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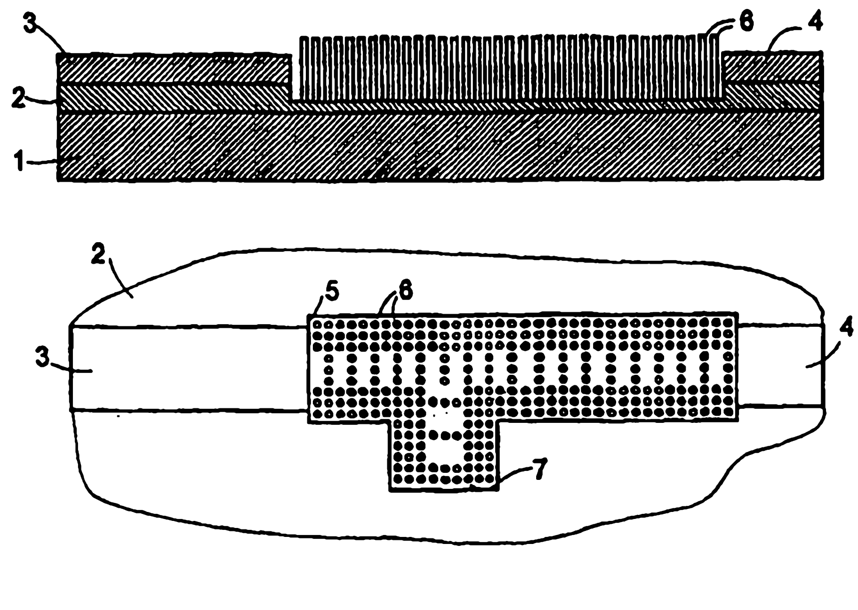
(54) Title: INTEGRATED OPTICAL CIRCUIT

(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.

Abstract

In an integrated optical circuit having a silicon substrate and waveguides arranged on it, at least one photonic crystal is provided as the waveguide.

Integrated optical circuit

The invention relates to an integrated optical circuit having a silicon substrate and waveguides arranged on it.

Integrated optical circuits are required for many purposes in information technology, for example for the distribution, combination, spectral splitting and switching of light beams modulated with information. Furthermore, other circuits, such as computer circuits, can be also be produced using optical structures.

At the moment, integrated optical circuits are constructed with waveguides composed of polymers or III-V compound semiconductors, which are structured using lithographic methods.

Suitable optically effective elements of such circuits include photonic crystals which, owing to their small geometric dimensions, produce their full effect only by means of a waveguide pattern into which they are inserted. Such waveguide patterns are normally strip waveguides composed of polymer or semiconductor material.

These waveguide patterns can be produced in a complementary structure, which prevent the propagation of photon pulses in the material by virtue of their configuration, and which structure allows propagation by means of deliberately incorporated defects in otherwise completely reflected material. In this case, there is no sudden change in refractive index as when waves are carried in optical waveguides which are formed by doping or as strip waveguides; instead of this, theoretically defined, forbidden bands bound the state solution of the intrinsic solutions, which are desired for specific wavelengths, for propagation of these waves. 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 specify an integrated optical circuit in which such waveguides are used for various functions, and which can be produced with the required precision.

This object is achieved according to the invention in that at least one photonic crystal is provided as the waveguide. In this case, the invention preferably provides for further waveguides to be in the form of strip waveguides, in which case an insulating layer is arranged between the strip waveguides and the silicon substrate, and for the photonic crystal to extend from a level underneath the lower boundary surface of the waveguides beyond the upper boundary surface of the waveguides.

The circuit according to the invention can advantageously be produced using the commercially available material "silicon on insulator", manufactured, for example, by SOITEC SA., Grenoble, France. This material has good permeability for wavelengths of 1.55 µm. In waveguides such as these, silicon has a very high dielectric constant of 12, which can also be used for the photonic crystals. Special photonic crystals which are used at specific points with low insertion loss in the circuit, ensure the operation of the circuit, for example as a computation circuit, in which case the entire circuit can be designed to be very small. Thus, for example, six periods of the grid of the photonic crystals with a grid spacing of 1/3 of the wavelength are sufficient to achieve an attenuation of 35 dB.

One advantageous refinement of the circuit according to the invention is for the at least one photonic crystal to be formed by needles having a high dielectric constant, in the form of a two-dimensional periodic grid with disturbance points. However, it is also entirely possible for the at least one photonic crystal to be formed by a body having a high dielectric constant with holes of low dielectric constant in the form of a two-dimensional periodic grid with disturbance points, as is described, for example, in DE 195 33 148 A1.

Depending on the preconditions, it is possible, in detail, for the needles to be located on the insulating layer, which is thinner in the region of the photonic crystal than underneath the waveguides, or for the needles to be located on the silicon substrate.

One advantageous development of the circuit according to the invention is for the intermediate spaces between the needles to be filled with a non-linearly optical material, and for the refractive index of the non-linearly optical material to be variable with the aid of a voltage which is applied to field electrodes. It is thus possible to control, for example, the response of filters which are designed as integrated optical circuits, see also DE 195 42 058 A1.

A further advantageous refinement is for the needles and holes to be located obliquely with respect to the optical axis. Light in one portion of the wavelength band can thus be split into a further plane of the integrated optical circuit. Another refinement of the invention offers an alternative to this in which the at least one photonic crystal represents, by the arrangement of the disturbance points, a splitting filter, in which split light in a selected wavelength band emerges at the side. The light which emerges at the side may be passed on in a large number of ways.

Another development of the invention provides for the capability to focus light, which emerges at the side and is in different wavelength bands, onto different points on a parallel-running, photonic crystal. This allows a plurality of computation levels to be connected in a simple manner.

The exemplary embodiments of the invention are explained in more detail in the following description and are illustrated in a number of figures in the drawing, in which:

Figure 1 shows a cross section of a detail from a circuit according to the invention,

Figure 2 shows a plan view of the detail illustrated in Figure 1,

Figure 3 shows a plan view of a part of a further exemplary embodiment,

Figure 4 shows an example of an optical link between two levels in the integrated optical circuit,

Figure 5 shows a schematic illustration of an example of an optical link between a number of computation levels in a circuit according to the invention, and

Figure 6 shows a Mach-Zehnder interferometer produced using the circuit according to the invention.

In the exemplary embodiment according to Figure 1, an insulating layer 2 composed of silicon oxide is located on a silicon substrate 1, with optical strip waveguides 3, 4 composed of silicon applied to this insulating layer 2. A photonic crystal 5, which is formed by a grid of needles 6, is located between the waveguides 3, 4.

In the exemplary embodiment, the needles 6 are located on the insulating layer 2, which has a cavity in the region of the photonic crystal 5. In consequence and as a result of the fact that the needles project beyond the upper boundary plane of the waveguides 3, 4, the photonic crystal also covers the area which continues in the edge regions beyond the waveguide.

The needles 6 can be produced in a manner known per se by Corpuscular beam deposition. A method relating to this is described, for example, in DE 195 33 148 A1.

As was shown in S.Y. Lin, G. Arjavalingam: Optics Letters, Vol. 18, No. 19, 1666 (1990) based on experiments with millimetric waves, even six periods of the grid with a grid constant of one third of the wavelength are sufficient to achieve an attenuation of 35 dB. Within the wavelength band which is attenuated in this way, deliberate disturbance points - that is to say the omission of needles - can be used to create wavelength bands with less attenuation. In the exemplary embodiment illustrated in Figures 1 and 2, light at a number of wavelengths is passed from the waveguide 3 to the waveguide 4, while light at a selected wavelength emerges at a splitting point 7. In this case, the selected intervals between the needles in the central region of the photonic crystal are intended only as examples of an accurate definition to ensure the filter characteristics to be achieved in each case.

In the exemplary embodiment shown in Figure 3, photonic crystals are provided not only for a filter but also for the feeder and outputs, in which case the feeder 11 and the outputs 12, 13 are in each case configured as all-pass filters, by not providing any needles in the central region.

Figure 4 shows an exemplary embodiment in which the needles 14 which form the photonic crystal are inclined. A covering layer 15 is applied in selected regions, so that light emerges there and is focused by lenses 16, which are fitted there and are preferably composed of polymer material, into inlet windows, which are not illustrated, in a level located above. Three-dimensional structures are thus possible, for example in a computer circuit. The lenses can in this case be produced in a known manner by electron-beam lithography or by using optical methods.

Figure 5 shows a detail from a circuit according to the invention, in which a plurality of splitting points 21 to 25 are formed by a photonic crystal 26, with a lens 27 to 31 focusing the light emerging from the splitting point onto inlet surfaces 32 to 36, which are arranged on further optical elements 37, 38 running alongside the photonic crystal 26.

Figure 6 shows an exemplary embodiment in the form of a Mach-Zehnder interferometer. In this case, all the elements, in particular waveguides, filters, mirrors and beam splitters, are formed by photonic crystals. The interferometer is intended to be used to measure the propagation time in a reflective measurement object 41, which is only indicated in Figure 6. For this purpose, the light which is supplied at 42 is first of all passed through an adjustable filter 43, which is used to select the wavelength to be used for the measurement. The light emerging from the filter 43 is passed straight on in equal parts, by using a beam splitter 44, to an adjustable phase shifter 45, and is reflected to the measurement object 41.

The adjustable filter 43 and the adjustable phase shifter 45 each comprise a photonic crystal, with the intermediate spaces being filled with non-linearly optical material, whose dielectric constant, and thus the optically effective intervals between the needles, can be controlled with the aid of voltages applied to electrodes 46, 47, and 48, 49, respectively.

The phase shifter 45 is followed by a completely reflective mirror 50, which supplies the light emerging from the phase shifter 45 to a further beam splitter 51.

A photonic crystal in the form of a directional filter 42 is arranged in front of the measurement object 41, resulting in the light which arrives from the beam splitter 44 being passed into the object 41, and the light reflected in the measurement object being passed via a waveguide 43 to the further beam splitter 51. The two light beams are superimposed at the output 54. The intensity emerging from the output 54 can be measured using a suitable measurement transducer, and the phase shift in the measurement object 41 is determined by varying the phase at 45 to produce minimum intensity at the output 54. For the reasons already mentioned above, the circuit illustrated in Figure 6 may also be designed to be extremely small, for example with an overall length of about 20 μm.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. Integrated optical circuit with a silicon substrate and thereon disposed waveguides having at least one photonic crystal, characterized in that elements, which are each formed by a needle or a hole 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, an insulating layer being disposed between the strip waveguides and the silicon substrate, and in 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.

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 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 stand on the insulating layer, which is less thick in the region of the photonic crystal than under the waveguides.

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.

8. Integrated optical circuit according to any one of the preceding claims, characterized 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.

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.

Dated this 12th day of September 2001

DEUTSCHE TELEKOM AG
By their Patent Attorneys
COLLISON & CO

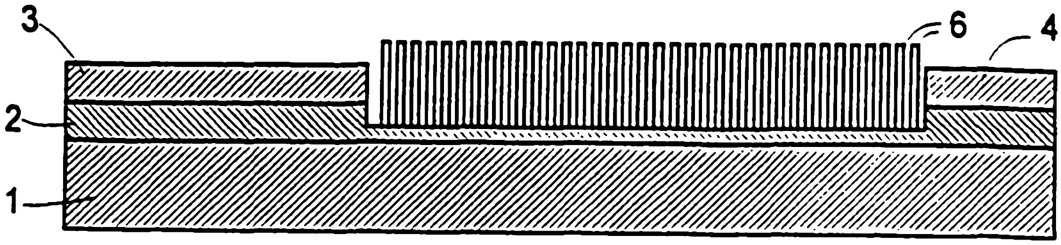


Fig.1

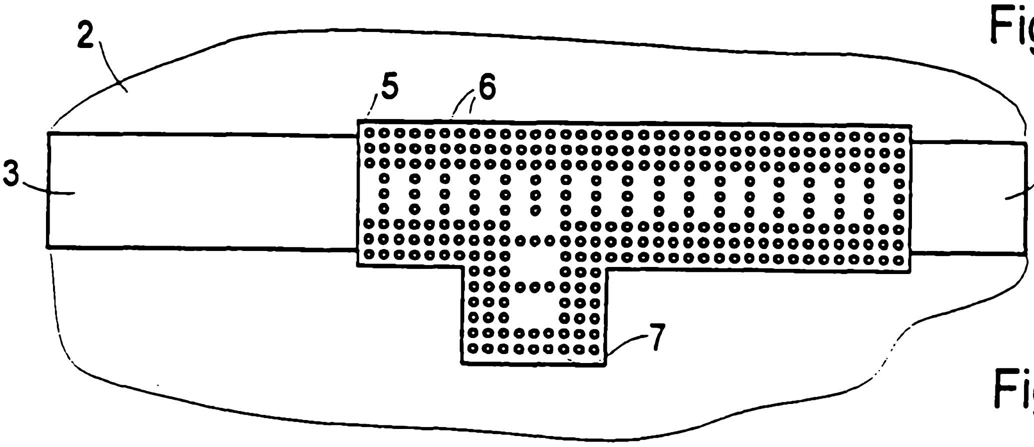


Fig.2

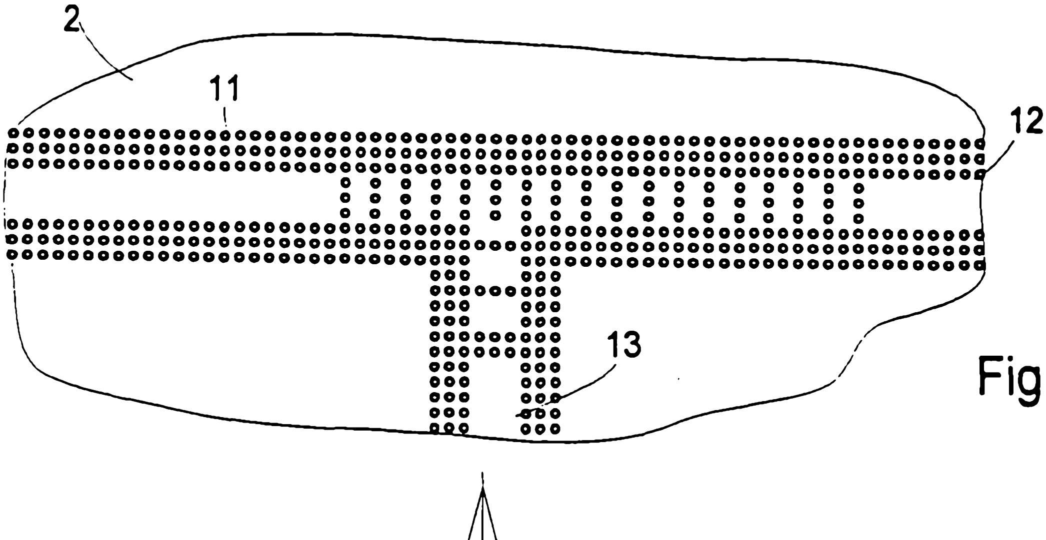


Fig.3

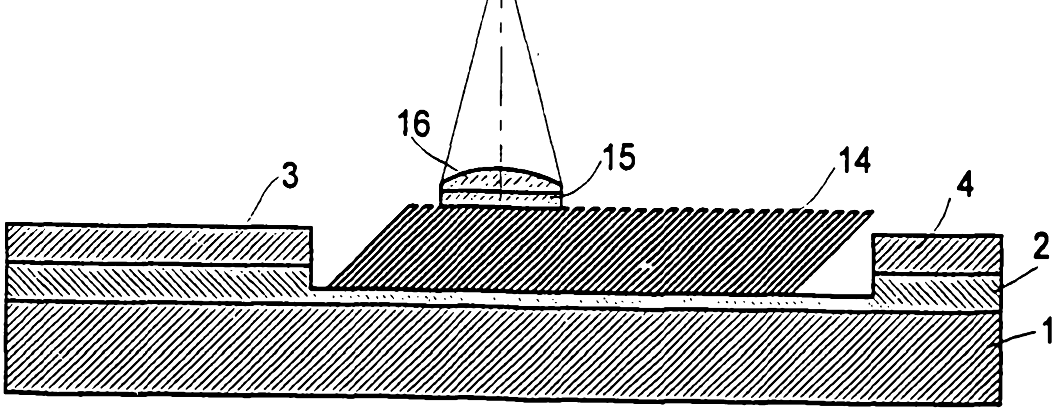


Fig.4

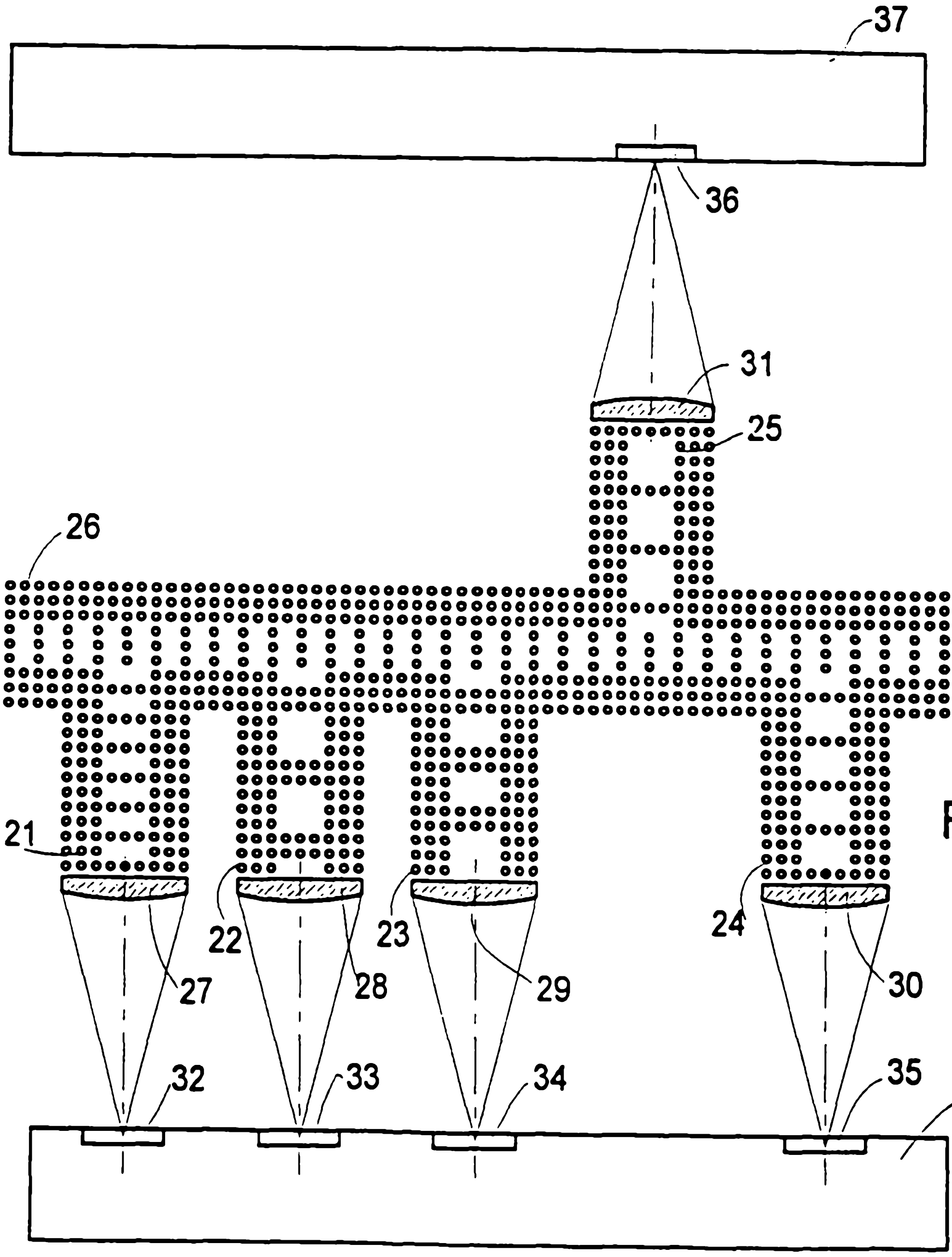


Fig.5

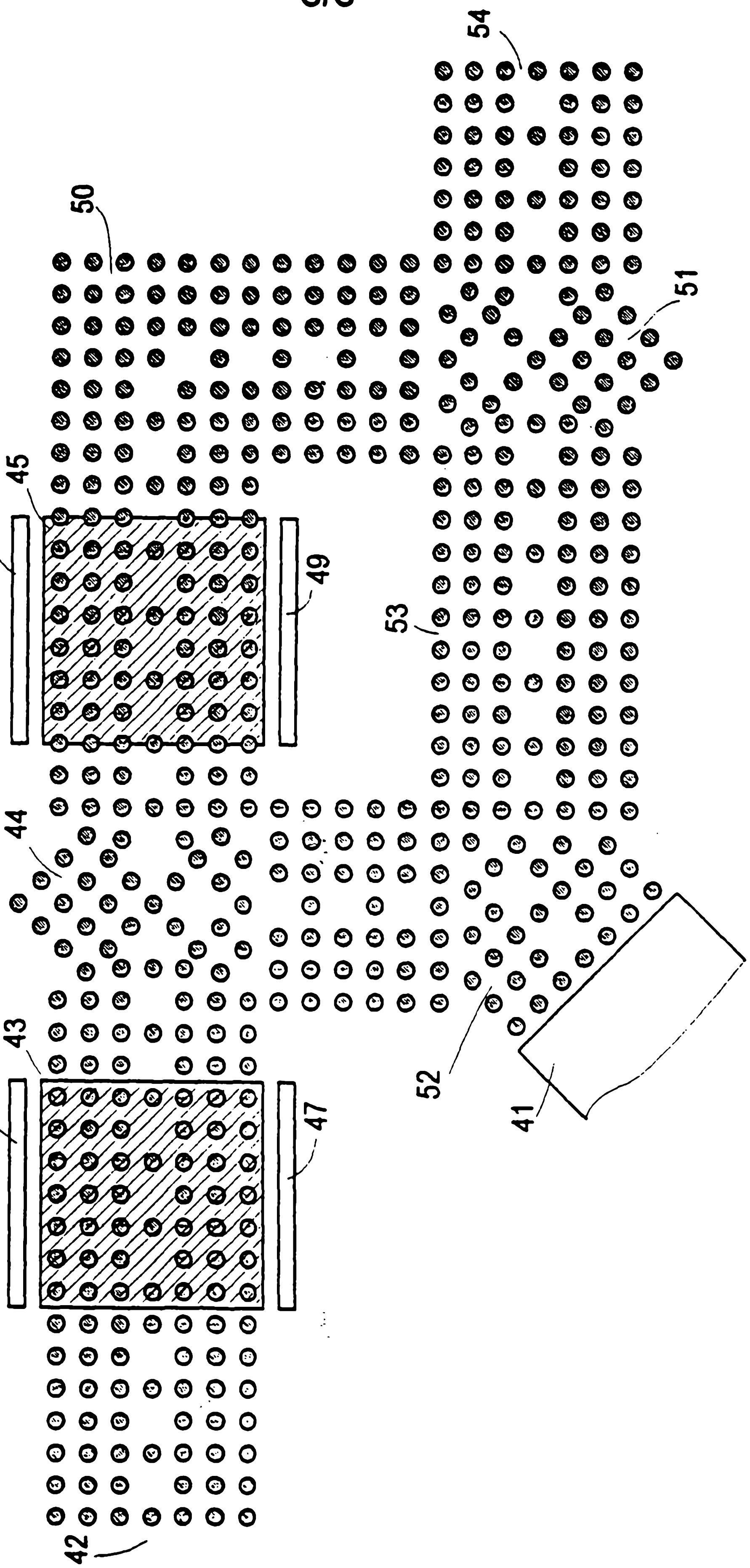


Fig.6