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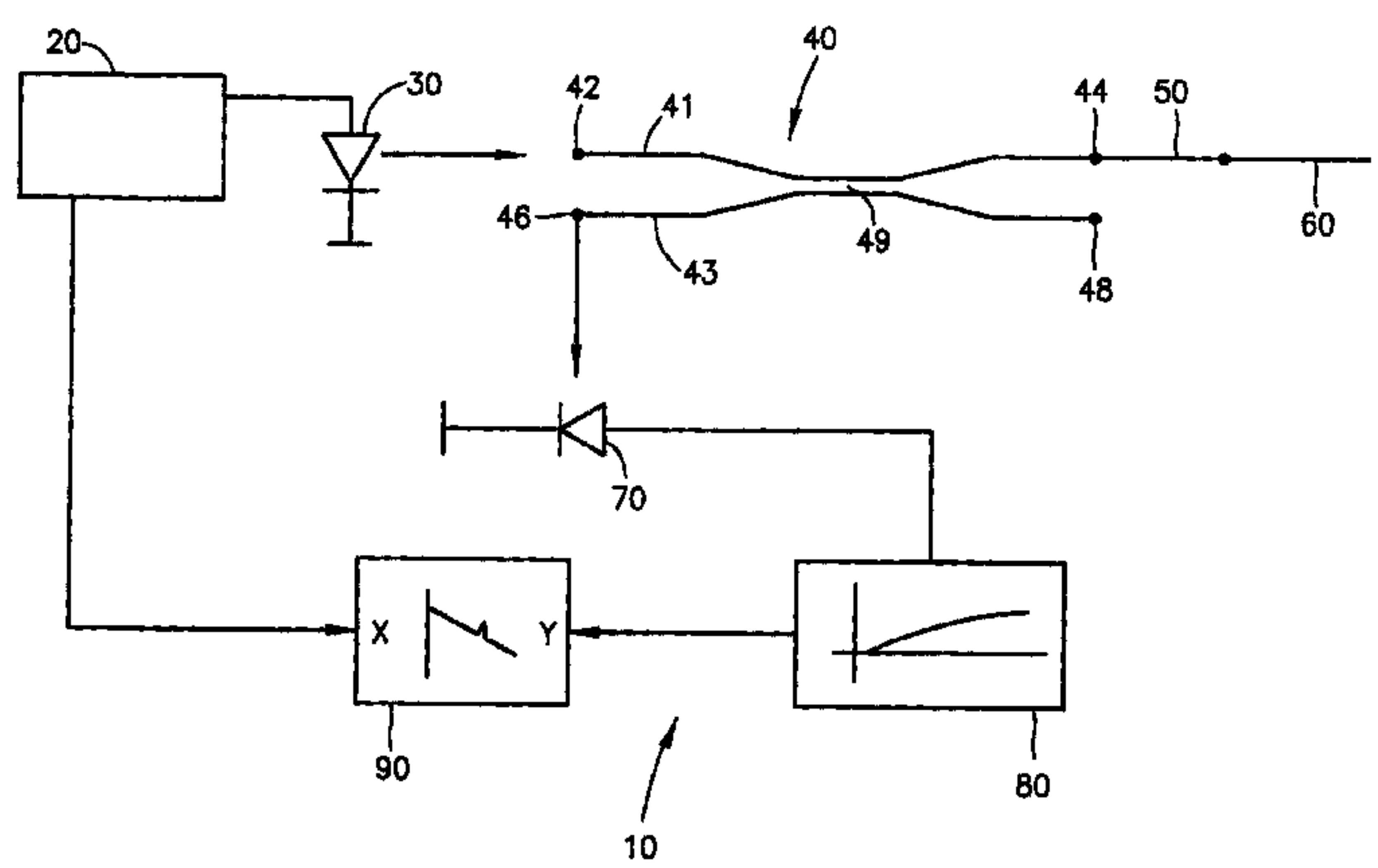


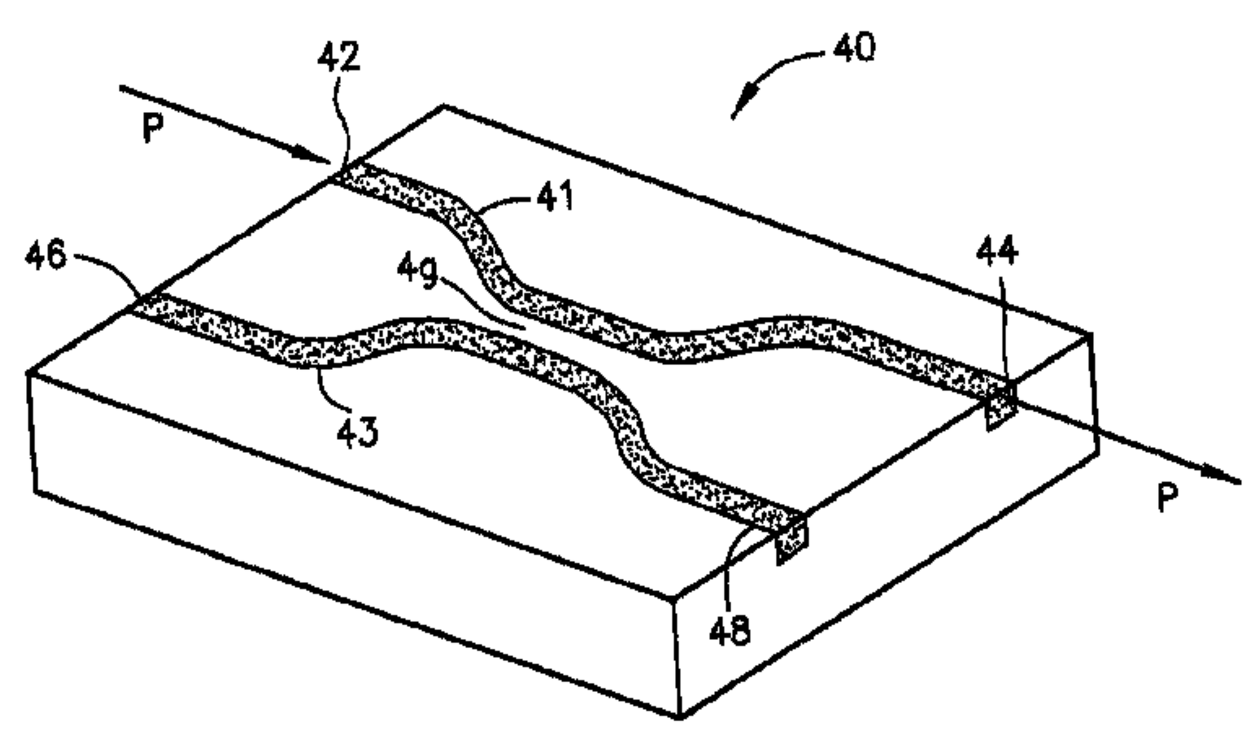


(57) Abrégé/Abstract:
The object of the invention is to improve the sensitivity of an optical pulse reflectometer (10) without having to increase the transmitting power of the light source (30). For this purpose, instead of a static beam splitter, such as a semi-opaque reflector or 2x2 directional coupler, use is made of an optical switch (40) for the selective connection of the light source (30) to the associated object under test (60) and for the selective connection of the object under test (60) to the associated photodetector (70). In this manner, it is possible to improve the power utilization and thus the sensitivity of conventional optical pulse reflectometers to a very great extent.

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## Abstract

The object of the invention is to improve the sensitivity of an optical pulse reflectometer (10) without having to increase the transmitting power of the light source (30). For this purpose, instead of a static beam splitter, such as a semi-opaque reflector or 2x2 directional coupler, use is made of an optical switch (40) for the selective connection of the light source (30) to the associated object under test (60) and for the selective connection of the object under test (60) to the associated photodetector (70). In this manner, it is possible to improve the power utilization and thus the sensitivity of conventional optical pulse reflectometers to a very great extent.

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# Optical Pulse Reflectometer

The invention relates to an optical pulse reflectometer.

The ongoing establishment and expansion of fibre optic networks calls for the use of suitable optical measuring instruments during installation, for maintenance purposes and for the monitoring thereof. A particularly important measuring instrument in this connection is the optical pulse reflectometer, known also as the Optical Time Domain Reflectometer (OTDR). Such a measuring instrument is used to measure and evaluate reflections in fibre optic transmission systems. Reflections occur in optical components, such as in a light conducting fibre, principally because of sharp changes in the refractive index, for example at the end of the fibre, and as a result of Rayleigh scattering, the cause of which lies in inhomogeneities of the fibre. Further examples of reflecting optical components are connectors, branches, and splices. In a known optical pulse reflectometer, the pulses emitted by a laser diode are supplied via a static or passive power splitter to the fibre which is being measured. The static power splitter, known also as a beam splitter, may be in the form of a semi-opaque reflector, a fibre optic 2x2 coupler (known also as a directional coupler) or a 2:1 coupler, i.e. an inversely operated Y-branch. The function of the passive beam splitter is to change the propagation direction of the fight pulse, i.e. to direct the light pulses spatially. The latter is necessary in order to ensure that the optical signal components reflected by the fibre because of Rayleigh and/or Fresnel scattering are directed onto a photodetector. However, the passive beam splitter has the disadvantage that approximately only half of the reflected signal component is returned to the photodetector. The other half of the reflected signal component is directed in an undesired manner towards the laser diode, with the consequence that an optical isolator must additionally be connected in front of the laser diode in order to protect against the undesired reflections. Furthermore, the reflected light component is additionally attenuated by inevitable imperfections of the fibre connections. If, instead of an inversely operated Y-branch, passive 2x2 couplers or semi-opaque reflectors are used, the light intensity emitted by the laser diode is only about one quarter utilized. In other words, the signal emitted by the laser diode is attenuated by a factor of 4 before it reaches the photodetector.

DE-A-4 437 821 discloses an aperture controller for an optical time-domain reflectometer, also known as OTDR, that uses a high-speed switch and a pumped light source to generate optical pulses. The principal function of the high-speed switch is to darken an area of the light reflected from the fibre that is to be measured, which is also referred to as Fresnel-reflected light. In order to do this, the optical high-speed switch is operated synchonously with the optical pulse generated from the light source.

US-A-5 388172 discloses an optical switching device for an OTDR in which a pulsed laser and an optical receiver are connected to a fibre that is to be tested. The optical switching device serves to isolate Fresnel reflections from the fibre from the optical receiver.

EP-A-0 502 422 discloses an optical time-domain reflectometer in which a Raman laser device and an optical detector are connected through an optical switch to the fibre that is to be tested. A Raman scattered light pulse is used in order to be able to detect the loss characteristics of the optical fibre at any wavelength within a broad spectrum. To this end, the Raman laser device has a solid-body laser that is pumped by a laser diode to generate a light pulse.

WO-A-91 12509 describes an OTDR that uses a pulsed laser to generate light pulses. The pulsed laser and an optical receiver are connected to the fibre that is to be tested by way of a passive optical coupler.

In the article titled "A Low Crosstalk and Polarization Independent Optical Waveguide Switch for OTDR," NEC Research and Development, No. 99, October 1990, Tokyo, Japan, pp. 75-83, XP000178479, H. Kawashima et al describe an optical waveguide switch for an OTDR at a wavelength of 1.3 $\mu$m with a $Ti:LiNbO_3$ wave guide. In this instance, too, a laser diode that generates light pulses is used as the light source.

The object of the invention, therefore, is to further develop the initially described optical pulse reflectometer in such a manner that switching outlay and thus costs can be reduced, since synchronization between the light source and the control device is no longer needed in order to change the optical switch.

In one aspect of the invention, there is provided an optical pulse reflectometer comprising: at least one light source operating in a constant light mode; at least one test object; at least one photodetector; an indication device connected downstream of an output of the at least one photodetector; at least one optical switch for selectively connecting the light source to the at least one test object and the at least one test object to the at least one photodetector; and a control device for driving the at least one optical switch so as to produce light pulses having a predefined frequency and duration.

The optical pulse reflectometer comprises at least one optical switch--known per se--for the selective connection of a light source, particularly a laser diode, to an associated object under test and for the selective connection of the object under test to an associated photodetector. The optical switch is switched, for example, by a control apparatus that switches the optical switch at predetermined points in time. In this manner, it is ensured that the optical transmitting power of the light source is injected virtually without loss of power into the object under test, particularly an optical fibre, and that the light reflected in the object under test is subsequently supplied virtually unattenuated to the photodetector. Consequently, it is possible, inter alia, without having to actually increase the optical transmitting power of the light source, to test fibres over greater lengths than has conventionally been the case with static power splitters. In addition, for a measured distance of given length it is possible to employ shorter light pulses, this increasing the spatial resolution of the measurement. Since, compared, say, with passive 2x2 couplers or semi-opaque reflectors, an optical switch allows approximately four times the power utilization, the pulse duration for detecting Rayleigh scattering can be reduced to a quarter. (Note that the intensity of the Rayleigh scattering depends on the energy (light intensity x pulse duration) of the pulse). For OTDR measurements, this means that significant points on the fibre can be located with greater accuracy. Consequently, for example, repairs to a fibre cable can be pinpointed with corresponding accuracy. Owing to the higher signal level, Fresnel reflections, too, produce correspondingly stronger echo signals in the photodetector, which can thus also be detected with higher sensitivity. Thanks to the optical switch, it is for all practical purposes possible, in contrast to a conventional optical pulse reflectometer, to dispense with an optical isolator that is used to protect the light source from reflections, for virtually all of the reflected signal component is directed to the photodetector.

The optical switch used may, for example, be a 2x2 directional coupler or an acousto-optical modulator, both of which are in effect known per se. An example of a switchable optical 2x2 directional coupler is the thermo-optically controlled coupler described by Norbert Keil in the article "Optische Schalter aus Kunststoff-Schlusselkomponenten in den Telekomnetzen der Zukuntft" [Optical switches made of plastic -

Key components in the telecom networks of the future], ntz, No. 12/1995, pages 36-41. The optical pulse reflectometer uses a light-source that is operated in constant-light mode, the optical switch also serving to generate light pulses. The pulse frequency and duration of the light pulses are determined by a control apparatus, by appropriate triggering of the optical switch. Operating a light source in constant light mode has several advantages over a pulsed light source. First, there is no need for synchronization between the light source and the control apparatus for switching the optical switch. Furthermore, the voltage peaks produced by an electric pulse generator are no longer able to have an adverse effect on the light source. In addition, the time requirements on the light source with regard to fast modulation in order to produce sufficiently short pulses can be reduced.

In order to ensure that all the reflections caused by the object under test are directed to the photodetector and can thus be evaluated by the optical pulse reflectometer, the optical test pulse must have completely passed through the optical switch before the switch can be switched. This is achieved by a launching fibre of predetermined length that is connected between the optical switch and the object under test. The length of the launching fibre must be $l \geq cT$, where c is the speed of the light in the launching fibre and T is the longest pulse duration of a pulse that can be emitted from the optical pulse reflectometer.

Consequently, the launching fibre acts as a delay line for the reflected light pulses.

In order to prevent light reflections to the light source or radiation to the environment caused by the unused connection of the optical switch, the unused connection of the optical switch is terminated with an absorber and an optical shield. In the case of a 2x2 coupler, the absorber may consist of a plurality of very narrow turns (with a diameter of a few mm) of the non-terminated fibre section. Suitable plastic sleeves may be used as shielding.

Connected in known manner between the photodetector and an indication apparatus is a data processing apparatus, comprising a known Boxcar averager as well as a logarithm conversion apparatus.

In the following, the invention is explained in greater detail with reference to a specimen embodiment in conjunction with the appended drawings, in which:

Fig. 1 shows a greatly simplified block diagram of an optical pulse reflectometer according to the invention;

Fig. 2 shows a switchable optical 2x2 directional coupler in the straight-ahead state for use in the optical pulse reflectometer according to Fig. 1;

Fig. 3 shows the switchable optical 2x2 directional coupler presented in Fig. 2 in the crossed-over state.

Fig. 1 shows an optical pulse reflectometer, known also as Optical Time Domain Reflectometer (OTDR ). The pulse reflectometer, identified in general with the reference number 10, comprises a generally known pulse generator 20, said pulse generator 20 being tunable with regard to pulse duration and wavelength and controlling, for example, a laser diode 30. Connected after the laser diode 30 is a switchable optical switch 40 which is switched in response to switching signals produced by a control apparatus (not shown herein). In the example described here, the switch 40 is a 2x2 directional coupler, as shown in Fig. 2 and Figure 3, which can be switched by means of an electric voltage. The 2x2 directional coupler 40, which is available, for example, in integrated optical design, comprises two light conducting strands 41 and 43, said light conducting strands 41 and 43 being disposed at a predetermined distance from each other. In a middle region 49, the two strands 41 and 43 come so close to each other that the 2x2 directional coupler can be selectively switched. Depending on the physical control variable, the 2x2 directional coupler is either in the straight-ahead state (see Fig. 2) or in the crossed-over state (see Fig. 3). On the side facing the laser diode 30, the strand 41 has a port 42, used as an input, and, on the opposite side, a port 44, used both as an output and also as an input. On the side facing the laser diode 30, the strand 43 has a port 46, acting as an output, and on the opposite side, an unused port 48. In order to prevent light pulses being reflected to the laser diode 30 or being radiated to the environment, the port 48 may be terminated with a shield and an absorber (not shown herein). The absorber may consist of a plurality of very narrow turns of the fibre section of the strand 43 on which the port 48 is located. The optical test pulses produced by the laser diode 30 are injected into the input port 42 of the strand 41. The port 44 of the strand 41 is connected to a launching fibre 50. Connected to the launching fibre 50 is an object under test, particularly an optical fibre 60, referred to in the following as a test fibre. A photodetector 70 is connected to the output port 46 of the strand 43 of the 2x2 directional coupler 40. The photodetector 70 is, for example, a photodiode (e.g. Avalanche Photo Diode - APD The photodiode 70 converts the optical echo pulse received through the output port 46 into an electric signal. The photodiode 70 is connected on the output side to a data evaluation apparatus 80 containing a known Boxcar averager and a logarithm conversion apparatus. The purpose of the data evaluation apparatus 80 is to process a plurality of received echo pulses into an amplified and easily displayable signal. The output of the data evaluation apparatus 80 is connected to the first input of an oscilloscope 90 on which the echo pulses produced in the test fibre 60 are displayed. Connected to the second input of the oscilloscope 90 is the pulse generator 20 that synchronizes the oscilloscope 90 with the laser diode 30.

The following is a brief explanation of the operating principle of the optical pulse reflectometer 10 according to the present invention.

As shown in Fig. 1, the light pulses emitted by the laser diode 30 are directed via the input port 42 of the 2x2 directional coupler to the output port 44. The 2x2 directional coupler 40 must be switched for the duration of each test pulse in such a manner that the entire light signal leaves the 2x2 directional coupler 40 at the output port 44 and is injected essentially without loss into the test fibre 60. To this end, the 2x2 directional coupler 40 is switched to the "straight-ahead" state, as shown in Fig. 2. Immediately after the light pulse has passed completely through the strand 41, the 2x2 directional coupler 40 is switched to the crossed-over state, as shown in Fig. 3. In this state, the reflection signal caused by the test fibre 60 and delayed in the launching fibre 50 is transferred via the port 44 (now acting as an input) of the strand 41 to the other strand 43. The reflection signal leaves the 2x2 directional coupler 40 at the port 46 and is directed to the photodetector 70. In order to ensure that all the test pulses reflected by the test fibre 60 are passed to the photodiode 70 and can be evaluated by the optical pulse reflectometer 10, the test pulse must have passed completely through the 2x2 directional coupler 40 before the 2x2 directional coupler 40 can be switched from the straight-ahead state to the crossed-over state. For this purpose, the launching fibre 50 is inserted between the optically switchable 2x2 coupler 40 and the test fibre 60. The launching fibre 50 delays the echo pulse until the 2x2 directional coupler 40 has been switched. The length of the launching fibre 50 should therefore be $1 \geq cT$, where c is the speed of the light in the launching fibre 50 and T is the longest pulse duration of a pulse which can be emitted from the laser diode 30. Usually, the duration of a light pulse emitted by the laser diode 3 0 will be 10 ns to 10 $\mu$s. The mark-to-space ratio is, for example, approximately 1: 1000. In this manner, each echo pulse reaches the photodetector 70 undistorted and can be used to measure the attenuation and reflection profile of the test fibre 60, and can be displayed on the oscilloscope 90. Furthermore, the use of the launching fibre 50 makes it possible to prevent any light components reflected in the test fibre 60 from being returned to the laser diode 30, and do this in a reliable manner.

Instead of the pulsed laser diode 30, it is also possible to employ a laser diode which is operated in constant light mode, light pulses being produced in this case in the optical switch. In the case of the described 2x2 coupler 40, the constant light of the laser diode 30 is, for this purpose, directed in the straight-ahead state to the test fibre 60 for the duration of a test pulse. After the desired pulse duration, which is stored, for example, in the control apparatus, the 2x2 coupler 40 is switched to the crossed-over state. The constant light, still emitted by the laser diode 30, is directed to the port 48 and is for all practical purposes completely attenuated in the connected absorber. At the same time, the light reflected by the test fibre 60 because of Rayleigh scattering and Fresnel reflections is passed to the photodetector 70 and is then processed and displayed as hereinbefore described.

The improved power utilization of the optical pulse reflectometer 10 according to the invention is accomplished in that, on both the outward and return journeys of a pulse, thanks to suitable selection of the instant of switching of the optical switch 40, there are no longer any structural, i.e. process-induced, power losses, as is the case with static power splitters. Consequently, the entire optical power arriving at a port of the 2x2 coupler 40 is switched through more or less unattenuated to only one port at a time on the opposite side. This is true both when the test pulse is emitted and also when the reflected components are returned.

The control or adjusted variable of presently customary and technically well-mastered versions of switchable 2x2 directional couplers is very often an electric voltage. The electric field associated therewith permits the use of the Pockels effect (linear electro-optical effect). Switchable optical 2x2 directional couplers can be implemented in integrated optical design in a variety of versions (waveguide structure material composition). Furthermore, there is the possibility of monolithic integration with the laser diode 30 of the optical pulse reflectometer 10. An alternative embodiment of a switchable optical switch for the free-beam guiding of the light may consist in a plate with a coating on both sides, the reflectivity of which can, for example, be electrically adjusted between virtually full transparency during the emission of the test pulse and virtually complete reflection during the reception of the reflections from the test fibre 60.

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CLAIMS:

1. An optical pulse reflectometer comprising:

at least one light source operating in a constant light mode;

at least one test object;

at least one photodetector;

an indication device connected downstream of an output of the at least one photodetector;

at least one optical switch for selectively connecting the light source to the at least one test object and the at least one test object to the at least one photodetector; and

a control device for driving the at least one optical switch so as to produce light pulses having a predefined frequency and duration.

2. The optical pulse reflectometer as recited in claim 1 wherein the at least one light source is a laser diode.

3. The optical pulse reflectometer as recited in claim 1 wherein the at least one test object is an optical fiber.

4. The optical pulse reflectometer as recited in claim 1 wherein the at least one optical switch is at least one of a 2×2 directional coupler and an acousto-optical modulator.

5. The optical pulse reflectometer as recited in claim 4 wherein an unused port of the at least one optical

switch is terminated with a light shielding and absorption device.

6. The optical pulse reflectometer as recited in claim 1 further comprising a launching fiber having a predetermined length, the launching fiber being connected upstream of the at least one test object.

7. The optical pulse reflectometer as recited in claim 1 further comprising a Boxcar averager and a logarithm converter connected between the at least one photodetector and the indication device.

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PATENT AGENTS

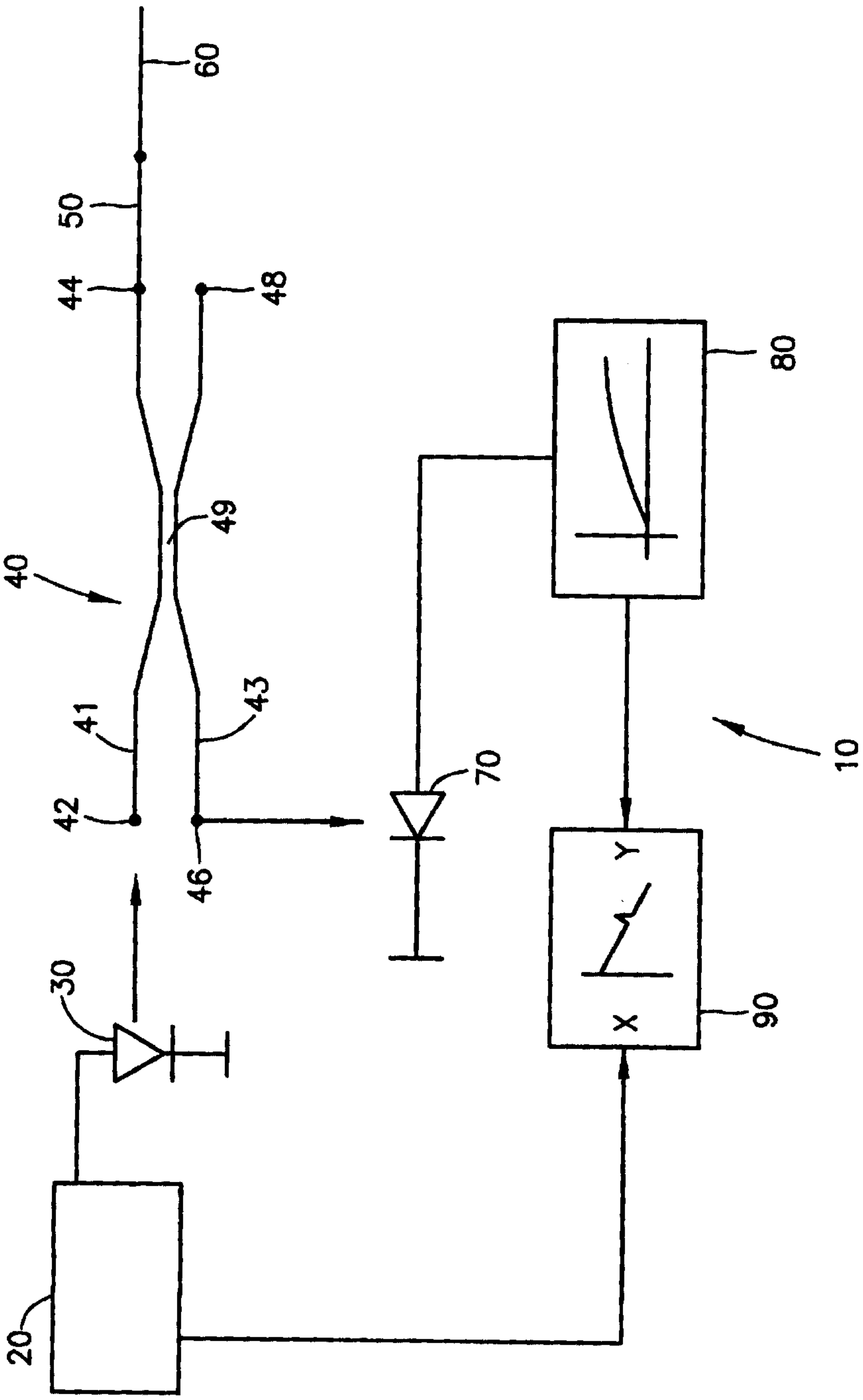



Fig. 1

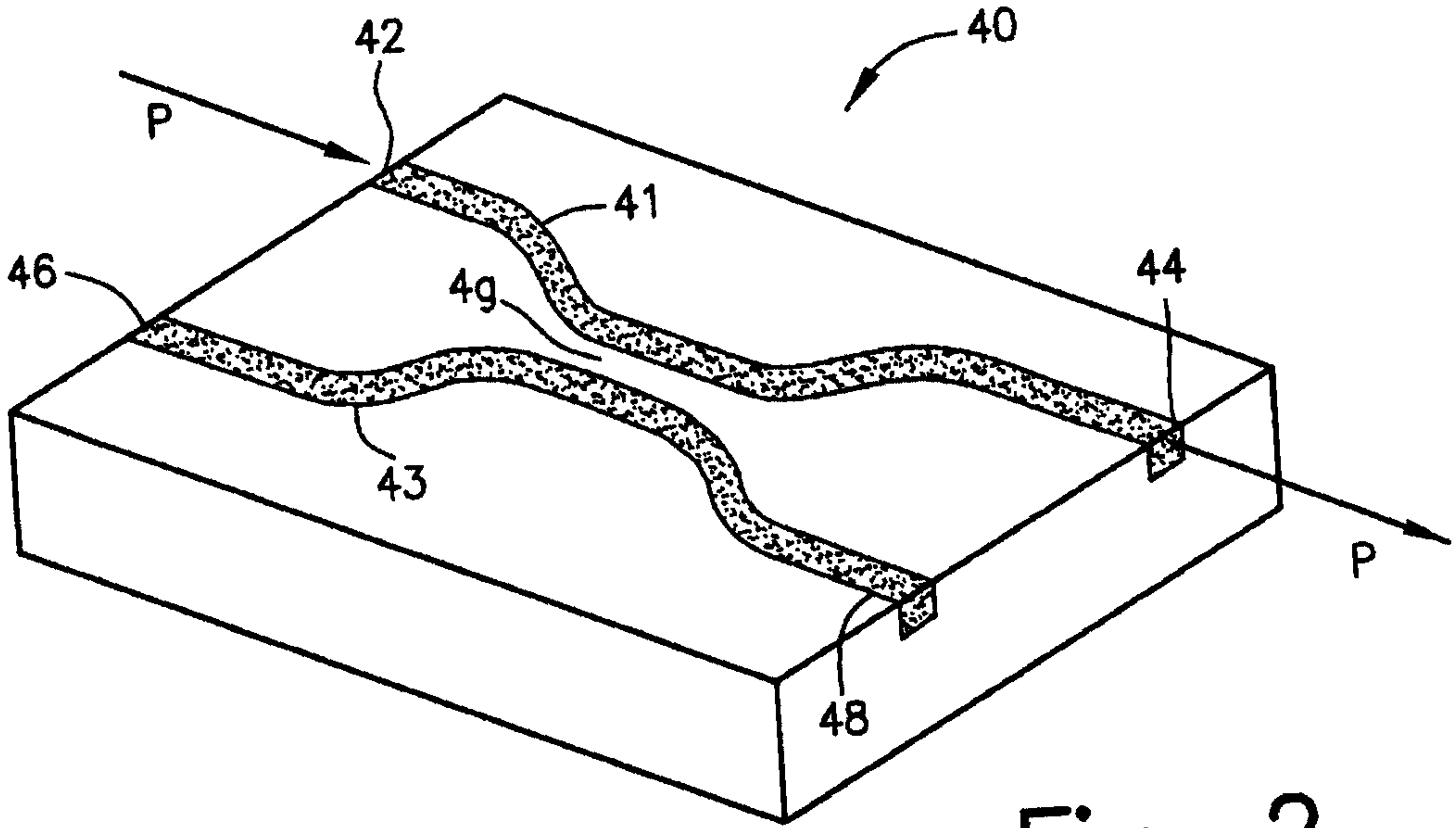



Fig. 2

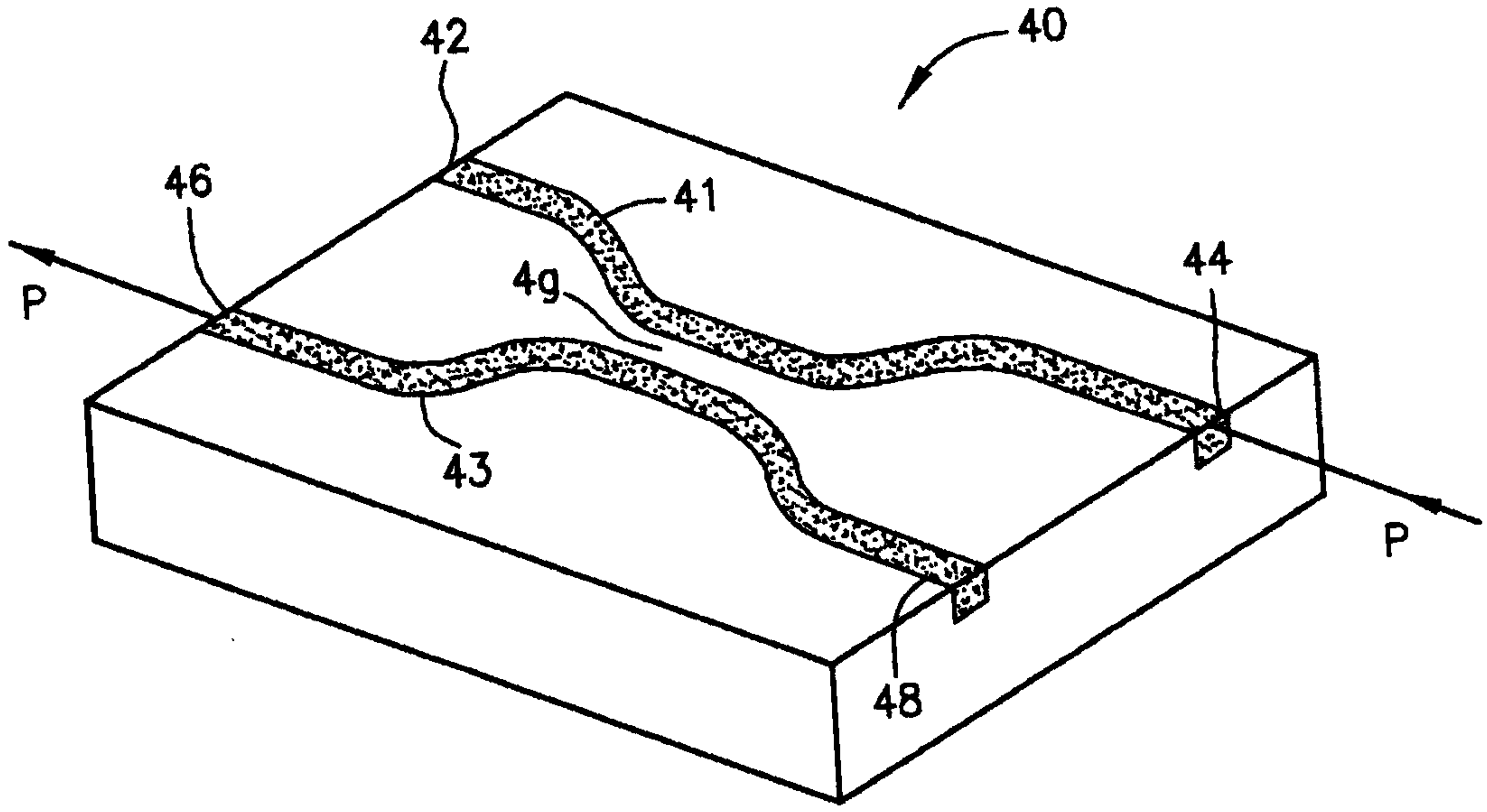
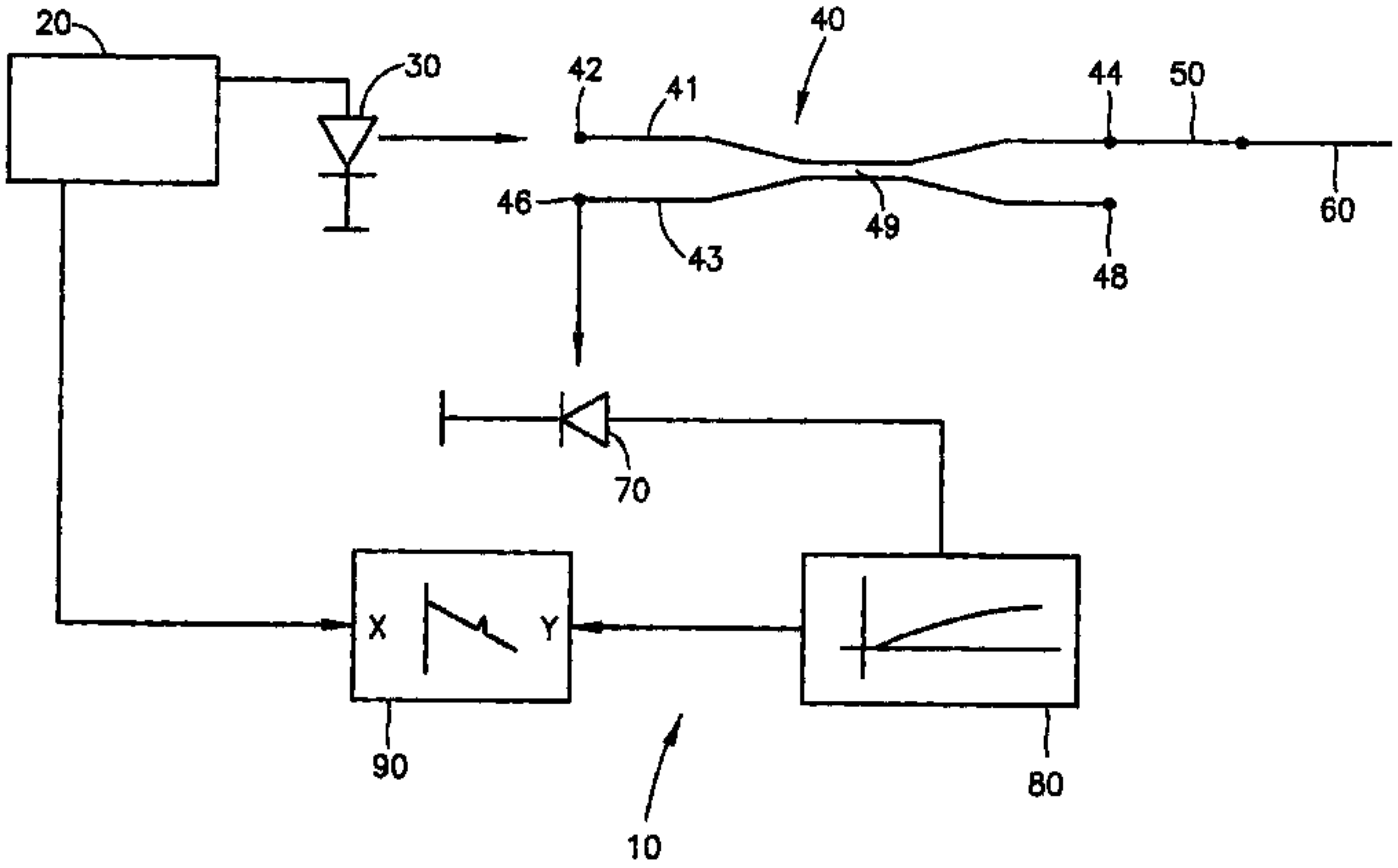



Fig. 3



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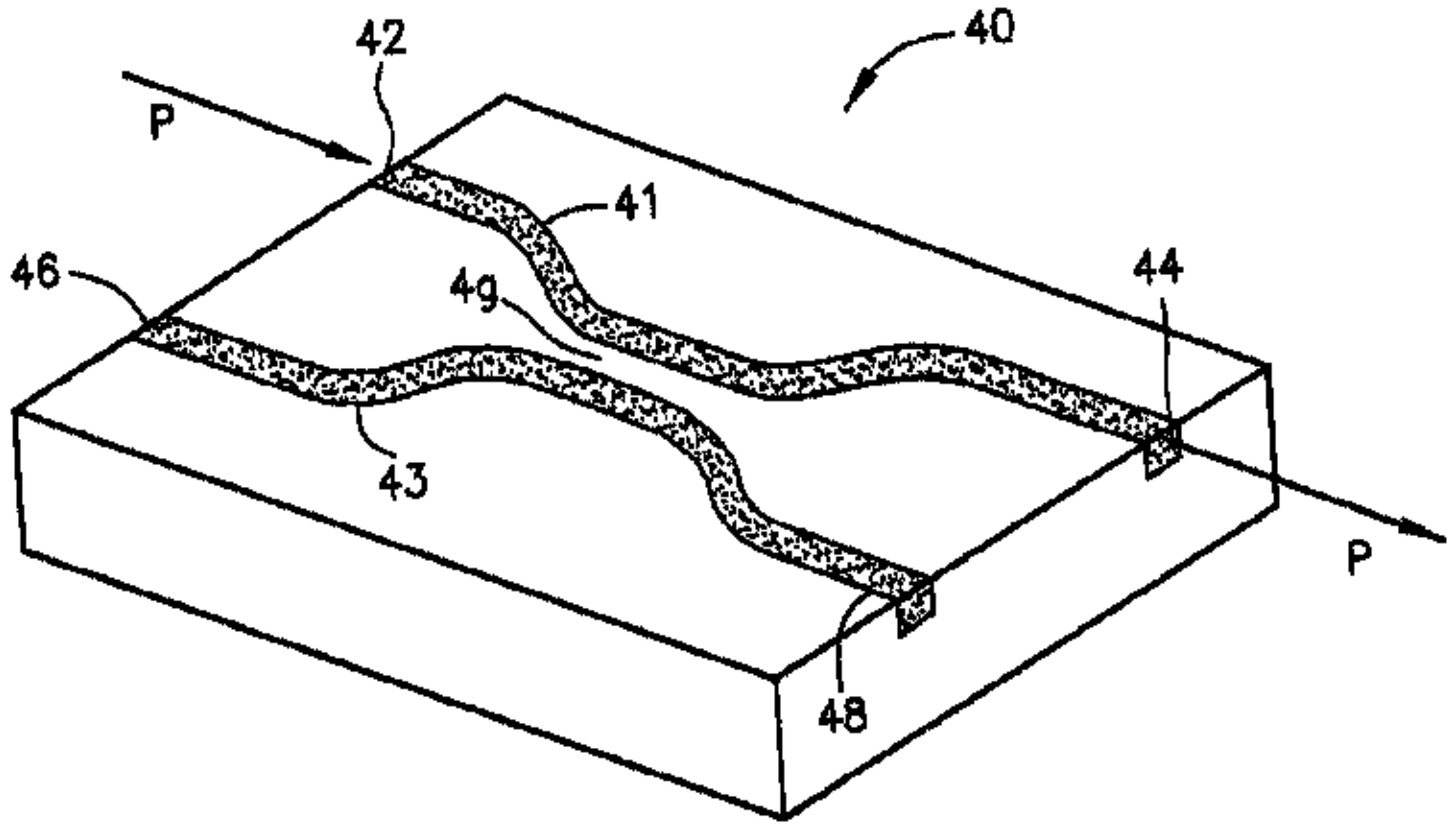

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