is compared with an average or a variation value of the pixel values of the noise image for learning, and the cropped image is used as the analysis image for learning according to the comparison result.

[7] An inference model for causing a computer to function to receive information based on an analysis image used for failure analysis of a semiconductor device, perform a calculation according to the input, and output information,

wherein the inference model is generated by the learning method according to any one of [1] to [6].

[8] A noise reduction method for reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices, comprising:

a reduction acquisition step of acquiring an analysis image for noise reduction that includes a target signal related to a semiconductor device and includes random noise; and

an image generation step of generating an inference image in which flickering due to random noise is reduced from the analysis image for noise reduction acquired in the reduction acquisition step, by using an inference model generated in advance by machine learning training.

[9] The noise reduction method according to [8], wherein the inference model is the inference model generated by the learning method according to any one of [1] to [6].

[10] The noise reduction method according to [8] or [9],

wherein in the reduction acquisition step, a pattern image of the semiconductor device corresponding to the analysis image for noise reduction is also acquired, and

wherein in the image generation step, a composite image obtained by superimposing the generated inference image and the pattern image acquired in the reduction acquisition step is generated.

[11] A noise reduction system for reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices, comprising:

a reduction acquisition means for acquiring an analysis image for noise reduction that includes a target signal related to a semiconductor device and includes random noise; and

an image generation means for generating an inference image in which flickering due to random noise is reduced from the analysis image for noise reduction acquired by the reduction acquisition means, by using an inference model generated in advance by machine learning training.

[12] The noise reduction system according to [11], wherein the inference model is the inference model generated by the learning method according to any one of [1] to [6].

[13] A noise reduction program for reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices, causing a computer to execute:

a reduction acquisition process of acquiring an analysis image for noise reduction that includes a target signal related to a semiconductor device and includes random noise; and

an image generation process of generating an inference image in

which flickering due to random noise is reduced from the analysis image for noise reduction acquired by the reduction acquisition process, by using an inference model generated in advance by machine learning training.

[14] The noise reduction program according to [13], wherein the inference model is the inference model generated by the learning method according to any one of [1] to [6].

Reference Signs List

[0110] 10: learning system, 11: learning acquisition unit, 12: noise addition unit, 13: training unit, 20: noise reduction system, 21: reduction acquisition unit, 22: image generation unit, 100: learning program, 101: learning acquisition module, 102: noise addition module, 103: training module, 110: recording medium, 111: program storage region, 200: noise reduction program, 201: reduction acquisition module, 202: image generation module, 210: recording medium, 211: program storage region.

CLAIMS

[Claim 1] A learning method for generating an inference model used to reduce flickering due to random noise from analysis images used for failure analysis of semiconductor devices, comprising:

a learning acquisition step of acquiring an analysis image for learning that includes a target signal related to a semiconductor device and includes random noise, and a noise image for learning that does not include the target signal and includes random noise;

a noise addition step of reducing contrast of the analysis image for learning acquired in the learning acquisition step, adding the random noise of the noise image for learning to the analysis image for learning with reduced contrast, and generating a noise-added image for learning; and

a training step of performing machine learning training of the inference model using the noise-added image for learning generated in the noise addition step.

[Claim 2] The learning method according to claim 1, wherein the machine learning training of the inference model is performed in the training step by treating the analysis image for learning with the reduced contrast as an image not including the random noise and treating the noise-added image for learning as an image including the random noise.

[Claim 3] The learning method according to claim 1 or 2, wherein in the noise addition step, a pixel value corresponding to the noise image for learning is subtracted from a pixel value of each pixel of the analysis image for learning, the pixel value of each pixel after the subtraction is multiplied by a coefficient less than 1 set in advance, the subtracted pixel

value is added to the pixel value of each pixel after the multiplication, and the analysis image for learning with the reduced contrast is generated.

[Claim 4] The learning method according to claim 3, wherein in the noise addition step, a plurality of analysis images for learning with the reduced contrast are generated using a plurality of mutually different coefficients, and a plurality of noise-added images for learning are generated.

[Claim 5] The learning method according to claim 1 or 2, wherein in the learning acquisition step, an original image that includes a portion that can serve as the analysis image for learning and is larger in size than the analysis image for learning is acquired, a part of the acquired original image is cropped, a value based on a pixel value of the cropped image is compared with a value corresponding to a pixel value of the noise image for learning, and the cropped image is used as the analysis image for learning according to the comparison result.

[Claim 6] The learning method according to claim 5, wherein in the learning acquisition step, a value based on the pixel value of the cropped image is compared with an average or a variation value of the pixel values of the noise image for learning, and the cropped image is used as the analysis image for learning according to the comparison result.

[Claim 7] An inference model for causing a computer to function to receive information based on an analysis image used for failure analysis of a semiconductor device, perform a calculation according to the input, and output information,

wherein the inference model is generated by the learning method

according to claim 1 or 2.

[Claim 8] A noise reduction method for reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices, comprising:

a reduction acquisition step of acquiring an analysis image for noise reduction that includes a target signal related to a semiconductor device and includes random noise; and

an image generation step of generating an inference image in which flickering due to random noise is reduced from the analysis image for noise reduction acquired in the reduction acquisition step, by using an inference model generated in advance by machine learning training.

[Claim 9] The noise reduction method according to claim 8, wherein the inference model is the inference model generated by the learning method according to claim 1.

[Claim 10] The noise reduction method according to claim 8,

wherein in the reduction acquisition step, a pattern image of the semiconductor device corresponding to the analysis image for noise reduction is also acquired, and

wherein in the image generation step, a composite image obtained by superimposing the generated inference image and the pattern image acquired in the reduction acquisition step is generated.

[Claim 11] A noise reduction system for reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices, comprising:

a reduction acquisition means for acquiring an analysis image for noise reduction that includes a target signal related to a semiconductor

device and includes random noise; and

an image generation means for generating an inference image in which flickering due to random noise is reduced from the analysis image for noise reduction acquired by the reduction acquisition means, by using an inference model generated in advance by machine learning training.

[Claim 12] The noise reduction system according to claim 11, wherein the inference model is the inference model generated by the learning method according to claim 1.

[Claim 13] A noise reduction program for reducing flickering due to random noise from analysis images used for failure analysis of semiconductor devices, causing a computer to execute:

a reduction acquisition process of acquiring an analysis image for noise reduction that includes a target signal related to a semiconductor device and includes random noise; and

an image generation process of generating an inference image in which flickering due to random noise is reduced from the analysis image for noise reduction acquired by the reduction acquisition process, by using an inference model generated in advance by machine learning training.

[Claim 14] The noise reduction program according to claim 13, wherein the inference model is the inference model generated by the learning method according to claim 1.