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# (54) Integrated semiconductor device including a heater for bringing about phase changes in microfluid systems

(57) An integrated device (40) forming a microfluid system includes a substrate (41) of semiconductor material and a lid element (56) forming a channel (55) filled with a liquid. A heating element (51) is carried by the substrate and faces the channel so as to heat the liquid and generate a gas bubble, when activated. The substrate (41) houses a cavity (42) arranged on the opposite side of the heating element (51; 66) with respect to the channel (55) in order to reduce thermal dispersion of the heating element (51) towards the substrate (41). The heating element includes a resistive region (45) coated, on the side facing the channel (55), by a protective region (49, 50) and, on the side facing the cavity (42), by an insulating layer (44).

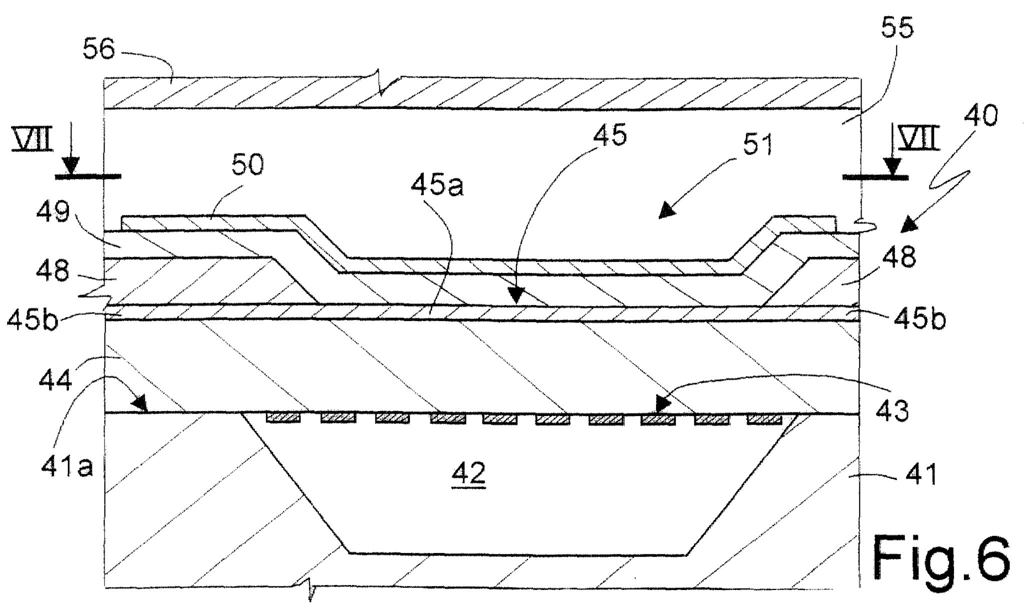


Fig.6

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## Description

[0001] The present invention regards an integrated device including a high-efficiency heater for bringing about phase changes in micro fluid systems.

[0002] Recently, optical-switching devices have been developed that use the variations in the optical properties of substances in the liquid phase or vapour phase for controlling passage of a light beam, for example a laser beam, along an light guide.

[0003] Figure 1 shows a known semiconductor optical device including a first waveguide 2 and a second waveguide 3, which are perpendicular to one another and intersect in an intersection area 4. In the intersection point, a deflection structure 7 is arranged, formed by a channel or slit 8, extending at an oblique angle with respect to both waveguides 2, 3, for example at an angle of 45°, and accommodating a liquid having, under normal conditions, optical properties similar to those of the waveguides 2, 3. A heater 10 (Figure 2) is formed underneath the channel 8, at the intersection area 4, and is controlled by a special circuit (symbolically represented in Figure 2 by a current source 11 and an electrical switch 12) so as to generate heat by Joule effect.

[0004] When activated, the heater 10 causes heating of the liquid 9 and formation of a gas bubble 15. Since the gas bubble has a refractive index different from that of the liquid 9 and of the waveguides 2, 3, it causes reflection, and hence deflection, of the light ray with respect to the direction of the incident rays. Consequently, as shown in Figure 1 by solid lines, in presence of the gas bubble 15, the incident light ray 16 is deflected by the first waveguide 2 towards the second waveguide 3. Instead, if the gas bubble 15 is absent, as shown in Figure 1 by dashed lines, the path of the incident light ray 16 proceeds along the first waveguide 2.

[0005] The heater 10 is generally made in the way shown in Figure 3, in which a substrate 20 of semiconductor material, for example monocrystalline silicon, is coated with an electrically insulating layer 21, for example of silicon dioxide, on which the heater 10, of resistive material (such as TaAl) is laid out. Electrical contact of the heater 10 is provided by conductive regions 22, for example of aluminium, and the heater is preferably coated with a passivation layer (not shown) . The channel 8 extends on top of the heater 10 and is closed upwardly by a body 23, formed, for example, in a different wafer.

[0006] In the optical switching device 1 of Figure 1 the problem exists that thermal dissipation of the heater 10 towards the substrate 20 reduces the efficiency of the device 1. This is particularly disadvantageous when it is necessary to maintain a gas bubble for a very long period of time. In addition, an excessive thermal dispersion prevents, in certain cases, integration of the electronic control circuitry within the chip on account of the risk of damage to the electronic components.

[0007] The same type of problem afflicts other devices that use the transition from the liquid to the gas phase (and/or vice versa), such as devices based on ink-jet technology and pumps for moving fluids in channels, with or without deflection or blocking of the fluid.

[0008] For example, Figure 4 shows a pump 24 for feeding microfluids, which includes a substrate 25 on top of which there extends a channel 26. In the channel 26, above the substrate 25, is formed a plurality of heaters 27, each of which is activated by a respective control circuit including a current source 28 and a switch 29.

[0009] By activating in sequence the three heaters 27 so as to generate gas bubbles of dimensions which may vary in time and at every instant have different dimensions from the adjacent bubbles, it is possible to cause the liquid to advance in a preset direction of the channel 26. Figure 4 shows, as an example, a sequence that causes the liquid to move towards the right.

[0010] Figure 5 is a top plan view of a device for moving liquids provided with a deviating switch 29. Here a channel 30 divides into two branches 31. Each branch 31 has a heater 32 activated by a respective control circuit which includes a current source 33 and a switch 34. By activating alternatively only one of the two switches 34, a gas bubble 35 is generated in a single branch (for instance, the bottom one, which is thus blocked) . The liquid can thus flow only in the uninterrupted branch (the top one, in Figure 5). A simplified device may include a single branch 31, which is opened or closed according to whether a gas bubble 35 is absent or present, so as to form an ON/OFF switch.

[0011] In all the applications described above it is necessary to reduce heat dispersion towards the substrate for maintaining a gas bubble for a long time and/or for energy saving.

[0012] The aim of the present invention is therefore to provide a semiconductor device including a heater, which is more efficient than known devices.

[0013] According to the present invention, an integrated device is provided, as defined in Claim 1.

[0014] For a better understanding of the present invention, two preferred embodiments thereof will now be described, purely as non-limiting examples, with reference to the attached drawings, wherein:

- Figure 1 is a top view of a known optical switching device;
- Figure 2 is a simplified cross-section of the optical switching device of Figure 1;
- Figure 3 shows a more detailed cross-section of the optical switching device of Figure 1;
- Figure 4 presents a cross-section through an integrated pump for moving fluids that uses the integrated heater;
- Figure 5 shows a cross-section through an integrated device for switching fluids that uses an integrated heater;
- Figure 6 shows a cross-section through a first embodiment of the integrated device according to the invention;

- Figure 7 shows a horizontal section, with layers removed for clarity, of the integrated device of Figure 6;
- Figure 8 shows a cross-section through a second embodiment of the present device; and
- Figure 9 shows a horizontal section, with layers removed for clarity, of the integrated device of Figure 8.

**[0015]** Figures 6 and 7 show an integrated device 40 including a high-efficiency heater 51, usable in a semiconductor optical device 1 of the type illustrated Figure 1, in a microfluid-feed pump 4, of the type shown in Figure 4, or in a deviating switch 29, of the type shown in Figure 5, and, generically, in any device that uses the ink-jet technology and in which the phase transition of a liquid is controlled.

**[0016]** The integrated device 40 comprises a substrate 41, preferably of monocrystalline silicon, that houses a cavity 42 overlaid by a grid 43, also of silicon. The cavity 42 advantageously has a depth of 5-10 mm and an area (at its maximum extension) of, for example, 70 x 30 $mm^2$. The cavity 42 may be filled with gas, for example a process gas (nitrogen). Alternatively, it may be filled with a thermally insulating material, air, or the fluid itself that is used in the microfluid device.

**[0017]** The substrate 41 has a top surface 41a covered by an insulating layer 44, for example of silicon dioxide, for thermal and electrical insulation. The insulating layer 44 closes the cavity 42 upwardly, and preferably has a thickness of 3-4 mm.

**[0018]** A resistive region 45 extends on top of the insulating layer 44, vertically aligned with the cavity 42; the resistive region 45 is preferably of refractory material, for example of a tantalum/aluminium alloy, and has an elongated shape. The resistive region 45 has a thickness of, for instance, 60-100 nm, preferably 80 nm, and comprises a central portion 45a and two end portions 45b. The central portion 45a, overlying the cavity 42, has a smaller width (Figure 7), for example 7-11 mm, preferably 9 mm, while the end portions 45b have a greater width. The central portion 45a of the resistive region 45 has a length of, for example, 40-80 mm, preferably 60 mm.

**[0019]** Conductive regions 48 extend on top of the end portions 45b to enable electrical connection. The conductive regions 48 are preferably of an aluminium/copper alloy and have a thickness of, for instance, 0.5 mm.

**[0020]** A first and a second protective layers 49, 50 (not shown in the section of Figure 7) extend on top of the conductive regions 48 and of the central portion 45a. Preferably, the first protective layer 49 is made of silicon nitride and has a thickness of approximately 200-300 nm, while the second protective layer 50 is made of silicon carbide and has a thickness of 100-150 nm.

**[0021]** A channel 55 is formed above the protective layers 49, 50 for passing or accommodating the liquid, the phase change of which -in particular, the formation of a gas bubble- is to be controlled. The channel 55 is closed at the top by a lid 56, for example of monocrystalline silicon formed in a different wafer or of glass and bonded to the substrate 41.

**[0022]** In practice, the ensemble comprising the resistive region 45, the conductive regions 48, and the protective regions 49, 50 forms a heater 51, a first side of which, the top side, directly faces the channel 55, and a second side of which faces towards the cavity 42 and is separated from the latter by the insulating layer 44.

**[0023]** The integrated device 40 of Figures 6 and 7 is formed as described hereinafter. Initially, a cavity 42 is formed in the substrate 41 by performing an isotropic etch using a grid-shaped mask above the area where the cavity 42 is to be formed, in a per se known manner. Then, the insulating layer 44 is thermally grown and/or deposited; a tantalum/aluminium alloy layer is deposited and then defined to obtain the resistive region 45; an aluminium layer is deposited and defined to form the conductive regions 48; and two layers, one of silicon nitride and one of silicon carbide, are deposited and defined (either together or separately) to form, respectively, the protective layers 49, 50. Finally, the wafer that forms the lid 56 and already contains the channel 55 is bonded in place.

**[0024]** The presence of the cavity 42 beneath the heater 51 considerably increases the thermal insulation of the heater 51 towards the substrate 40, and hence reduces the power required for generating a gas bubble. This reduction is particularly advantageous when the liquid is to be kept at a controlled temperature to obtain good reproducibility of the process of forming the gas bubble. In this case, in fact, it is advantageous for the power required for generating the gas bubble to be negligible as compared to the thermostatting power.

**[0025]** The integrated device 40 moreover reduces the overall dimensions as compared to known devices. In fact, the reduction in the dissipation towards the substrate and hence in heating of the substrate allows integration in one and the same chip both of the microfluid device (whether of the optical type, or based on ink-jet technology, or for movement and/or switching of fluids) and of the electronic control circuit of the resistive region 45, as well as possible electronic control circuitry for controlling the integrated device as a whole.

**[0026]** The heater may be of any material compatible with current manufacturing processes used in microelectronics, in so far as it requires a smaller current density and improves resistance to electromigration phenomena.

**[0027]** The integrated device according to the invention moreover allows a completely suspended heater to be formed, as shown, for example, in Figure 8.

**[0028]** Figures 8 and 9 show an integrated device 60 having a main channel 61 from which three deflection channels 62, 63, 64 extend, which may be intercepted through three heaters 66 which are identical to one another and extend at right angles to the main channel 61.

**[0029]** In detail, the integrated device 60 comprises a substrate 67 accommodating a cavity 68 which communicates with the main channel 61. The heaters 66 extend at right angles to the plane of the drawing and comprise a resistive region 70, for example of a tantalum/aluminium alloy, overlaid with a protective region 71, which, analogously to Figure 6, may be of a silicon nitride-silicon carbide double layer. An insulating layer 73 extends underneath the resistive region 70 of each heater 66, as well as on top of the substrate 67, and covers the surface 67a of the substrate 67 outside the cavity 68. Conductive regions 74 (visible only in Figure 9) are formed on top of the ends of the resistive regions 70 for electrical connection, as for the conductive regions 48 of Figure 6.

**[0030]** The main channel 61 is closed at the top by a lid 75 in which the deflection channels 62-64 are formed. The deflection channels 62-64 face towards the heaters 66 so that, when the heaters are activated, they generate gas bubbles such as to obstruct passage of the liquid towards the corresponding deflection channel 62-64. This process is illustrated in Figure 8, in which the heaters 66 facing towards the deflection channels 62 and 63 are activated and have caused generation of two gas bubbles 80, which surround the heaters 66 and obstruct the inlets of the deflection channels 62 and 63. The heater 66 facing the deflection channel 64 is, instead, inactive and allows passage of the liquid towards the corresponding deflection channel 64. If necessary, the integrated device 60 may be provided with a heater arranged downstream of the inlet area of the deflection channels 62-64 and formed as shown in Figure 6, and thus having a cavity 42 for intercepting the flow of liquid along the main channel 61, after deflection.

**[0031]** Thereby, the heaters 66 are suspended and completely surrounded by a gas bubble, when activated, thus minimizing heat dispersion.

**[0032]** The integrated device 60 is made similarly to the integrated device 40 of Figure 6, except for the fact that the insulating layer 73 is removed from above the cavity 68. To this aim, the insulating layer 73 may be made before forming the cavity 68 and may be defined using the same etching mask used for the cavity 68. Alternatively, the cavity 68 is formed in the same way as described for the cavity 42 of Figure 6 using a grid mask, and the insulating layer 73 is made subsequently and defined using a special mask.

**[0033]** Finally, it is clear that numerous variations and modifications may be made to the device described and illustrated herein, all of which fall within the scope of the invention as defined in the attached claims. In particular, it is pointed out that the heaters 51 or 66 may extend parallel or perpendicular to the channel 55 or 61 filled with liquid, according to which arrangement is more convenient. The material for the heater may be chosen as desired, compatibly with its function, and the fabrication process may vary with respect to the one described herein.

**Claims**

1. An integrated device (40; 60) comprising:

   a body (41, 56; 67, 75) at least partially of semiconductor material;
   a heating element (51; 66) in said body, said heating element having a first and a second side;
   a first channel (55; 61) extending in said body (41, 56; 67, 75), said first channel facing towards said first side of said heating element (51; 66) and containing a liquid;

   **characterized in that** said body (41, 56; 67, 75) houses a cavity (42; 68) facing towards said second side of said heating element (51; 66).

2. An integrated device according to Claim 1, **characterized in that** said body comprises a substrate (41; 67) of semiconductor material having a surface (41a; 67a) and housing said cavity (42; 68), and a lid element (56; 75) forming said first channel (55; 61) and facing towards said surface.

3. An integrated device according to Claim 2, **characterized in that** said heating element (51; 66) comprises a resistive region (45; 70) having a first side facing towards said first channel (55; 61), and a second side facing towards said cavity (42; 68), said resistive region (45; 70) including a central portion (45a) and two end portions (45b), said central portion (45a) extending above said cavity (42; 68), and said end portions (45b) being carried by said substrate (41; 67).

4. An integrated device according to Claim 3, **characterized in that** said central portion (45a) of said resistive region (45; 70) has a smaller width than said end portions (45b).

5. An integrated device according to Claim 3 or 4, **characterized in that** said central portion (45a) of said resistive region (45; 70) has a smaller width than said cavity (42; 68).

6. An integrated device according to any of Claims 3-5, **characterized in that** said resistive region (45; 70) is made of a tantalum/aluminium alloy.

7. An integrated device according to any of Claims 3-6, **characterized by** an insulating layer (44; 73) extending along said second side of said resistive region (45; 70).

8. An integrated device according to Claim 7, **characterized in that** said insulating layer (44) extends on top of said surface (41a) of said substrate (41) and

closes said cavity (42) at the top.

**9.** An integrated device according to Claim 7, **characterized in that** said insulating layer (73) extends on top of said surface (67a) at the sides of said cavity (68), and said cavity directly faces said first channel (61).

**10.** An integrated device according to any of Claims 3-9, **characterized by** a protective region (49, 50; 71) covering said first side of said resistive region (45; 70).

**11.** An integrated device according to Claim 10, **characterized in that** said protective region (49, 50; 71) comprises a silicon nitride-silicon carbide double layer.

**12.** An integrated device according to any of the foregoing claims, **characterized in that** said heater (51) extends parallel to said first channel (55).

**13.** An integrated device according to any of the foregoing claims, **characterized in that** said heater (66) extends transversely with respect to said first channel (61).

**14.** An integrated device according to any of the foregoing claims, **characterized in that** said cavity (42; 68) is filled with a material chosen from among air, nitrogen atmosphere, and liquid.

**15.** An integrated device according to any of the foregoing Claims, **characterized in that** said heating element (66) is suspended between said first channel (61) and said cavity (68).

**16.** An integrated device according to any of Claims 1-14, **characterized by** a supporting layer (44; 73) extending between said heating element (51; 66) and said cavity (42; 68).

**17.** An integrated device according to any of Claims 2-16, **characterized in that** said lid element (75) houses at least one second channel (62-64) which leads into said first channel (61), and **in that** said heating element (66) faces said second channel (62-64).

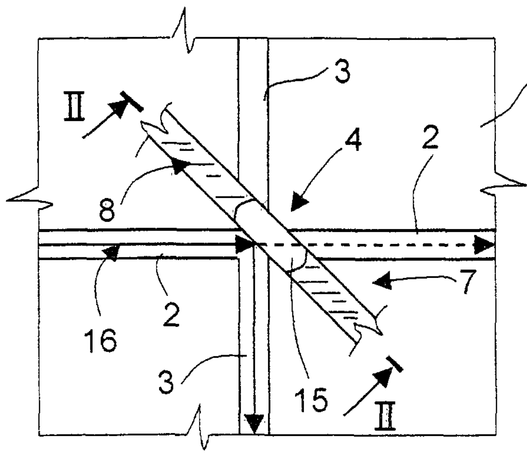


Fig.1

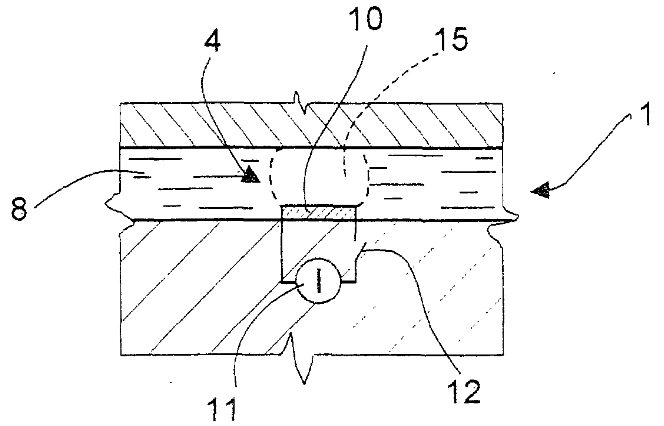


Fig.2

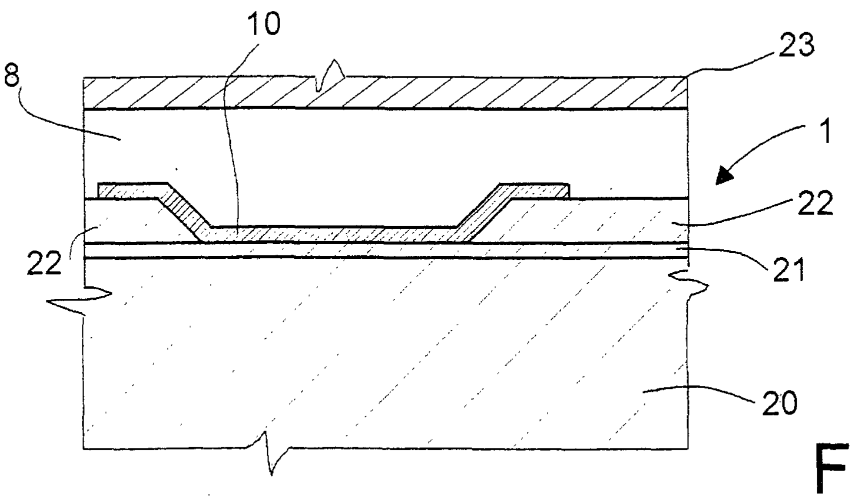


Fig.3

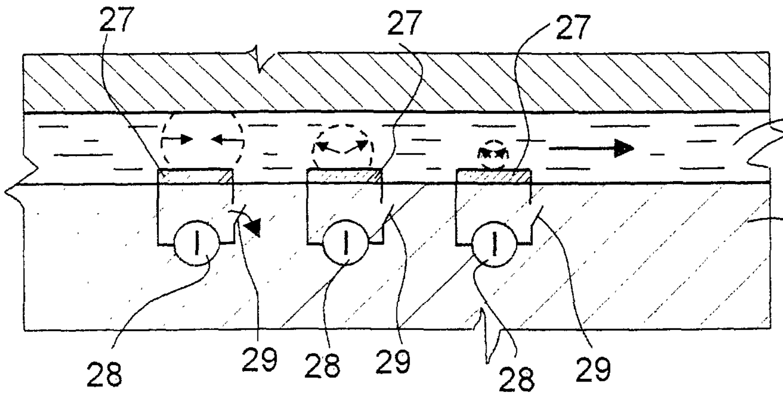


Fig.4

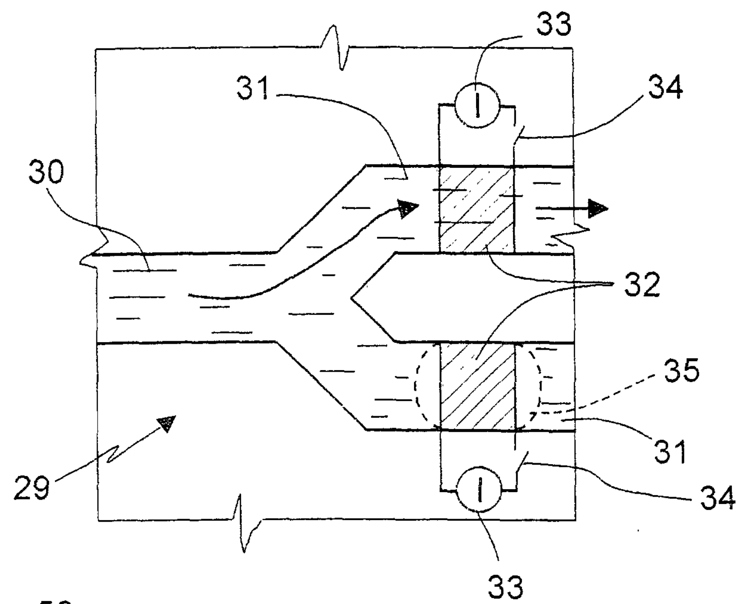


Fig.5

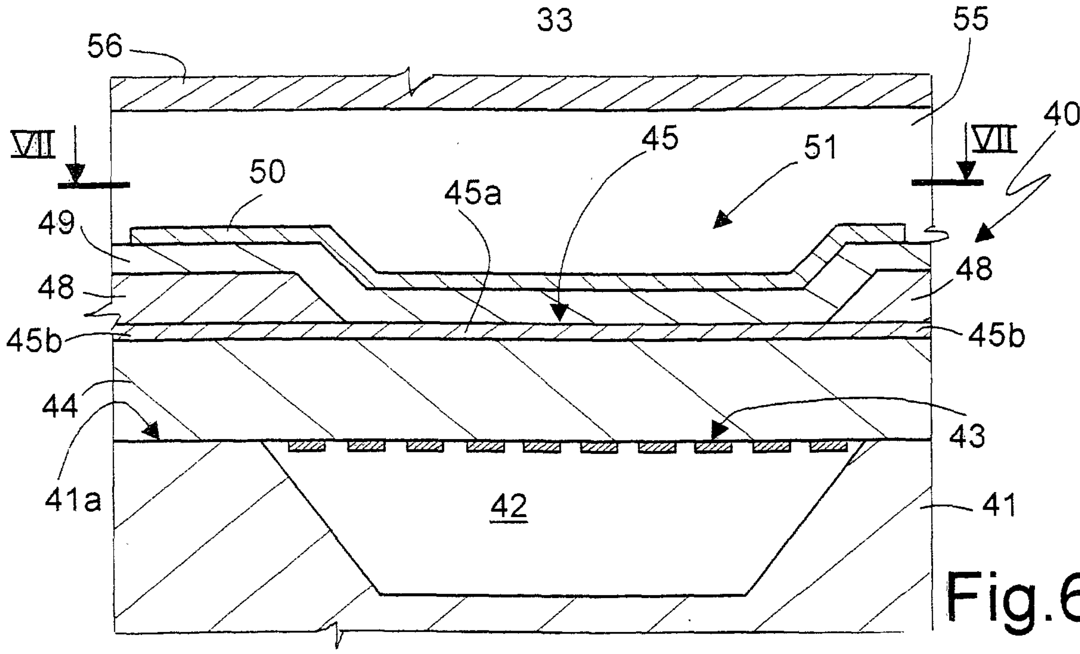


Fig.6

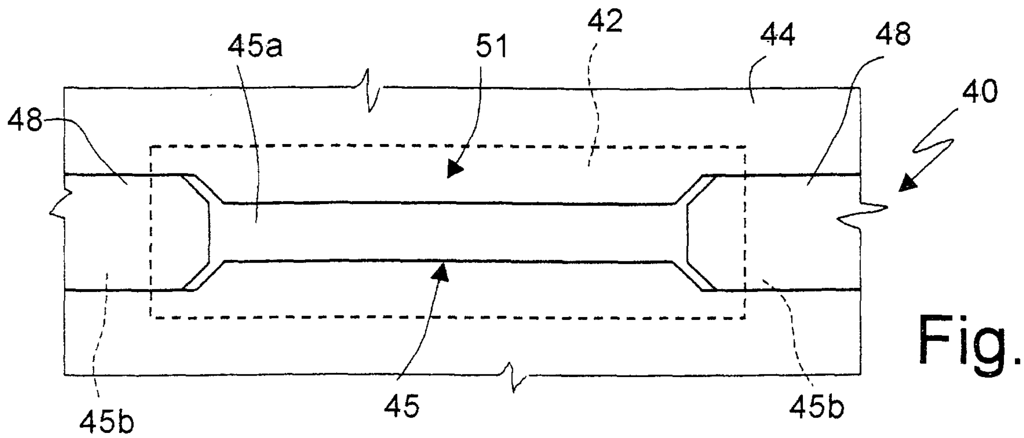


Fig.7

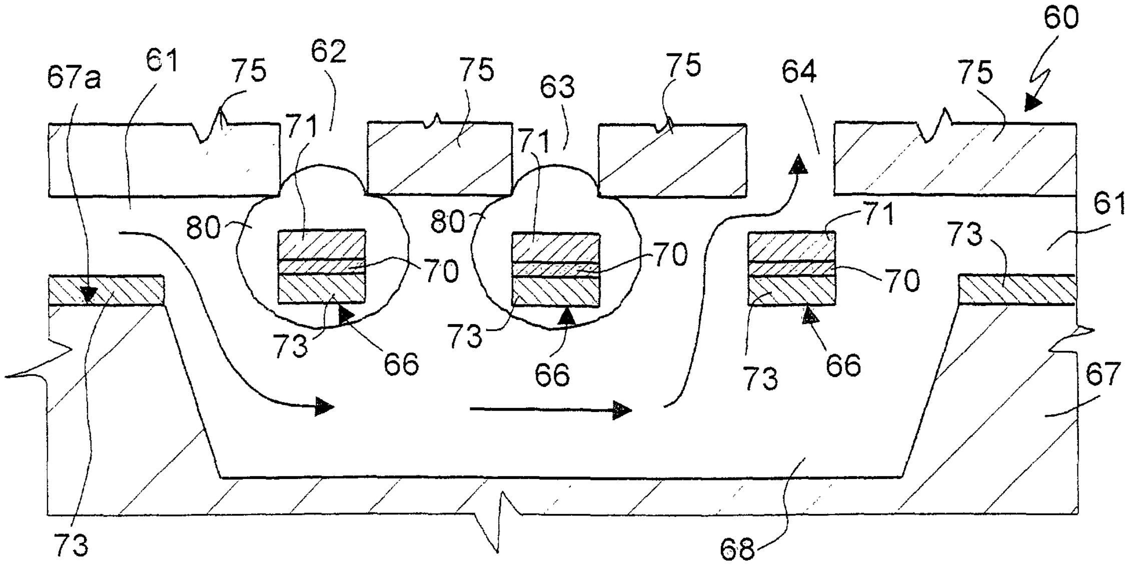


Fig.8

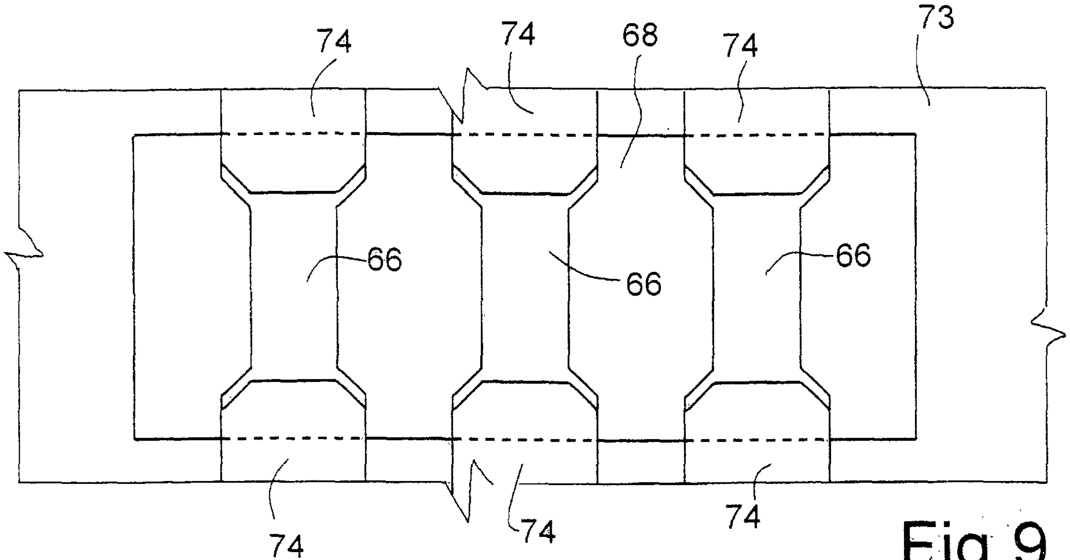


Fig.9

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Application Number
EP 00 83 0536

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The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 6 December 2000 | Bardet, M |

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