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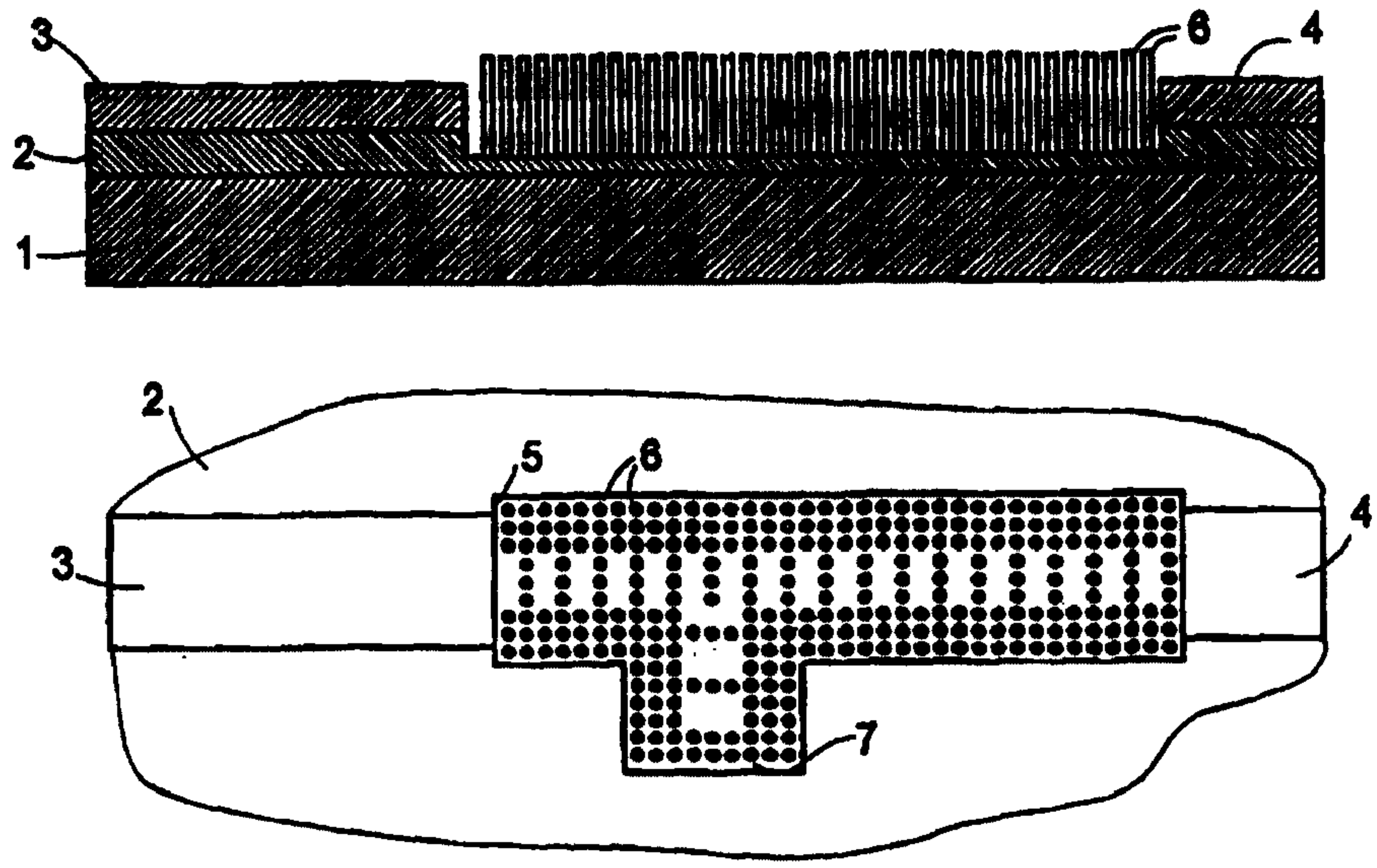
(54) **CIRCUIT OPTIQUE INTEGRE**

(54) **INTEGRATED OPTICAL CIRCUIT**



(57) L'invention concerne un circuit optique intégré comportant un substrat de silicium (1) sur lequel sont disposés des guides d'ondes (2, 3). Au moins un cristal photonique faisant office de guide d'ondes est formé d'un réseau d'aiguilles (6), lesquelles peuvent être produites par dépôt par rayonnement corpusculaire.

(57) The invention relates to an integrated optical circuit comprising a silicon substrate (1) and waveguides (2, 3) arranged thereon. At least one photonic crystal is provided as a waveguide, which is formed by a mesh of needles (6). The needles (6) can be produced by corpuscular radiation deposition.

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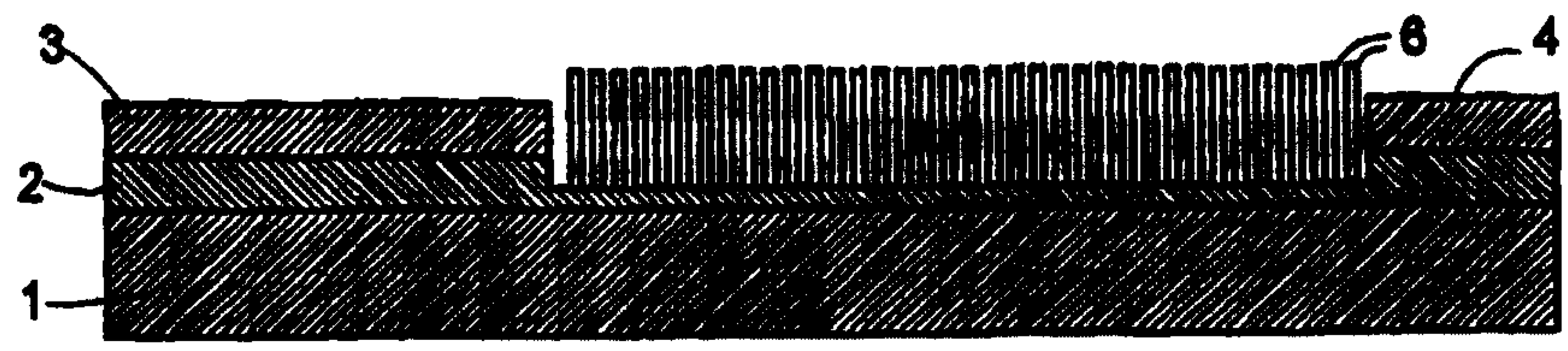
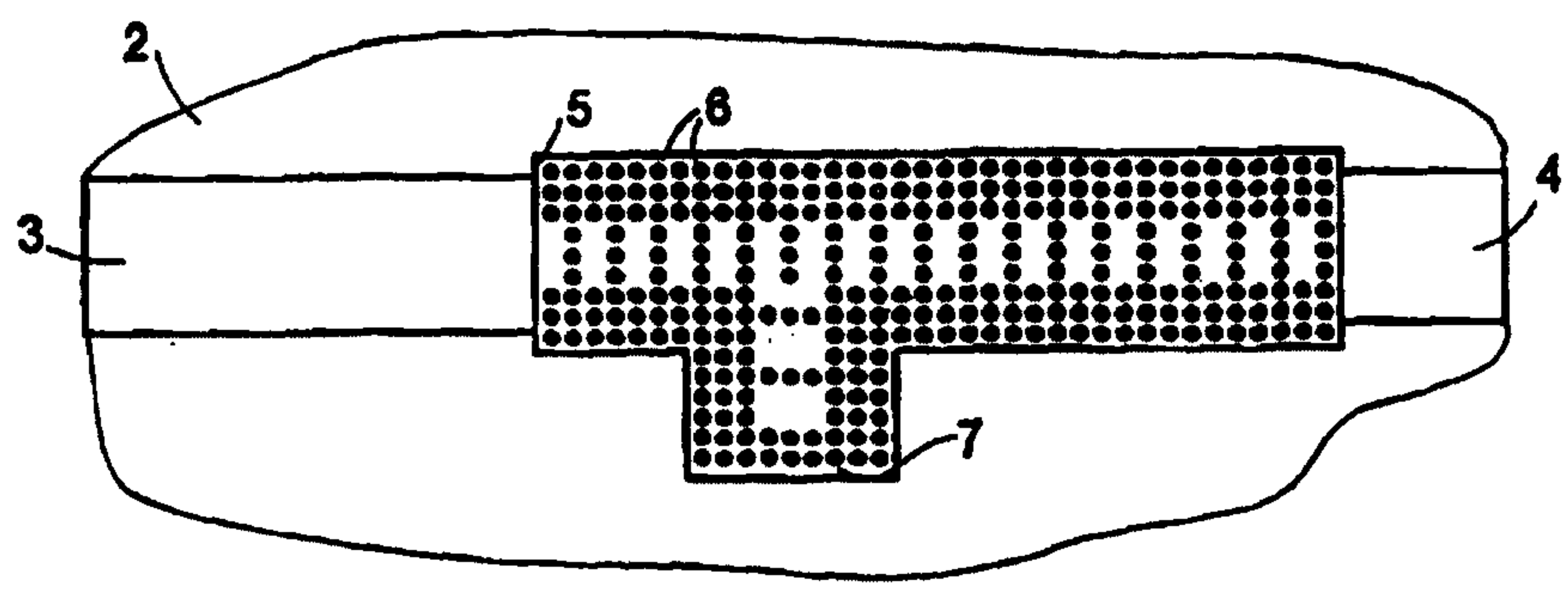
(54) Bezeichnung: INTEGRIERTE OPTISCHE SCHALTUNG





(57) Abstract

The invention relates to an integrated optical circuit comprising a silicon substrate (1) and waveguides (2, 3) arranged thereon. At least one photonic crystal is provided as a waveguide, which is formed by a mesh of needles (6). The needles (6) can be produced by corpuscular radiation deposition.

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Integrated optical circuit

The invention relates to an integrated optical circuit with a silicon substrate and thereon disposed waveguides.

Integrated optical circuits are required in communications engineering for various purposes, such as for the distribution, combining, spectral splitting or switching of information-modulated flows of light. In addition, it is also possible to realize other circuits with the aid of optical structures, such as computer circuits.

At present, integrated optical circuits are constructed using waveguides made of polymers or III-V compound semiconductors which are structured by lithographic processes.

Suitable as the optically active components of such circuits are, inter alia, photonic crystals, which, because of their small geometrical dimensions, require, in order to develop their full effect, a waveguide pattern into which they are inserted. Such waveguide patterns are usually strip waveguides made of polymer or semiconductor material.

These waveguide patterns can be produced in a complementary structure which, through its form, prevents the propagation of the photon pulses in the matter and, through selectively built-in defects, allows propagation into otherwise completely reflecting matter. In this regard, there is not a step change in refractive index as in the guiding of waves in optical waveguides formed by doping or in the form of strip waveguides, but, in this case, for the propagation of said waves, - theoretically existing - forbidden bands limit the state solution of the eigensolutions desired for specific wavelengths. These waveguides are described, for example, by Mekis A. et al in Physical Review Letters, Volume 77, No. 18, p. 3787.

The object of the present invention is to indicate an integrated optical circuit in which such waveguides are used for various functions and which can be manufactured with the requisite precision.

The object of the invention is achieved in that at least one photonic crystal is provided as a waveguide. It is preferably provided that further waveguides are in the form of strip waveguides, an insulating layer being disposed between the strip waveguides and the silicon substrate, and that the photonic crystal extends from a plane below the lower boundary surface of the waveguides to beyond the upper boundary surface of the waveguides.

The commercially available material "silicon on insulator", for example from the manufacturer SOITEC SA., Grenoble, France, can advantageously be used to manufacture the circuit according to the invention. Said material has good transmission properties for wavelengths of 1.55 µm. Silicon has in such waveguides a very high dielectric constant of 12, which can also be used with the photonic crystals. Special photonic crystals, inserted with very low insertion loss at defined locations of the circuit, guarantee the functioning of the circuit, for example as a computing circuit, it being possible for the entire circuit to be made very small. Thus, for example, 6 periods of the lattice of the photonic crystals with a lattice spacing of 1/3 of the wavelength are sufficient to obtain an attenuation of 35 dB.

An advantageous embodiment of the circuit according to the invention consists in that the at least one photonic crystal is formed by needles with a high dielectric constant in the form of a two-dimensional periodic lattice with imperfections. It is, however, also perfectly possible that the at least one photonic crystal is formed by a body with a high dielectric constant with holes of low dielectric constant in the form of a two-dimensional periodic lattice with imperfections, this being described, for example, in DE19533148 A1.

Depending on the specific requirements, it may be provided that the needles stand on the insulating layer, which is less thick in the region of the photonic crystal than under the waveguides, or that the needles stand on the silicon substrate.

An advantageous further development of the circuit according to the invention consists in that the spaces between the needles are filled with non-linearly optical material and in that the refractive index of the non-linearly optical material is adjustable by means of a voltage applied to field electrodes. It is thus possible to control, for example, the behavior of filters in the form of integrated optical circuits; see also DE19542058 A1.

A further advantageous embodiment consists in that the needles or holes stand obliquely with respect to the optical axis. This allows the branching of light in a part of the wavelength range into a further plane of the integrated optical circuit. An alternative thereto is provided by another embodiment of the invention in that the at least one photonic crystal constitutes, through the arrangement of the imperfections, a branch filter in which branched-off light of a selected wavelength range escapes laterally. The laterally escaping light can be guided further in various manners.

In another further development of the invention, it is provided that laterally escaping light of different wavelength ranges is capable of being focused on different locations of a parallel extending photonic crystal. This makes it possible in a simple manner to connect a plurality of computing planes.

Hereinbelow, example embodiments of the invention are described in greater detail with reference to the drawings, in which:

Fig. 1 shows a cross section of a detail from a circuit according to the invention;

Fig. 2 shows a top view of the detail represented in Fig. 1;

Fig. 3 shows a top view of a part of a further example embodiment;

Fig. 4 shows an example of the optical connection of two planes of the integrated optical circuit;

Fig. 5 shows the schematic representation of an example of the optical connection of a plurality of computing planes in a circuit according to the invention; and

Fig. 6 shows a Mach-Zehnder interferometer realized with the circuit according to the invention.

In the example embodiment shown in Fig. 1, a silicon substrate 1 accommodates an insulating layer 2 of silicon oxide to which are applied optical strip waveguides 3, 4 made of silicon. Situated between the waveguides 3, 4 is a photonic crystal 5 formed by a lattice of needles 6.

In the example embodiment, the needles 6 stand on the insulating layer 2, which has a cavity in the region of the photonic crystal 5. This, allied to the fact that the needles protrude beyond the upper boundary plane of the waveguides 3, 4, means that the field conducted in peripheral regions outside of the waveguide is also covered by the photonic crystal.

The needles 6 may be manufactured in known manner by corpuscular-beam deposition. An associated process is described, for example, in DE19533148 A1.

As was demonstrated in S.Y. Lin, G. Arjavalingam: Optics Letters, Vol. 18, No. 19, 1666 (1990) with reference to experiments with millimeter waves, just six periods of the lattice with a lattice constant of one-third of the wavelength are sufficient in order to obtain an attenuation of 35 dB. Within the thus attenuated wavelength range, it is possible, by means of selective imperfections, i.e. by the omission of needles, to create wavelength ranges of reduced attenuation. In the example embodiment shown in Figs. 1 and 2, light of a plurality of wavelengths is guided from waveguide 3 to waveguide 4, while light of a selected wavelength escapes at a branch 7. The selected intervals of the needles in the central region of the photonic crystal represent merely an example of a precise configuration for obtaining the desired filter characteristics.

In the example embodiment shown in Fig. 3, photonic crystals are provided not only for a filter, but also for the inlet and outlets, the inlet 11 and the outlets 12, 13 being in the form of all-pass filters in that there are no needles in the central region.

Fig. 4 shows an example embodiment in which the needles 14 forming the photonic crystal are tilted. A covering layer 15 is provided in selected regions, with the result that light escapes there and is focused through attached lenses 16 made preferably of polymer material into entrance windows (not shown) of an above-lying plane. This allows three-dimensional structures, such as in a computer circuit. The lenses may be produced in known manner by electron-beam lithography or using optical processes.

Fig. 5 shows a detail from a circuit according to the invention in which a plurality of branches 21 to 25 are formed by a photonic crystal 26, a lens 27 to 31 focusing the light escaping from the branch onto entrance surfaces 32 to 36 disposed on further optical components 37, 38 extending next to the photonic crystal 26.

Fig. 6 shows an example embodiment in the form of a Mach-Zehnder interferometer. All the components, particularly waveguide, filter, mirror and beam splitter, are formed by photonic crystals. The interferometer is to be used to measure the transit time in a reflecting test specimen 41 merely schematically indicated in Fig. 6. For this purpose, the light supplied at 42 is first guided through an adjustable filter 43, by means of which the wavelength to be used for measuring is selected. By means of a beam splitter 44, the light escaping from the filter 43 is guided in equal parts straight ahead to an adjustable phase shifter 45 and reflected to the test specimen 41.

The adjustable filter 43 and the adjustable phase shifter 45 each consist of a photonic crystal, the spaces being filled with non-linearly optical material, the dielectric constant of which and thus the optically active intervals of the needles are controllable by means of voltages applied to electrodes 46, 47 and 48, 49.

The phase shifter 45 is adjoined by a completely reflecting mirror 50, which supplies the light escaping from the phase shifter 45 to a further beam splitter 51.

Disposed in front of the test specimen 41 is a photonic crystal in the form of a directional switch 42, with the effect that the light arriving from the beam splitter 44 is guided into the test specimen 41 and the light reflected in the test specimen passes through a waveguide 43 to the further beam splitter 51. Both flows of light are superimposed at the output 54. Using a suitable instrument transformer, the intensity escaping from the output 54 can be measured and the phase shift in the test specimen 41 can be determined by adjusting the phase at 45 to a minimum of the intensity at the output 54. For the reasons already mentioned hereinbefore, it is also possible for the circuit shown in Fig. 6 to be made extremely small, for example with an overall length of approximately 20 μm.

New Claims

1. Integrated optical circuit with a silicon substrate and thereon disposed waveguides having at least one photonic crystal, characterized in that elements (14), which are each formed by a needle or a bore and which form the photonic crystal, stand obliquely with respect to the optical axis and are arranged parallel to one another.

2. Integrated optical circuit according to claim 1, characterized in that further waveguides are in the form of strip waveguides (3, 4), an insulating layer (2) being disposed between the strip waveguides (3, 4) and the silicon substrate (1), and in that the photonic crystal extends from a plane below the lower boundary surface of the waveguides (3, 4) to beyond the upper boundary surface of the waveguides (3, 4).

3. Integrated optical circuit according to any one of claims 1 or 2, characterized in that the elements of the at least one photonic crystal are needles (14) having a high dielectric constant which are arranged in the form of a two-dimensional periodic lattice.

4. Integrated optical circuit according to any one of claims 1 or 2, characterized in that the elements of the at least one photonic crystal are holes of a low dielectric constant in a body having a high dielectric constant which are arranged in the form of a two-dimensional periodic lattice.

5. Integrated optical circuit according to claim 3, characterized in that the needles (14) stand on the insulating layer (2), which is less thick in the region of the photonic crystal than under the waveguides (3, 4).

6. Integrated optical circuit according to claim 3, characterized in that the needles stand on the silicon substrate.

7. Integrated optical circuit according to any one of claims 3, 5 or 6, characterized in that the spaces between the needles are filled with non-linearly optical material and in that the refractive index of the non-linearly optical material is adjustable by means of a voltage applied to field electrodes (46 to 49).

8. Integrated optical circuit according to any one of the preceding claims, characterized in that the at least one photonic crystal (26) constitutes, through the arrangement of the imperfections, a branch filter in which branched-off light of a selected wavelength range escapes laterally.

9. Integrated optical circuit according to any one of the preceding claims, characterized in that laterally escaping light of different wavelength ranges is capable of being focused on different locations of a parallel extending photonic crystal.

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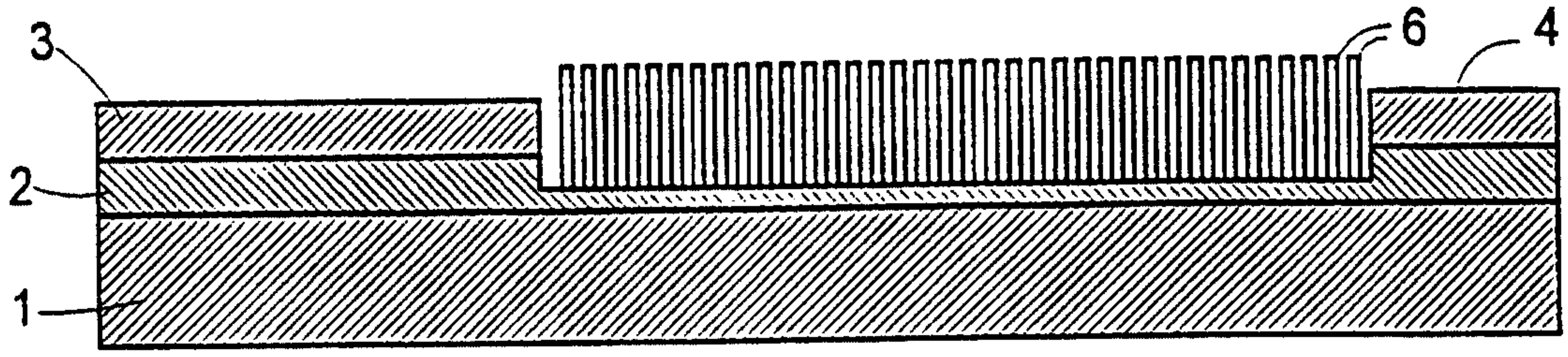

Fig.1

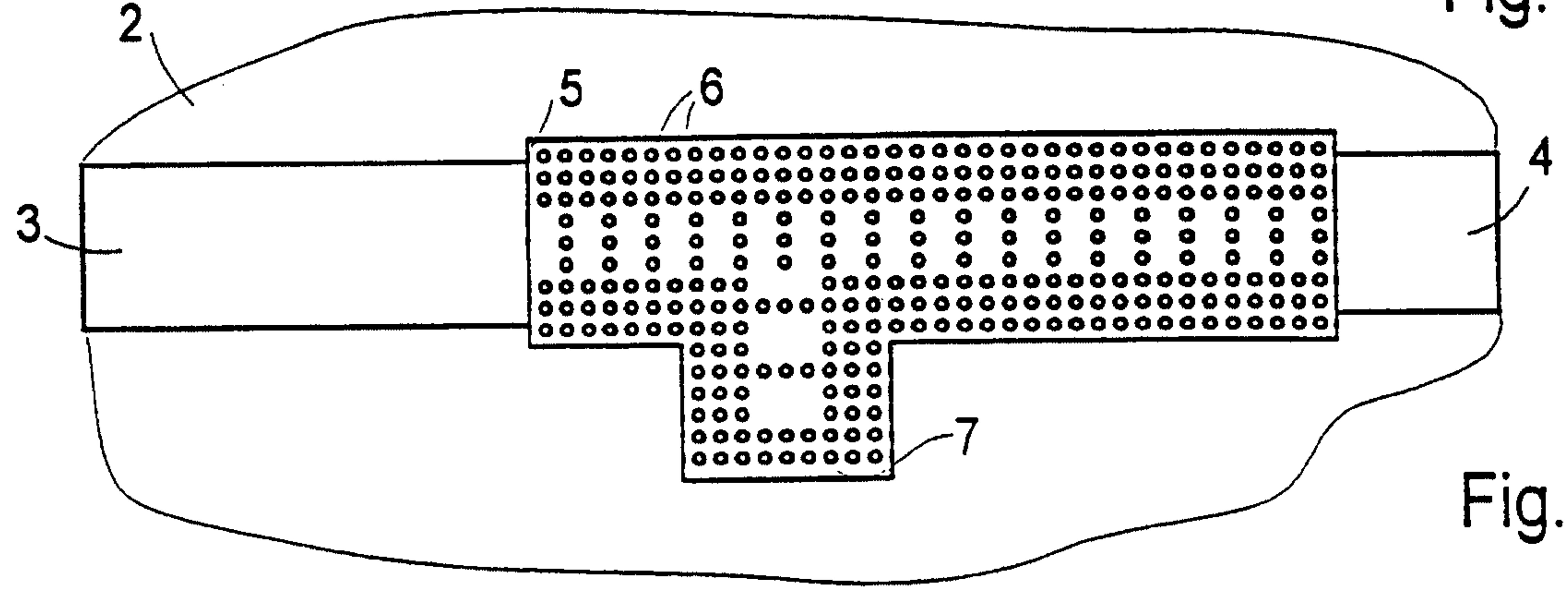

Fig.2

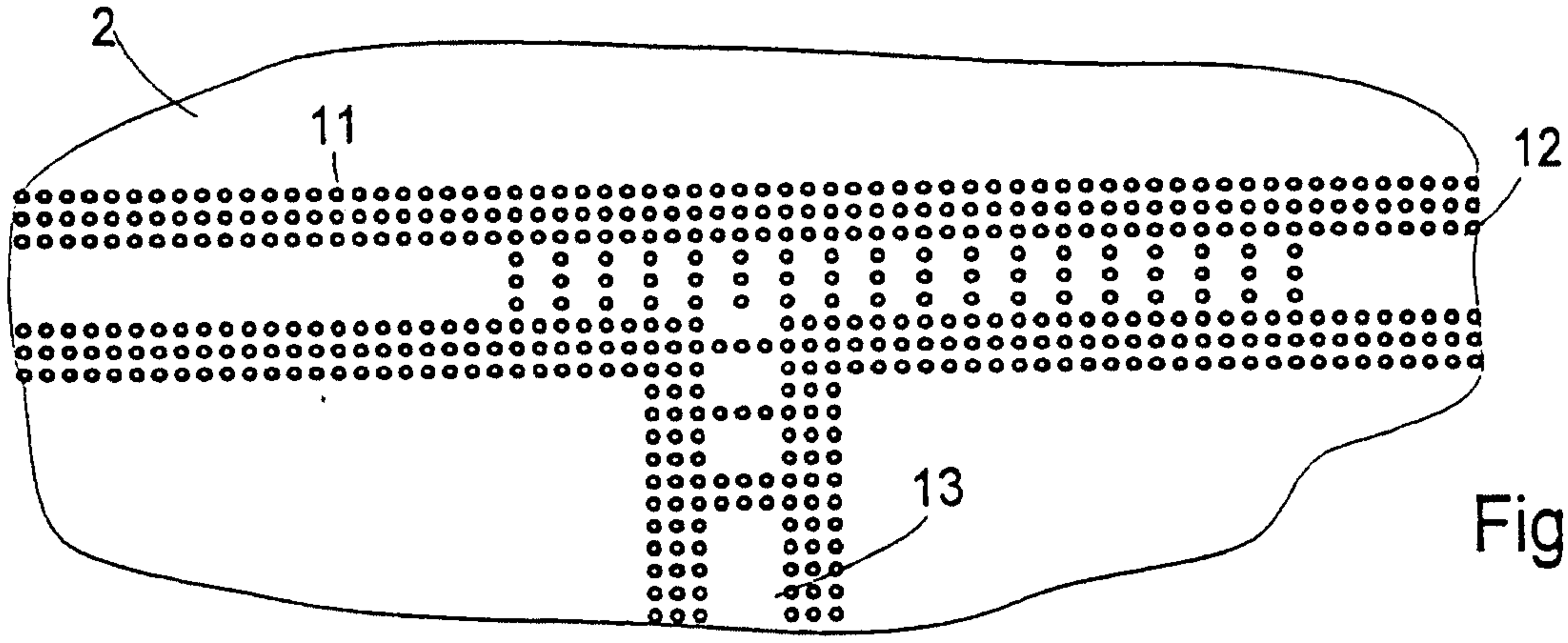

Fig.3

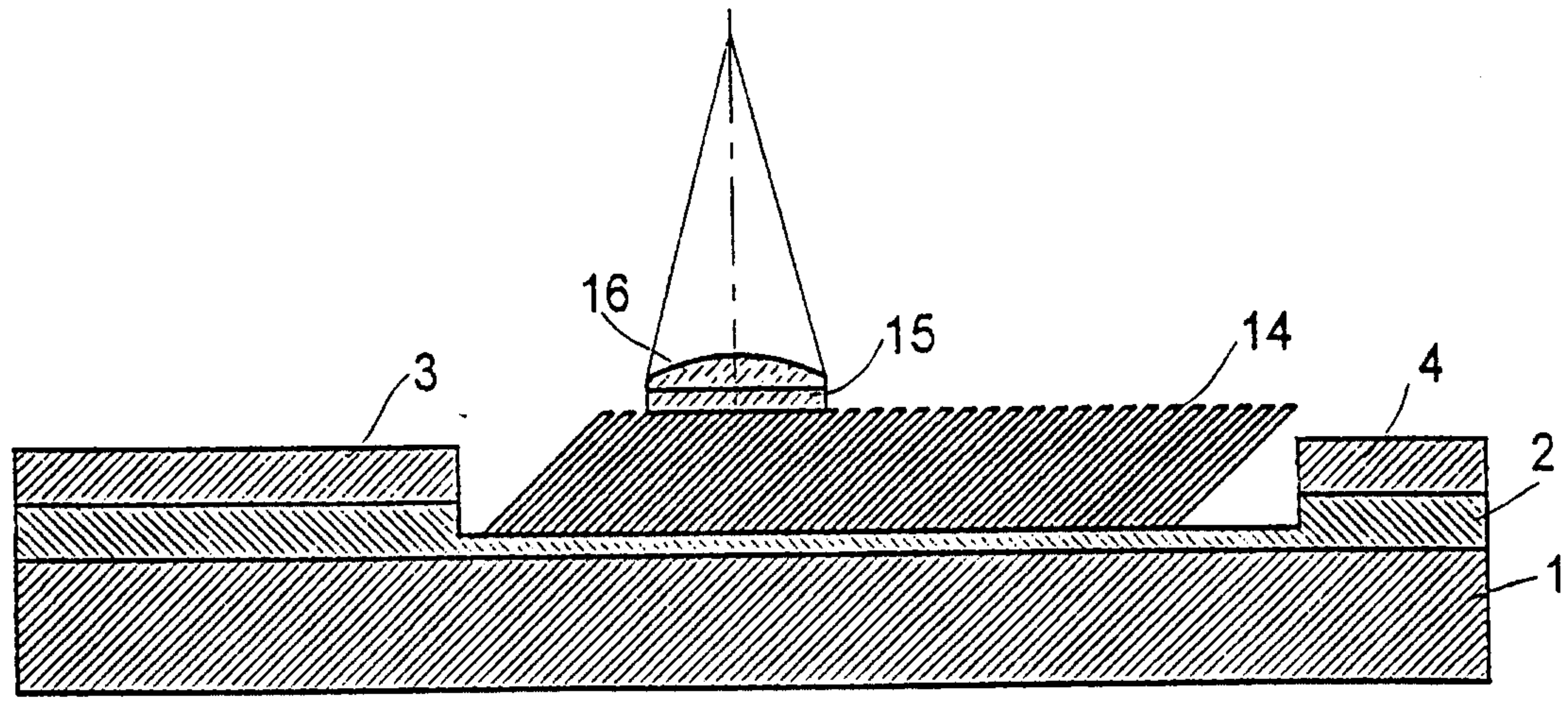

Fig.4

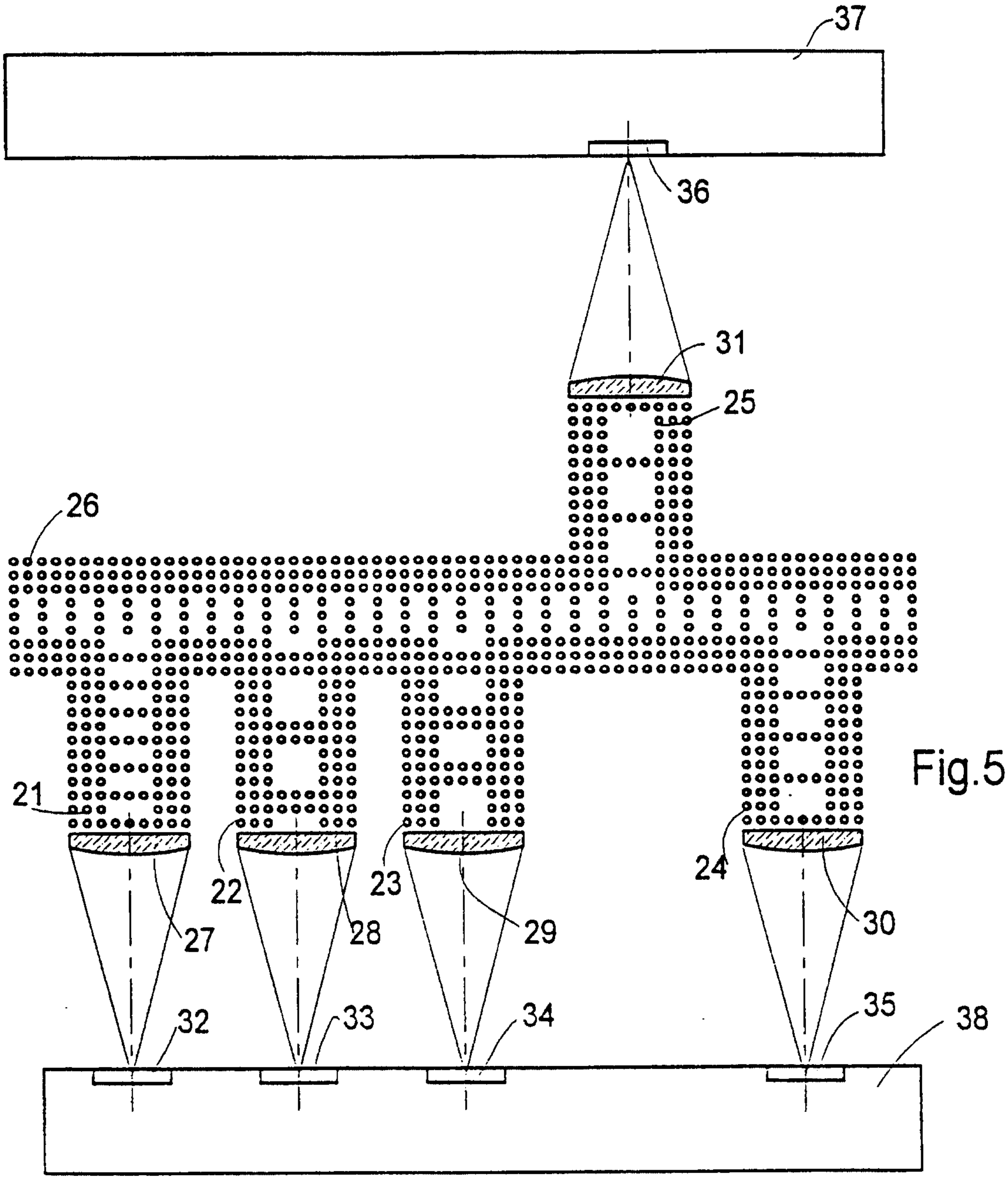

Fig.5

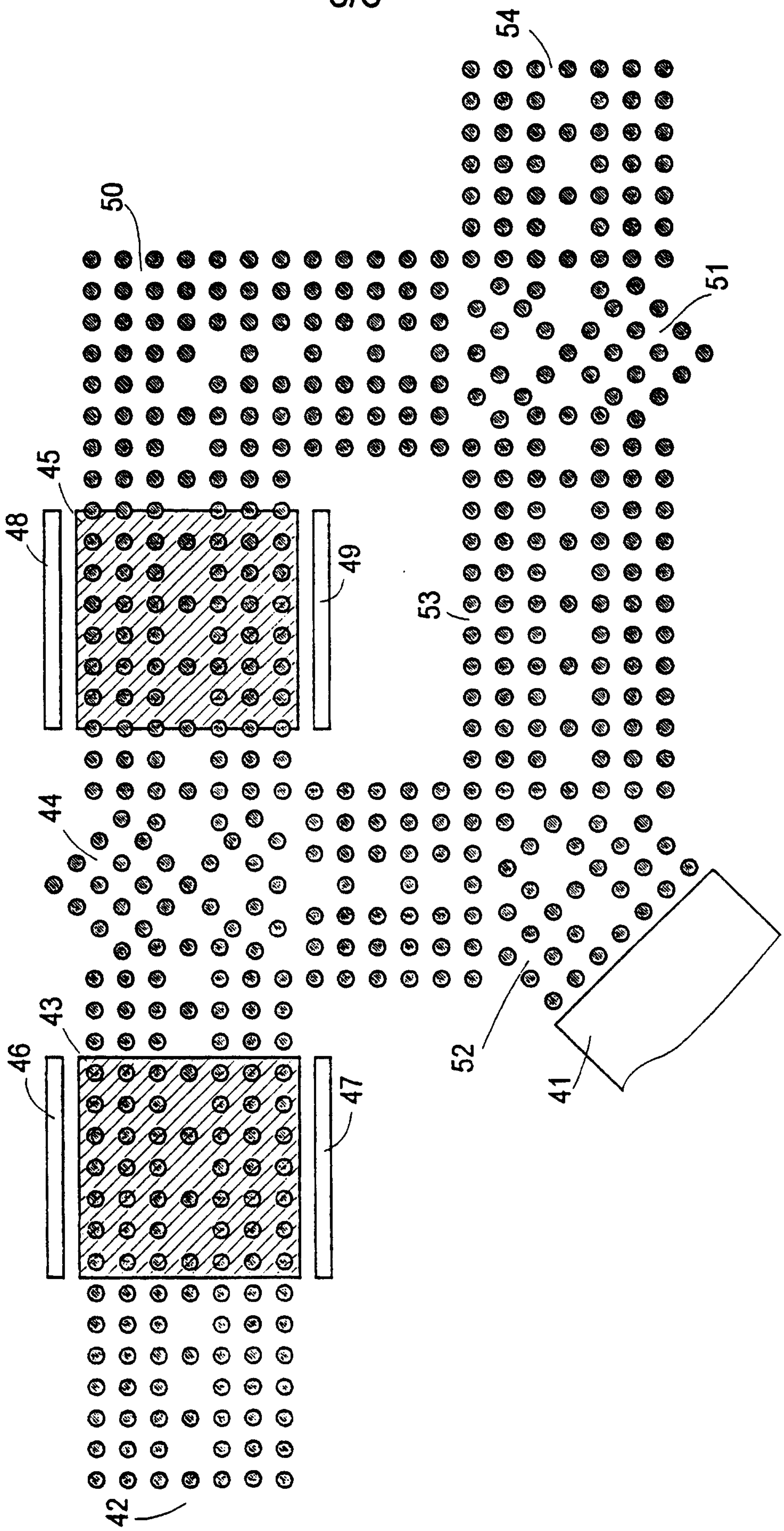

Fig.6