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(54) Title of the Invention: **Method and system for optical evaluation, and optical detector**
Abstract Title: **Optical detector with a plurality of pixel pairs for laser ultrasonic surface inspection**

(57) An optical detector 50 comprises a plurality of pixels, each pixel comprising a photodiode operable to detect light incident on that pixel and to generate a signal indicative of an intensity of that light. The plurality of pixels comprises a plurality of pixel pairs, and for each pixel pair, in a configuration mode, the detector is arranged to compare the signal generated by *a* first pixel of the pair with the signal generated by a second pixel of the pair. The plurality of pixels may comprise an array and the signal indicative of intensity generated by each pixel may be connected to either a first output 52 or a second output 54 depending on the result of the comparison. In an experiment mode, the signals indicative of intensity received at the first output 52 may be summed and those received at the second output 54 may be summed. The difference between the two summed signals may be obtained. The optical detector may be a speckle knife edge detector used in laser ultrasonic evaluation of both rough and smooth surfaces.

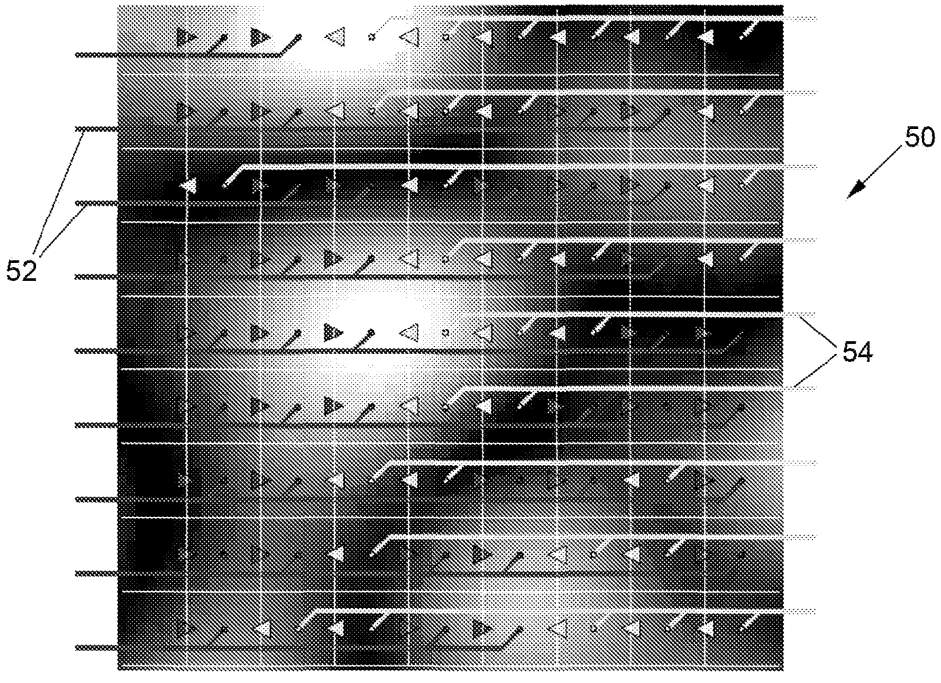


Fig. 5

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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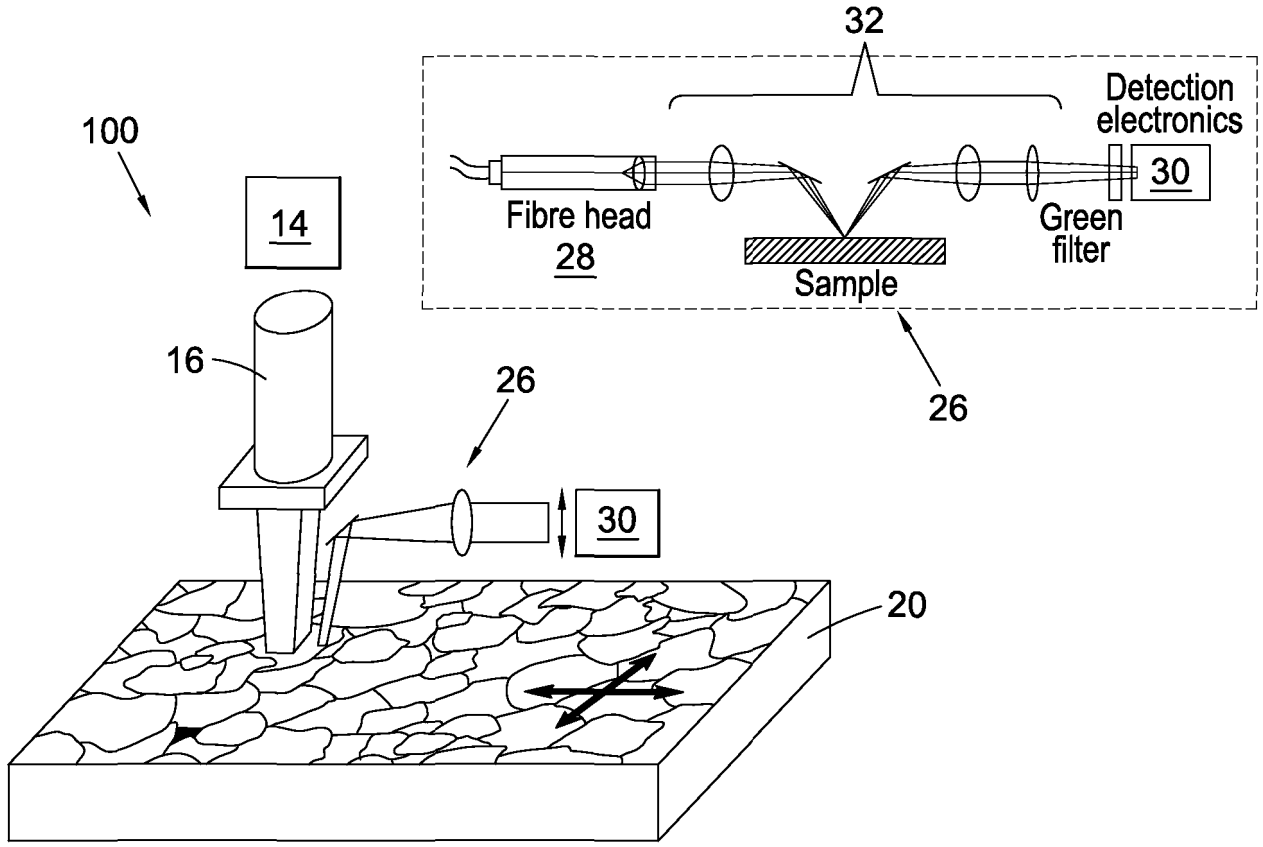


Fig. 1

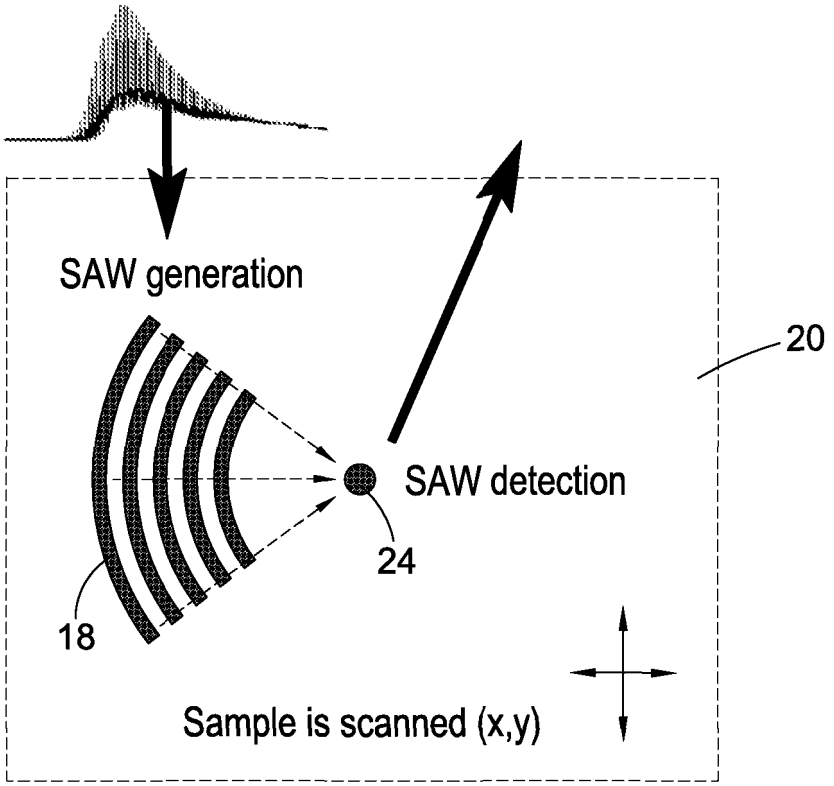


Fig. 2

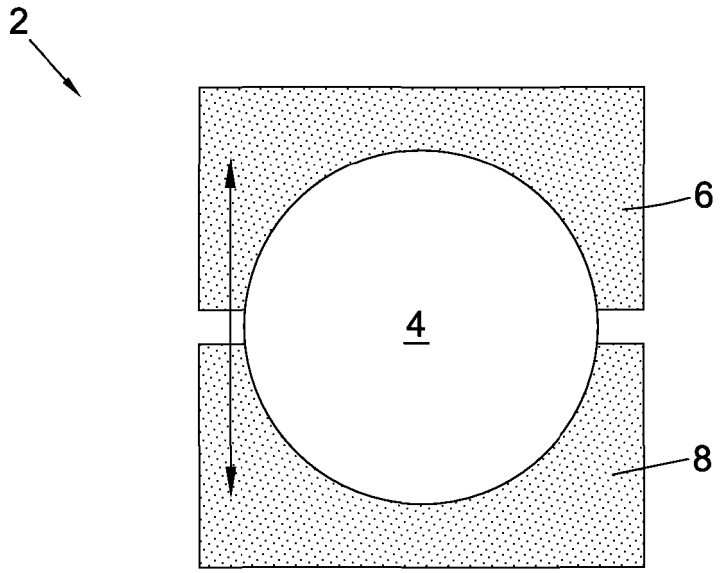


Fig. 3A

17 01 13

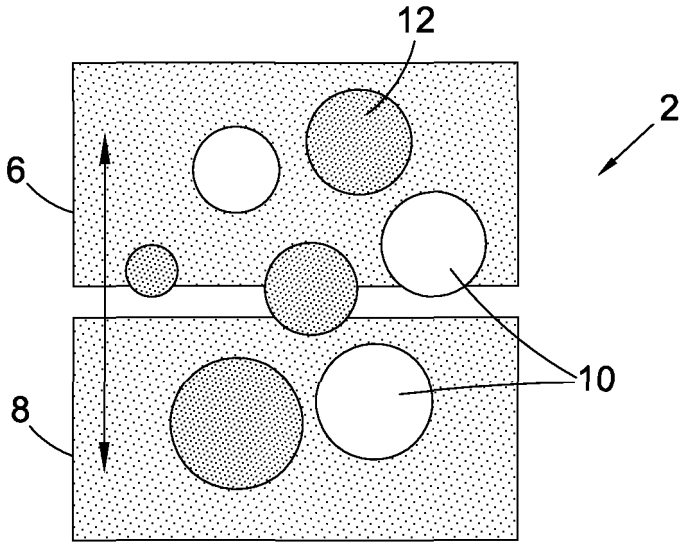


Fig. 3B

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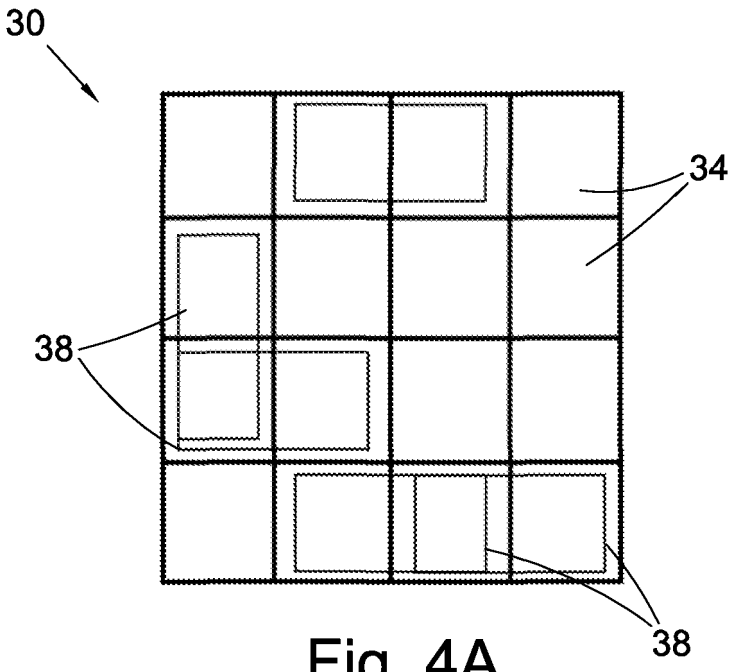


Fig. 4A

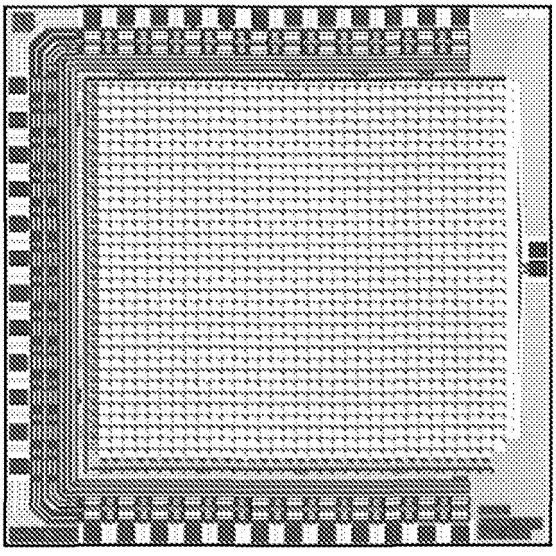


Fig. 4B

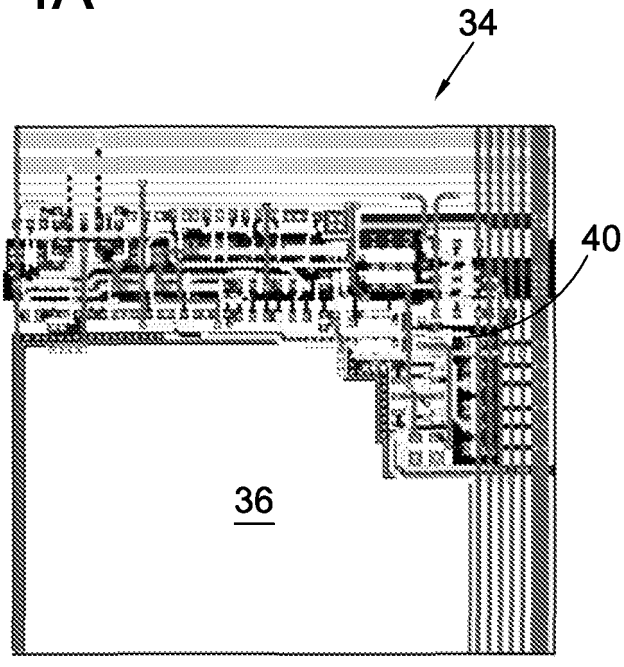


Fig. 4C

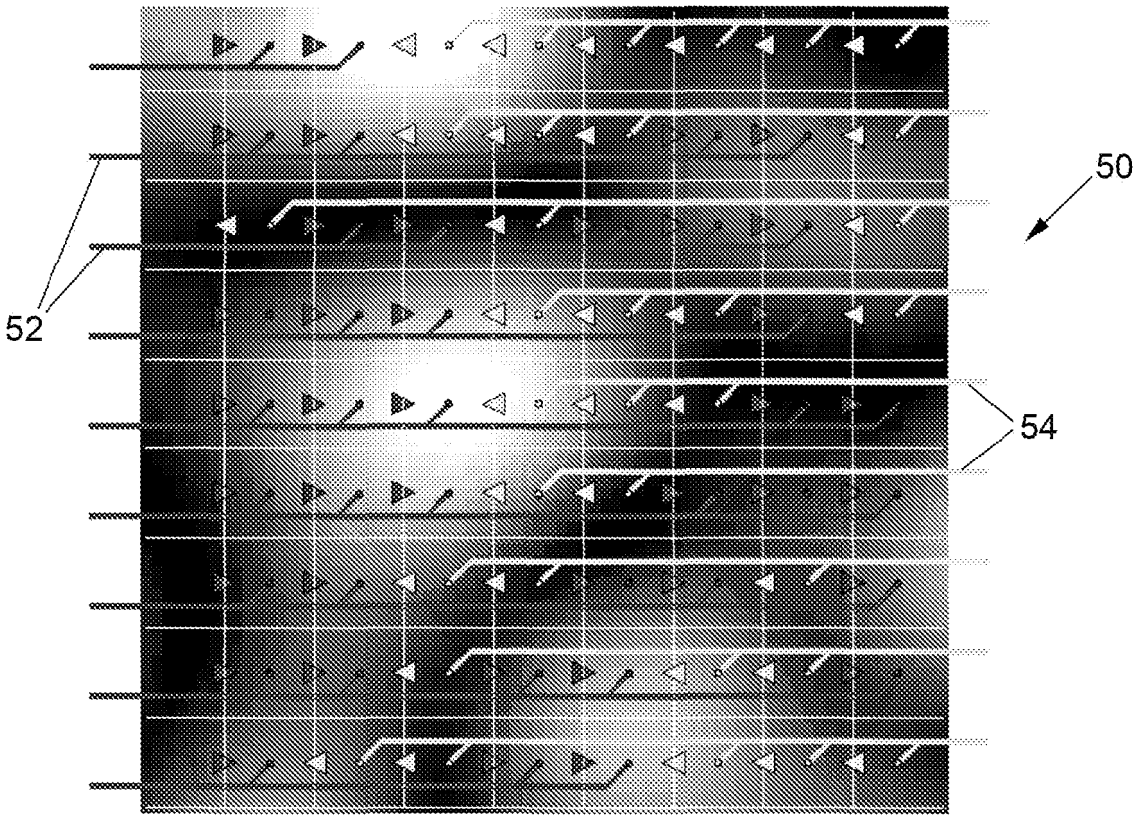


Fig. 5

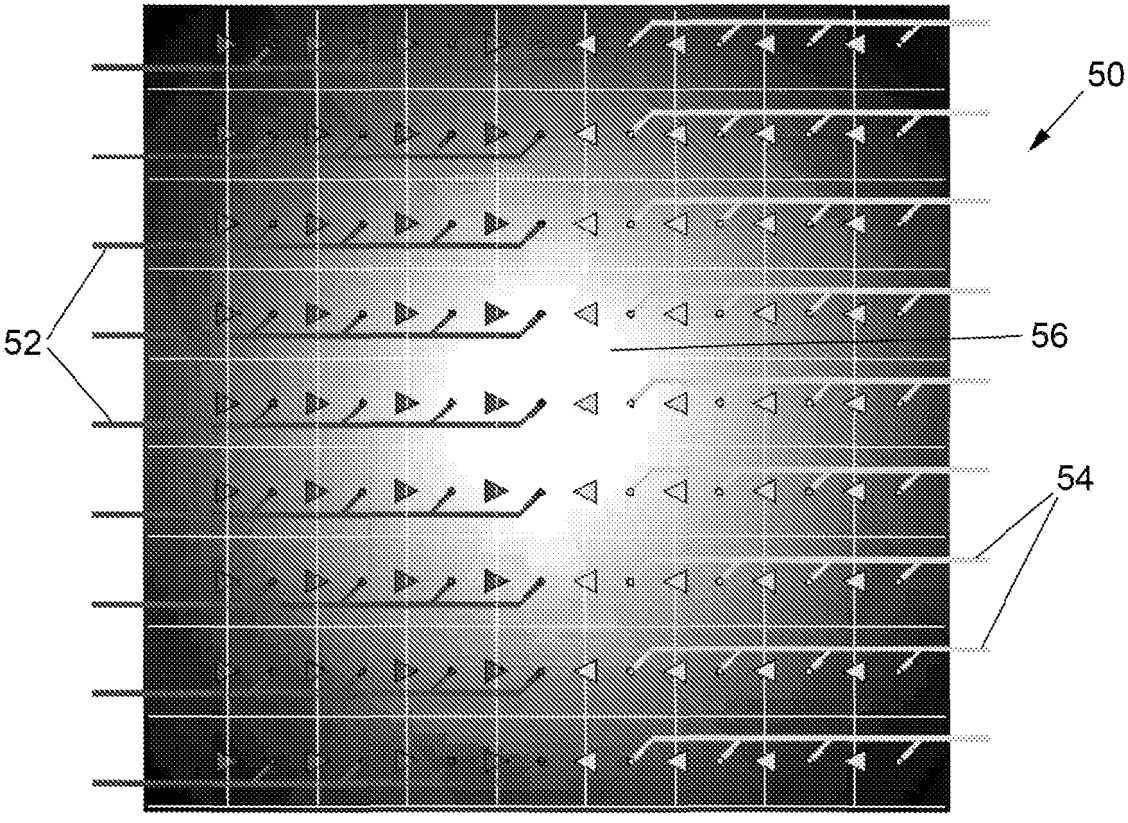


Fig. 6

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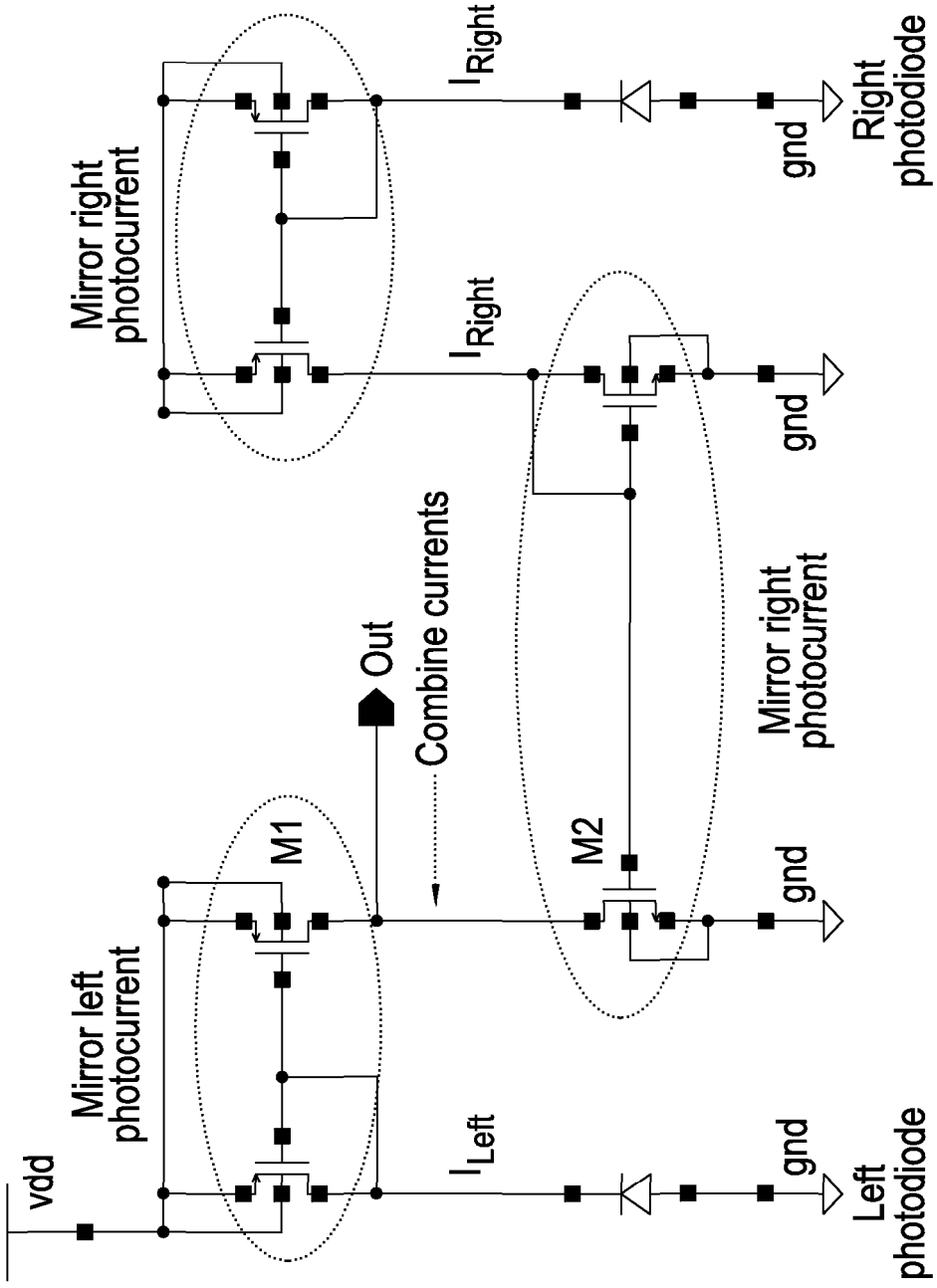

vdd
Mirror left photocurrent
M1
I_{Left}
gnd
Left photodiode
Out
Combine currents
M2
Mirror right photocurrent
gnd
I_{Right}
Mirror right photocurrent
gnd
I_{Right}
Right photodiode

Fig. 7

17 01 13

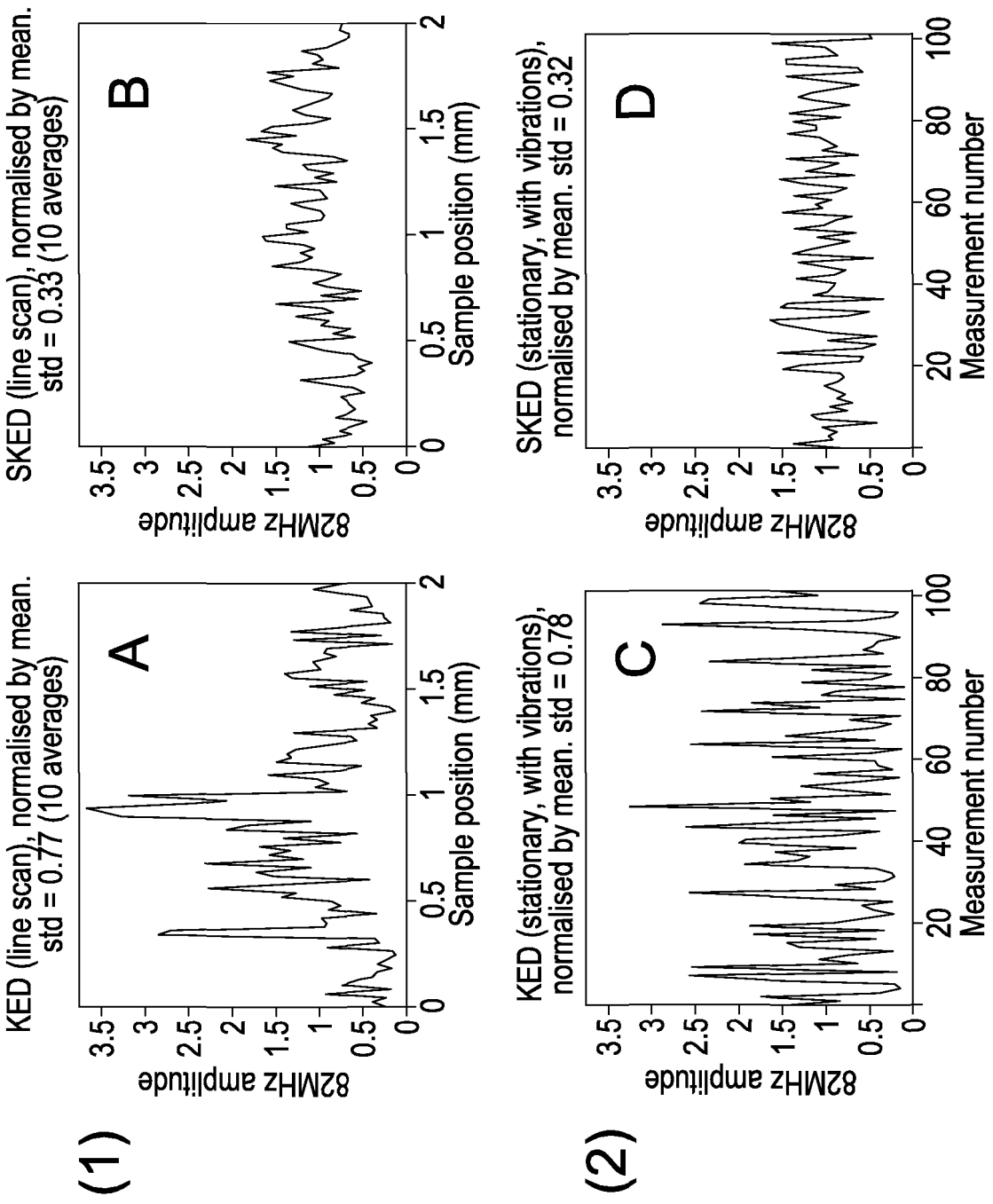

(1)
KED (line scan), normalised by mean.
std = 0.77 (10 averages)
A
82MHz amplitude
Sample position (mm)
SKED (line scan), normalised by mean.
std = 0.33 (10 averages)
B
82MHz amplitude
Sample position (mm)
(2)
KED (stationary, with vibrations),
normalised by mean. std = 0.78
C
82MHz amplitude
Measurement number
SKED (stationary, with vibrations),
normalised by mean. std = 0.32
D
82MHz amplitude
Measurement number

Fig. 8

17 01 13

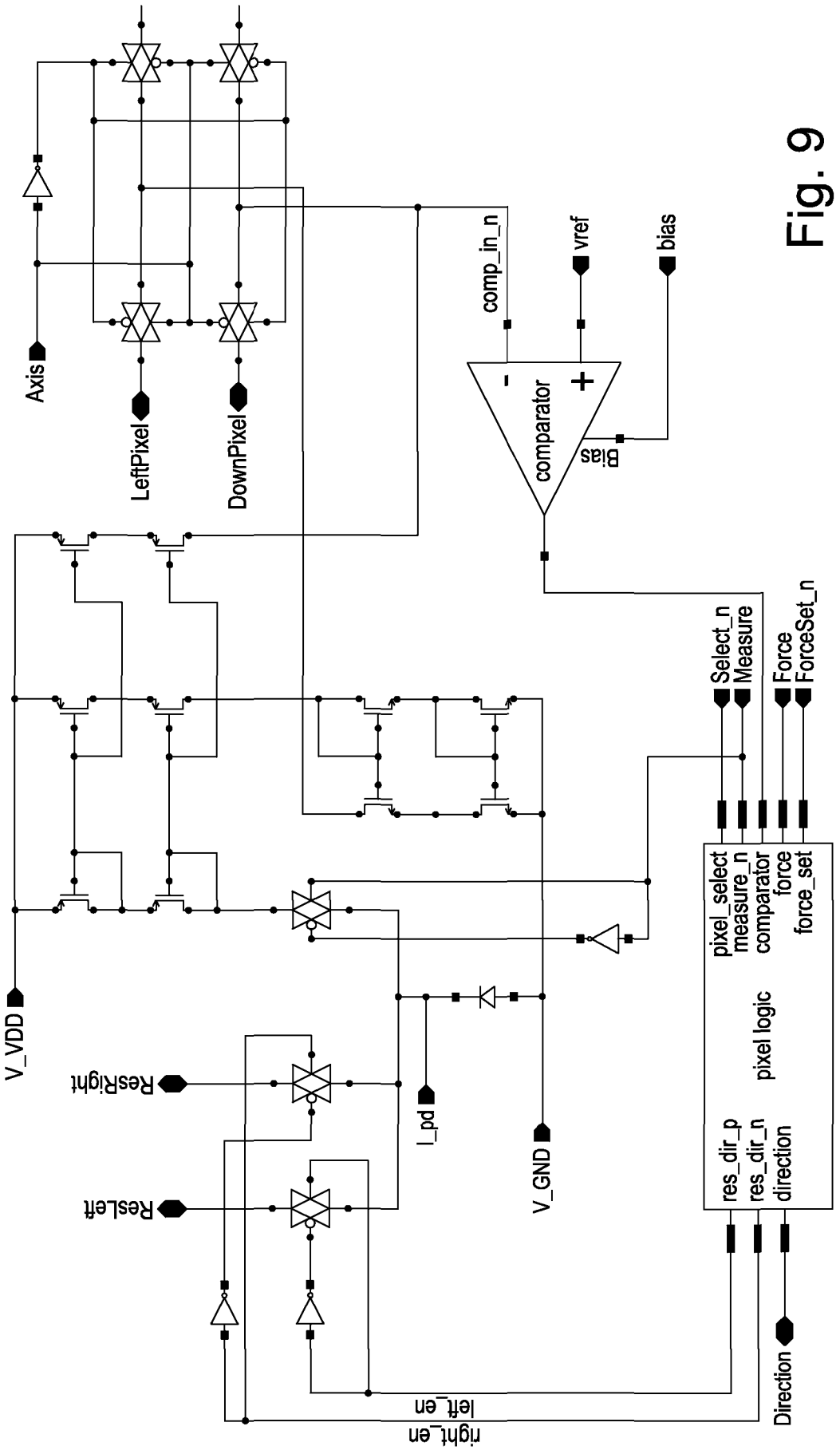

Axis
LeftPixel
DownPixel
comp_in_n
vref
bias
comparator
Bias
Select_n
Measure
Force
ForceSet_n
pixel_select
measure_n
comparator
force
force_set
pixel logic
res_dir_p
res_dir_n
direction
Direction
V_VDD
ResRight
ResLeft
I_pd
V_GND
right_en
left_en

Fig. 9

METHOD AND SYSTEM FOR OPTICAL EVALUATION, AND OPTICAL DETECTOR

The present invention relates to a method and system for optical evaluation, as well as to optical detectors for use in such methods and systems. The present invention relates particularly, but not exclusively, to optical detection of ultrasonic waves on the surface of materials.

Ultrasonics is widely used for testing materials for defects, wear, cracks etc and has the key advantage that it allows inspection of optically opaque materials. A problem with conventional (non-laser) ultrasonics is that it requires contacting transducers to generate and detect the ultrasonic waves. This means the methods are unsuitable for inaccessible or hazardous environments. Laser ultrasonics overcomes these problems by using a laser to generate and detect the sound waves. One laser generates the sound by heating the sample which induces thermal expansion, which, in turn, produces a sound wave, typically including a surface acoustic wave (SAW) which travels across the surface of the material under test. Such a sound wave can be detected with a second laser system which measures the small changes in the shape of the surface as the sound wave passes under it.

Laser ultrasonics is, however, not without its own problems, the main one being that when the sample we wish to examine is 'rough' as many engineering components are (rough here only means sufficiently unpolished that it is not a good mirror) the light is scattered randomly and conventional optical techniques will not detect the presence of sound waves passing under the optical beam.

We propose herein an optical detector which may be used in laser ultrasonic evaluation of rough as well as smooth surfaces. The optical detector is also applicable for use in other circumstances.

According to a first aspect of the invention there is provided an optical detector comprising a plurality of pixels, each pixel comprising a photodiode operable to detect light incident on that pixel and to generate a signal indicative of an intensity of that light, wherein the plurality of pixels comprises a plurality of pixel pairs, and wherein for each pixel pair, in a configuration mode, the detector is arranged to compare the

signal generated by a first pixel of the pair with the signal generated by a second pixel of the pair.

The optical detector may be operable to use the comparison to determine whether the intensity of light incident on the first pixel of the pair is higher (or lower) than the intensity of light incident on the second pixel of the pair.

The optical detector may comprise a first output and a second output, and the signal indicative of intensity generated by the first pixel may be connected to either the first output or the second output depending on the result of the comparison. For example, if the first intensity signal is higher than the second intensity signal, the signal from the first pixel may be connected to the first output. Conversely, if the first intensity signal is lower than the second intensity signal, the signal from the first pixel may be connected to the second output.

The comparison may be performed simultaneously and in parallel over the plurality of pixel pairs.

The plurality of pixels may comprise an array, and in use the signal indicative of intensity generated by each pixel in an active area of the array may be connected to either the first output or the second output.

The optical detector may further comprise an experiment mode in which the signals indicative of intensity received at the first output are summed to produce a first composite intensity signal, and in which the signals indicative of intensity received at the second output are summed to produce a second composite intensity signal.

The second composite intensity signal may be subtracted from the first composite intensity signal (or vice versa).

Each pair of pixels may comprise a pair of adjacent pixels. The arrangement of the pairs may be periodic, such that the first pixel of each pair always has the same spatial relation with respect to the second pixel of that pair.

The pairs may overlap, such that the first pixel in one pair comprises the second pixel in an adjacent pair.

The plurality of pixels may be provided in a regular planar array having a first axis and a second axis which is perpendicular to the first axis. The comparison may be performed based on pairs arranged in alignment with the first axis or the second axis. The comparison may be switchable/operable to be switched between a comparison of pairs in the first axis and a comparison of pairs in the second axis.

The comparison may be effected by comparison means coupled between the first and second pixels of a respective pair. Comparison means may be provided between a first pixel and a plurality of neighbouring pixels, so that the intensity signal of the first pixel may be compared with the intensity signal of any one of the plurality of neighbouring pixels.

The comparison may comprise a comparison of currents generated by the photodiodes of the first and second pixels of a respective pair.

The plurality of pixels may comprise an array having an active area and a dummy area, and pixels of the dummy area might not have their intensity signals connected to the first or second output.

According to a second aspect of the invention there is provided an optical detector comprising a plurality of pixels, each pixel comprising a photodiode operable to detect light incident on that pixel and to generate a signal indicative of an intensity of that light, wherein the detector comprises a first output and a second output, and wherein the detector is operable such that the signal indicative of intensity generated by each pixel is connected either to the first output or to the second output, and wherein signals indicative of intensity received at the first output are summed to produce a first composite intensity signal, and signals indicative of intensity received at the second output are summed to produce a second composite intensity signal.

The second composite intensity signal may be subtracted from the first composite intensity signal (or vice versa).

The output to which each pixel is connected may be selected (e.g. programmed) by a user. The output to which each pixel is connected may be selected based on a comparison with another pixel of the plurality of pixels, as described above with reference to the first aspect of the invention,

According to a third aspect of the invention there is provided an optical evaluation system comprising a detection optical source, detection optics and an optical detector as described above in respect to the first or second aspect of the invention, or any of the dependent clauses.

The optical evaluation system may further comprise an excitation optical source operable to generate sound waves in a sample under test, and may further comprise optical imaging means such as a spatial light modulator to shape optical radiation generated by the excitation optical source. The optical imaging means may be operable to shape the optical radiation so as to cause the sound waves to come to a focus.

According to a further aspect of the invention there is provided a method of operating an optical detector having a plurality of pixels, each comprising a photodiode operable to detect light incident on that pixel and to generate a signal indicative of an intensity of that light, the method comprising grouping a plurality of pixels into pairs, and, in a configuration mode, comparing the signal generated by a first pixel of the pair with the signal generated by a second pixel of the pair.

The method may further comprise using the comparison to determine whether the intensity of light incident on the first pixel of the pair is higher than the intensity of light incident on the second pixel of the pair.

The method may further comprise connecting the signal indicative of intensity generated by the first pixel to either a first detector output or a second detector output depending on the result of the comparison.

The method may further comprise summing the signals indicative of intensity received at the first output to produce a first composite intensity signal, and summing the signals indicative of intensity received at the second output to produce a second

composite intensity signal, and may further comprise subtracting the second composite intensity signal from the first composite intensity signal (or vice versa).

The comparison may be performed simultaneously and in parallel over the plurality of pixel pairs.

An example of the invention will now be described, by way of example only, with reference to the following drawings:

Figure 1 shows schematically an optical evaluation system, and in particular a laser ultrasonic evaluation system;

Figure 2 schematically shows the generation of an ultrasonic wave (SAW) in the system of Figure 1;

Figure 3 schematically depicts reflected light falling on a prior art knife edge detector for A, a smooth surface; and B, a rough surface;

Figure 4 shows A, a schematic illustration of an optical detector; B, the layout of an optical detector chip; and C, the layout of a single pixel of the detector chip of picture B;

Figure 5 depicts an optical detector in use during analysis of a rough surface;

Figure 6 depicts an optical detector in use during analysis of a smooth surface;

Figure 7 is a circuit schematic for a current comparator;

Figure 8 shows (1) a comparison between a scan of a rough sample produced by a prior art knife edge device (picture A), and a scan of the same rough sample produced by an optical detector of the type described herein (picture B); and (2) a similar comparison when the sample under test is subjected to mechanical vibrations (picture C being the prior art knife edge device and picture D being an optical sensor as described herein); and

Figure 9 is a more detailed circuit schematic for a pixel.

One of the simplest and most effective detectors for the detection of ultrasound by lasers is the knife edge detector. A knife edge detector takes advantage of the fact that a sound wave passing across the surface of a sample causes the surface of the sample to move. If an optical beam is directed onto the surface, the light of the beam is reflected from the surface and is deflected by a tiny angle as the sound wave passes. Optics, in the form of an array of lenses, converts the deflection to a horizontal movement of the beam synchronous with the passing sound wave, which can then be detected by a light-sensitive detector. It is possible to detect the beam deflection using either a conventional knife edge, or a split photodiode 2 as shown in Figure 3.

For a smooth surface, the reflected light focuses to a well-defined specular reflection in the form of disc 4 shown in the left hand image (picture A) of Figure 3. As the sound wave passes, the disc of light moves vertically across the detector. The 'split' detector 2 subtracts signal from the top photodiode 6 from the signal from the bottom photodiode 8. Thus a positive signal is obtained when the beam moves from top to bottom and a negative signal is obtained when the movement is from bottom to top. Thus the movement of the sound wave is tracked in a simple and effective way by the oscillating beam when the sample is smooth.

When the sample is rough, however, the light is no longer a neat disc but is 'speckled', as shown in picture B of Figure 3. 'Speckled' as used herein means the reflected light forms a group of light 10 and dark 12 patches. The light and dark patches move together as an ultrasonic wave crosses the surface of the sample. This means that as the beam moves from top to bottom of the photodiode shown in Figure 3, a simple subtraction between the two halves will not give a useful signal because some parts of the top/bottom subtraction will give a positive number and others will give a negative number, so that on average there will be no signal at all.

'Rough' surfaces, as referred to herein typically mean surfaces which are not sufficiently polished to act as a good mirror. Thus the vast majority of industrially-used components comprise 'rough' surfaces. Similar issues with speckle and/or irregular beam deflection can occur when rough or smooth surfaces are subjected to mechanical vibrations.

An optical evaluation system 100 which aims to address the above issues is shown in Figures 1 and 2.

The system 100 includes an excitation optical source 14, which is operable to produce a beam 16 of optical radiation in order to induce surface acoustic waves (SAWs) on the surface of a sample under test 20. A suitable excitation optical source would be an excitation laser, for example a Nd:YAG laser (neodymium-doped yttrium aluminium garnet laser).

The system further includes a detection system 26, which is shown more completely in the inset to Figure 1. The detection system includes a detection optical source, in this case a detection laser 28, which is operable in use to direct a beam of optical radiation onto the surface of the sample 20 at a suitable location in the expected path of the SAWs. The detection beam is arranged to reflect from the surface of the sample onto an optical detector 30. The path of the detection beam and its reflection is controlled by detection optics 32.

In use, the excitation source is used to generate surface acoustic waves (SAWs) in the sample under test in any suitable way (e.g. by thermally heating the surface to cause expansion, or by ablation). The SAWs are then detected at the optical detector 30 via the reflection of the detection laser. The progress of the SAWs may then be analysed to obtain information about the surface of the sample under test at the point of reflection. An image of the surface of the sample may be built up by raster scanning the surface in a conventional way.

If required, the beam of optical radiation generated by the excitation laser 14 may be shaped to produce SAWs of a predefined shape using a suitable imaging means such as a spatial light modulator (SLM) 22. In the example shown the SLM 22 is arranged to image a regular grating of arbitrary spacing. The grating spacing can be adjusted during operation if required. We have found it desirable to match the grating spacing as closely as possible to the wavelength of the SAWs. We have also found it desirable to arrange the grating such that the SAWs come to a focus at a predetermined location 24. The detection laser 28 can then be positioned so as to image SAWs at the focus

where maximum deflection is experienced. The optical illumination pattern used to assist in SAW generation is indicated in Figure 2 at 18.

An optical detector 30 is shown schematically in Figure 4 picture A. The optical detector 30 comprises a plurality of pixels 34. Each pixel comprises a photodiode 36 (see e.g. Figure 4 picture C) which is operable to detect light incident on that pixel and to generate an electrical signal indicative of the intensity of that light.

The optical detector is arranged to be interactively configurable, in that it is able to alter its architecture in dependence on the light falling on each pixel. In particular, the signal generated by each pixel may be directed to one of a plurality of outputs. Which output is selected is dependent on the optical conditions in which the pixel finds itself. The conditions in which the pixel finds itself are determined with reference to another pixel of the array. Thus the plurality of pixels is grouped into a plurality of pixel pairs 38. For each pair, a comparison is made between the light intensity falling on a first pixel of a pair and a second pixel of the pair. This comparison influences the selection of output for the first pixel.

Because the detector is configurable, as described in more detail below, the arrangement of the pairs may be selected by a user if required. It will thus be appreciated that the 'pairs' referred to are not physical structures so much as associations between two pixels.

A typical pixel pair arrangement includes pairs in which the first and second pixels in any given pair are adjacent to one another. In the ultrasonics example discussed herein, we have found best results are achieved when the pairs are adjacent and arranged periodically (i.e. in the same spatial orientation - all in the same axis, which might be 'horizontal', or 'vertical'). The detector works most efficiently when neighbouring pairs overlap, so that the first pixel of one pair is the second pixel of an adjacent pair. Thus output to which the second pixel directs its intensity signal is determined based on a comparison with a different pixel than the first pixel, and also with respect to a different pair grouping.

The intensity comparisons between pixels are, in one example, performed substantially simultaneously (i.e. in parallel) with one another. This is more efficient

than conducting the comparisons in series. Comparisons between pixel intensities are performed by comparators coupled between pixels, for example in the form of comparison electronics. Each pixel may be linked to more than one other pixel by a comparator, as this allows that pixel to form part of more than one pair. For example, the pixels may be arranged in a regular planar arrangement, such as a rectangular array, having two perpendicular axes, e.g. an x-axis and a y-axis. Each pixel of the array therefore has four pixels abutting it, two in the x-axis and two in the y-axis (excluding in this case diagonals). If comparison electronics are provided between the centre pixel and the four surrounding pixels a user is able to elect to arrange the pairs in alignment with the x-axis, or in alignment with the y-axis. The user may alter pair groupings and switch from one axis to the other as required. Providing four pair options allows for significant versatility without excessive complexity. However, further pair options might be provided for if required (e.g. comparison means might be provided between a pixel and diagonally adjacent pixels).

Typically, the detector includes a configuration mode, in which the architecture of the detector is configured using the selected pixel pair arrangement based on the optical radiation falling on the detector, and an experiment mode, in which the detector operates as configured in the configuration mode. In the configuration mode, the signals generated by each pixel of any given pixel pair are compared in the detector, e.g. by circuitry 40 present on the detector. The comparison is used to determine whether the intensity of light incident on the first pixel of a pair is higher than the intensity of light incident on the second pixel of that pair. If the intensity of light on the first pixel is higher than the intensity incident on the second pixel, the signal from the first pixel is directed to a first output. If the intensity of light on the first pixel is lower than the intensity incident on the second pixel, the signal from the first pixel is directed to a second, different, output.

Thus the detector is sensitive to light gradients at points across the pixel array (i.e. between the pairs of pixels). The detector can be reconfigured regularly, for example at the direction of a user or at pre-programmed intervals, to take into account changing optical conditions.

Referring now to Figure 5, a more detailed example of a configurable optical detector is described. The detector shown in Figure 5 is sometimes referred to herein as a

speckle knife edge detector (SKED), and includes an array of 32x32 active photodiode pixels (not all of which are visible in the figure). The detector also includes a row of dummy pixels along each edge of the array, as described in more detail below.

The optical detector 50 has two modes of operation: configure, and experiment, and the two modes are selectable by an external digital input. In configure mode, all photodiode outputs (in terms of an electrical current proportional to the light intensity) are isolated from each other. The relative intensity of light impinging on pairs of pixels (in this case the pairs are arranged horizontally, and overlap) is determined using an electrical current comparator, in order to determine which of the two pixels has more light falling on it. There is a comparator between each possible pair of horizontally adjacent pixels.

The detector 50 is arranged to measure changes in light intensity across the detector array. Between pairs of adjacent pixels, the chip calculates whether there is more light falling on the left, or the right (represented by the left and right arrows). If there is more light falling on the right, then the signal from the right hand pixel is sent to a first output (indicated by dark arrows, 52); if there is more light falling on the left, then the signal from the right hand pixel is sent to a second, different, output (indicated by light arrows, 54). The choice of output for the left pixel is determined in the same way, but by reference to the pixel on its left.

All the pixel pair comparisons are performed in parallel, so that all the signals from the positive gradient 'dark arrow' pixels are sent to the first output and summed, whilst all the signals from the negative gradient 'light arrow' pixels are sent to the second output and summed. In particular, the output of each comparator determines the setting of an electronic switch, which itself determines to which of two output connectors – A or B – the first pixel of each pair of photodiodes will be connected, once the output is in experiment mode.

Thus, in experiment mode, there will be a number of pixels connected to output A, and a number to output B. Those connected to output A will be those whose incident optical intensity was, during configuration, lower than the pixel to the right, those connected to output B will be those whose incident optical intensity was greater than the pixel to the right. There is an extra row, and an extra column, of "dummy" pixels

at the edges of the array of pixels that are identical to the normal pixels but never have their output connect to the A or B outputs, so that comparisons can be made at the edges of the array.

The result during experiment mode is that the sum of all the dark arrow pixels 52 is subtracted from the sum of all the light arrow pixels 54. This results in a signal proportional to the horizontal movement of the speckles across the detector. The detector thus unravels the speckles to produce an output analogous to that of a conventional knife edge detector. Measurement of the intensity changes thus allows us to use the light reflected from the rough sample and reorganise it so that it behaves as if the reflection were from a smooth surface.

It is possible to switch between configure and experiment mode at a rate greater than 1000 times/second (i.e. >1kHz), for example greater than 50kHz. Configuration – where the chip adapts to the optical speckle – can take place in less than 5 microseconds, e.g. in around 1 microsecond.

Figure 6 shows a situation where the optical detector 50 is used to image a smooth surface (note the disc-like specular reflection 56). It can be seen that the pixels on the left are all directed to the same output, as signified by dark arrows 52, whilst the pixels on the right are all directed to the other, different, output, signified by light arrows 54. Thus the SKED behaves in an identical way to a conventional knife edge detector when evaluating a smooth surface.

Figure 7 shows a simplified circuit schematic of how the signals indicative of incident light intensity in two adjacent pixels of a pair are compared. Each pixel includes a photodiode which is operable to generate the signal - an electrical current - which is proportional to the light intensity incident on that pixel. The current in the first, in this case right hand, photodiode (marked as I_{Right}) is mirrored twice using two current mirror circuits as shown. This duplicates the current flowing in the photodiode so that the same amount of current is flowing in the adjacent pairs of transistors. The second, in this case left hand, photodiode current (marked as I_{Left}) is mirrored once. At the wire marked “Combine currents”, the left and right currents are connected together through transistors M1 and M2. It is important to note that there is nowhere else for the current in M1 and M2 to flow – the terminal Out here is a high impedance. If the

current in the right hand photodiode is greater, M2 will try to sink more current than M1 is sourcing. Consequently, the voltage at the Out terminal will drop to a low voltage. If the left hand photocurrent is higher then the voltage at the Out terminal will rise to a high voltage. If both photocurrents are exactly equal, the voltage at the Out terminal will be at the mid point between the voltage rails. The output of this circuit is provided as an input to a voltage comparator. Thus, by setting the second input (the reference) to the voltage comparator to the mid point between the voltage rails, the output of the comparator will indicate which photodiode current is higher.

A circuit for a complete pixel is shown in Figure 9. The circuit shown in Figure 9 includes comparison means in the form of a current comparison circuit, and is suitable for use in a detector having two axes, e.g. x and y axes as discussed above, so that a comparison can be made in either axis (or both). As before, the pixel is operable to switch between first and second outputs, A and B, and the detector has two modes, configure and experiment.

During configure mode, each pixel compares its light intensity with the adjacent pixel. If the intensity is higher in the first pixel, it sets its output to A. If the light intensity in the adjacent pixel is higher, the first pixel sets its output to B.

During experiment mode, all pixel outputs A are tied together and all outputs B are tied together. This means that the chip outputs A and B represent the sum of the light intensity/photo current from the 'A' pixels and the 'B' pixels, respectively.

Each pixel contains a photodiode, which is the photo sensitive element in the pixel. During operation the photodiode is connected in one of three ways as controlled by three transmission gates (switches). If the "Mode" digital input to the pixel (indicated in Figure 9 as "Measure") is held high, then the pixel is in configure mode and the photodiode is connected to the comparison circuitry.

The comparison circuitry consists of a current mirror that reproduces the photocurrent in two arms. In one of those arms the photocurrent is again reproduced to act as a current sink, with the other arm functioning as a current source. The outputs of these two mirrors are connected to the two adjacent pixels through transmission gates. One arm goes to the "next" photodiode for comparison and the other arm goes to the

"previous" photodiode. This arrangement allows the comparison to happen in parallel across the chip. The "Axis" digital input allows the photodiodes to compare with to be chosen. If Axis is high, the comparison happens in a first, in this case horizontal, axis. If Axis is low, the comparison is in a second, in this case perpendicular, vertical, axis. This feature allows comparisons in both axes without requiring the detector to be moved. Comparisons between adjacent pixels is done by connecting the current source output of the pixel doing the comparison with the current sink output of the adjacent pixel, both through the respective transmission gates for the selected axis. The point between these two current mirrors is connected to the input of a voltage comparator. If the current in both the source and the sink is identical, a voltage of half the supply voltage is expected at the voltage comparator input. If the source current is higher, the voltage will increase and vice versa. A reference voltage (global for all pixels in the chip) is supplied to the second comparator input.

The comparator output is connected to a digital latch. When the pixel is placed in experiment mode, the digital latch retains the comparator value. The photodiode is also disconnected from the comparison circuit and connected to either output A or B ("ResLeft" and "ResRight" in the diagram) depending on the value of the digital latch.

There is further digital logic stored within the "pixel logic" block. This creates the ability to read the value of the digital latch at each pixel and take it off chip, as well as to program a value for the latch at each pixel from off chip. These are both useful additions to the design. Being able to see the configuration data is useful in an experimental environment because it gives an indication of the light on the sensor for example. Being able to program the configuration data allows the sensor to be programmed as a standard knife-edge detector or any other pattern. The configuration data can be programmed by setting "Force" high, setting "Select_n" low, setting the desired configuration value on "Direction" then briefly setting "ForceSet_n" low.
The configuration data can be read by setting "Force" Low, setting "Select_n" low and reading the configuration data from "Direction".

Some experimental characterisation has been performed, and it has been found that a bandwidth of around 100MHz can be achieved with a detector of the type described herein. It may be possible to increase this in future versions of the design, for example to 200MHz.

Figure 8 shows some experimental results achieved with an experimental optical detector having a bandwidth of approximately 20MHz, which is adequate for many laser ultrasonic applications.

The experimental detector was tested using a laser ultrasound system called the O-SAM (all-optical scanning acoustic microscope), in which the generation laser excites surface acoustic waves at a frequency of 82MHz. The experimental detector was compared against a standard knife edge detector (KED) on an optically rough aluminium surface. The pair of graphs in panel (1) of Figure 8 shows the normalised amplitude of the 82MHz waves as the sample is scanned over a distance of 2mm. The output of the conventional KED is shown in picture A on the left, and is shown to fluctuate considerably, due to the changing speckle. In some sample locations, very little signal is present at all. The output of the experimental optical detector is shown in picture B on the right. It can be seen that the signal is much more constant, as the SKED adapts to the optical speckle at each sample location. The ideal behaviour would be a flat line at a height of 1.

Similar comparative behaviour is observed when the instrument is subject to ambient mechanical vibrations, which also changes the speckle pattern, as shown in panel (2) of Figure 8, again with the KED on the right in picture C and the experimental detector on the left in picture D. Again, it can be seen that the new detector provides improved results. As before, the ideal behaviour would be a flat line with a height of 1.

The optical detectors described herein are able to operate as a drop in replacement for the conventional knife edge detectors, but are operable to obtain measurements on rough as well as smooth surfaces. Detector architecture (e.g. which of a plurality of outputs a pixel signal is directed/connected to) is configured interactively with reference to another pixel of the array, in response to local illumination conditions. Intensity gradients across pixel pairs are compared during the configuration. The detector can be reconfigured regularly, for example at pre-programmed intervals (e.g. once every 0.01s, 0.05s or every 0.1s), or in response to a user command.

A traditional knife edge detector measures beam deviations in a single axis, but the configurable detectors described herein are able to detect beam deviations in both the vertical and horizontal axes, based on a user controllable input. This means that measurements in both axes can be made without physically moving the device. It is also be possible to read out the configuration data from the device. This allows the user to obtain information about the roughness of their sample surface and determine whether the illumination and detector is correctly aligned. Configuration data can be stored, and also input, allowing a user to program the architecture of the detector directly if required, e.g. to operate in accordance with a previous configuration, or with a predefined pattern such as a conventional knife edge.

Although optical detectors have been described herein primarily with respect to laser ultrasonic applications, it will be appreciated that such sensors have utility in other applications, for example in situations where varying light levels mean that it is desirable to be able to control the sensitivity of a detector chip quickly and cheaply.

CLAIMS

1. An optical detector comprising a plurality of pixels, each pixel comprising a photodiode operable to detect light incident on that pixel and to generate a signal indicative of an intensity of that light, wherein the plurality of pixels comprises a plurality of pixel pairs, and wherein for each pixel pair, in a configuration mode, the detector is arranged to compare the signal generated by a first pixel of the pair with the signal generated by a second pixel of the pair.

2. An optical detector as claimed in claim 1, wherein the comparison is used to determine whether the intensity of light incident on the first pixel of the pair is higher than the intensity of light incident on the second pixel of the pair.

3. An optical detector as claimed in claim 1 or claim 2, wherein the detector comprises a first output and a second output, and wherein the signal indicative of intensity generated by the first pixel is connected to either the first output or the second output depending on the result of the comparison.

4. An optical detector as claimed in claim 3, wherein the plurality of pixels comprises an array, and wherein the signal indicative of intensity generated by each pixel in an active area of the array is connected to either the first output or the second output.

5. An optical detector as claimed in claim 4, wherein, in an experiment mode, the signals indicative of intensity received at the first output are summed to produce a first composite intensity signal, and wherein the signals indicative of intensity received at the second output are summed to produce a second composite intensity signal.

6. An optical detector as claimed in claim 5, wherein, in the experiment mode, the second composite intensity signal is subtracted from the first composite intensity signal (or vice versa).

7. An optical detector as claimed in any preceding claim, wherein, in the configuration mode, the comparison is performed simultaneously and in parallel over the plurality of pixel pairs.

8. An optical detector as claimed in any preceding claim, wherein each pair of pixels comprises a pair of adjacent pixels.

9. An optical detector as claim in any preceding claim, wherein the arrangement of the pairs is periodic, such that the first pixel of each pair always has the same spatial relation with respect to the second pixel of that pair.

10. An optical detector as claimed in claim 8 or claim 9, wherein the pairs overlap, such that the first pixel in one pair comprises the second pixel in an adjacent pair.

11. An optical detector as claimed in any preceding claim, wherein the plurality of pixels is provided in a regular planar array having a first axis and a second axis which is perpendicular to the first axis, and wherein the comparison is performed based on pairs arranged in alignment with the first axis or the second axis.

12. An optical detector as claimed in claim 11, wherein the comparison can be switched between a comparison of pairs in the first axis and a comparison of pairs in the second axis.

13. An optical detector as claimed in any preceding claim, wherein the comparison is effected by comparison means coupled between the first and second pixels of a respective pair.

14. An optical detector as claimed in a claim 13, wherein comparison means is provided between a first pixel and a plurality of neighbouring pixels, so that the intensity signal of the first pixel may be compared with the intensity signal of any one of the plurality of neighbouring pixels.

15. An optical detector as claimed in claim 13 or claim 14, wherein the comparison comprises a comparison of currents generated by the photodiodes of the first and second pixels of a respective pair.

16. An optical detector as claimed in any preceding claim, wherein the plurality of pixels comprises an array having an active area and a dummy area, wherein pixels of the dummy area do not have their intensity signals connected to the first or second output.

17. An optical evaluation system comprising a detection optical source, detection optics and an optical detector as claimed in any preceding claim.

18. An optical evaluation system as claimed in claim 17 further comprising an excitation optical source operable to generate sound waves in a sample under test.

19. An optical evaluation system as claimed in claim 18 further comprising optical imaging means such as a spatial light modulator to shape optical radiation generated by the excitation optical source.

20. An optical evaluation system as claimed in claim 19 wherein the optical imaging means is operable to shape the optical radiation so as to cause the sound waves to come to a focus.

21. A method of operating an optical detector having a plurality of pixels, each comprising a photodiode operable to detect light incident on that pixel and to generate a signal indicative of an intensity of that light, the method comprising grouping a plurality of pixels into pairs, and, in a configuration mode, comparing the signal generated by a first pixel of the pair with the signal generated by a second pixel of the pair.

22. A method of operating an optical detector as claimed in claim 21, further comprising using the comparison to determine whether the intensity of light incident on the first pixel of the pair is higher than the intensity of light incident on the second pixel of the pair.

23. A method of operating an optical detector as claimed in claim 21 or claim 22, further comprising connecting the signal indicative of intensity generated by the first

pixel to either a first detector output or a second detector output depending on the result of the comparison.

24. A method of operating an optical detector as claimed in claim 23, wherein the method further comprises summing the signals indicative of intensity received at the first output to produce a first composite intensity signal, and summing the signals indicative of intensity received at the second output to produce a second composite intensity signal.

25. A method of operating an optical detector as claimed in claim 24, further comprising subtracting the second composite intensity signal from the first composite intensity signal (or vice versa).

26. A method of operating an optical detector as claimed in any one of claims 21 to 25 wherein the comparison is performed simultaneously and in parallel over the plurality of pixel pairs.

27. An optical detector substantially as described herein, with reference to the accompanying drawings.

28. An optical evaluation system substantially as described herein, with reference to the accompanying drawings.

29. A method of operating an optical detector substantially as described herein, with reference to the accompanying drawings.

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Claims searched: 1-26 **Date of search:** 21 March 2013

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1, 21 at least	US 2006/0138306 A1 (AFRIAT) See in particular paragraphs 0048-0052 and Fig. 4a, 4b
X	1, 21 at least	WO 03/049018 A1 (EM MICROELECTRONIC-MARIN) Whole document relevant
X	1, 21 at least	US 4032801 A (FULKERSON) See in particular column 2 lines 3-28 and Fig. 4
X	1, 21 at least	US 2009/0140981 A1 (KWAK et al) See in particular paragraphs 0016-0019, 0064-0076 and Fig. 2

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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Field of Search:

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G01J; G01N

The following online and other databases have been used in the preparation of this search report

Online: EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
G01J	0001/16	01/01/2006
G01N	0029/24	01/01/2006