

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
28 July 2011 (28.07.2011)

(10) International Publication Number
WO 2011/089398 A2

PCT

(51) International Patent Classification:
H01L 27/146 (2006.01)

(21) International Application Number:
PCT/GB2011/000081

(22) International Filing Date:
21 January 2011 (21.01.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1001029.6 22 January 2010 (22.01.2010) GB

(71) Applicant (for all designated States except US): **THE SECRETARY OF STATE FOR DEFENCE** [GB/GB]; Whitehall, London SW1A 2HB (GB).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **SMITH, Graham, Whale** [GB/GB]; AWE, Aldermaston, Reading, Berkshire RG7 4PR (GB).

(74) Agent: **LUETCHFORD, Richard, Barrie**; DIPR Formalities, Oak 2E#6228, Abbey Wood (North), Bristol BS34 8JH (GB).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

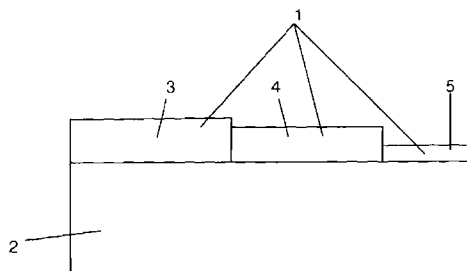
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) Title: IMPROVED EPITAXIAL LAYER

Figure 2



(57) Abstract: An epitaxial layer (1) comprising at least two different thicknesses in which a first thickness (3) is configured to detect a first frequency range of incident photons and a second thickness (4) is configured to detect a second frequency range of incident photons, which are converted by related apparatus into images. This allows a user to use different light sources from two or more different images of the same article, without having to change the equipment the epitaxial layer is a part of. Also an epitaxial layer of continuous thickness (11) is disclosed which is configured to detect at least two frequency ranges of photons allowing images comprising electrons/ photoelectrons in at least the same two frequency ranges to be constructed.

WO 2011/089398 A2

Improved epitaxial layer

The invention relates to the configuration and manufacture of an epitaxial layer. Such a layer may be used in conjunction with a suitable substrate which typically incorporates one or more charge coupled delay line(s), and is of particular use in semiconductor devices such as charged couple devices (CCD's) or metal oxide/ complementary metal oxide semiconductors (MOS/ CMOS respectively), photo diodes, charge injection devices (CID), amorphous silicon devices, bipolar devices as well as devices suited for use in the infra-red range, and thus is suited to a large range of articles which make use of such elements ranging from digital cameras and optical mice to x-ray detectors and many more besides.

Epitaxy is a known process in which one or more layers or films of single-crystal material are formed and may be deposited on single-crystal substrate(s), and are grown from gaseous or liquid precursors. The skilled reader will note the present invention is equally applicable to other thin layer or film deposition methods which deposit polycrystalline or amorphous film(s) even on single-crystal substrates, including but not limited to homoepitaxy and heteroepitaxy.

An epitaxial layer is typically (but not necessarily) supported by an appropriate substrate, and when part of a photoelectrically sensitive device traps incident light or photons which are converted by related apparatus in to electrons and/ or photoelectrons.

The epitaxial layer is typically modified to suit the subject matter being assessed as different thicknesses and/ or materials absorb different frequencies of electrons and/ or photoelectrons. It is known that incoming electrons and/ or photoelectrons at specific wavelengths are absorbed across a wide range of electron volts at particular absorption

depths, such that for example at an absorption depth of circa 10 μ m of silicon both visible light as well as soft x-rays in the 1keV region can be detected. It is acknowledged there are known methods of illuminating the rear or back side of certain types of CCD's which have a chemically etched substrate to enable photon detection to be realisable at shorter wavelengths in the uv and soft x-ray regions by removing attenuation caused by transfer electrodes.

According to a first aspect of the invention there is provided an epitaxial layer comprising at least two different thicknesses in which a first thickness is configured to detect a first frequency range of incident photons and a second thickness is configured to detect a second frequency range of incident photons.

Optionally at least one of the first and second thicknesses is configured to detect photons in the visible range. This allows for the precise alignment of related apparatus such as x-ray tubes, and for system testing using simple conventional light sources as opposed to requiring a user to set up specific types of equipment to produce photon sources which can be expensive or time consuming to arrange.

Optionally at least one of the first and second thicknesses is configured to detect photons in the x-ray range. This furthers the utility to the user as x-rays are common applications requiring epitaxial elements.

Optionally as an alternative to the detection of photons in the x-ray range, at least one of the first and second thicknesses is configured to detect photons in the ultra-violet range. This again furthers the utility to the user who can then analyse subjects using ultra-violet photons which can be used for example for fluorescence analyses, or to show surface

defects and changes that visible light and the x-ray range do not. Alternatively a third thickness of epitaxial layer can be used to detect ultra-violet photons. In practice any number of thicknesses may be used to detect any combination of photons that may be desirable to the user.

Optionally different thicknesses of the epitaxial layer are aligned to adjacent or alternative pixels on a receiving sensor. This allows a user to obtain coherent images, potentially even simultaneously, of a scene of interest, in at least two different frequency resolutions without having had to prepare the same subject twice with different photon sources and different receiving capabilities, greatly reducing the time and cost of analysis.

According to a second aspect the invention provides an epitaxial layer of continuous thickness is configured to detect at least two frequency ranges of photons allowing images comprising electrons/ photoelectrons in at least the same two frequency ranges to be constructed.

When used in conjunction with related apparatus which can convert both frequency ranges of photons in to electrons and/ or photoelectrons, a user can have a complete composite picture of the same subject in two different frequency ranges. This is possible because the same depth of particular materials can absorb a plurality of wavelengths, thus an epitaxial layer of only one thickness can be used to detect multiple types of incoming photon. An example of such a material is silicon however any material that performs such a function may be used.

Optionally for the first and second aspects of the invention a plurality of doping levels are used to achieve required photon detection depths. This allows for even greater utility for a user who can have more than one doping level corresponding to even the same thickness epitaxial layer, as well as one or more doping level per thickness of epitaxial layer.

Optionally for the first and second aspects of the invention a plurality of materials are used to form the epitaxial layer to achieve required photon detection depths. These different materials may be selected to allow for different light absorption depths, further increasing the utility to the user.

Optionally for the first and second aspects of the invention a CCD, CMOS, CID or a complete optical sensing system comprising an epitaxial layer according to the invention is provided, for ease of use by the user.

Optionally there is provided a method of aligning a related device comprising an epitaxial layer as herein described which in use different thicknesses of the epitaxial layer are aligned to predetermined pixels on a receiving sensor. This provides great utility to a user in that subject matter can be aligned using perhaps, visible light, as opposed to having to use photons from different, perhaps expensive sources.

Methods of manufacturing an epitaxial layer in accordance with the invention are also disclosed in embodiments herein described.

The present invention will now be described, by way of example only, with reference to the following figures in which:

Figure 1 shows a side view of a conventional epitaxial layer.

Figure 2 shows a side view of an epitaxial layer in accordance with a first aspect of the invention.

Figure 3 shows an overhead view of an embodiment of the invention allowing for alignment of related apparatus.

Figure 4 shows an overhead view of an embodiment of the invention allowing for alignment of different thicknesses of the epitaxial layer with specified pixels.

Figure 5 shows an overhead view of an embodiment of the invention which yields a graduated epitaxial layer.

Figure 6 shows a single epitaxial layer of continuous or reasonably continuous thickness being used in accordance with a second aspect of the invention.

In the figures like elements are denoted by like reference numerals.

Figure 1 shows a conventional epitaxial layer 1 which, if it were for example silicon, may be around 20 μm thick providing a bulk resistivity of 20 $\Omega\text{ cm}$. This is grown on a substrate 2 around 625 μm thick providing a bulk resistivity of 0.01 $\Omega\text{ cm}$. Such a substrate can be chemically etched to allow ultra-violet or x-ray detection in conjunction with a rear or backside illumination device (not shown). Classic CCD, CMOS or CID based imaging devices can be fabricated by a precise tuning of the thickness of the epitaxial layer 1 to, for example, detect and image x-rays. CCD based dental x-ray imagers are based on this

principle. The substrate can be made from a material suited to the particular application a user requires, in this example silicon has been selected, in other applications quartz, optical glass, gold, or gallium arsenide are suited, as may be germanium. Tungsten/graphite substrates are also applicable having applications in the solar-cell field.

As it is known that incoming photons/ photoelectrons at specific wavelengths are detected (whether wholly or partially within an epitaxial layer) across a wide range of electron volts at particular absorption depths, the embodiment of the invention shown in figure 2 makes use of a plurality of different thicknesses of the epitaxial layer 1 irrespective of the substrate 2 that is used. Indeed it may be the case that the epitaxial layer may be used without a substrate at all.

There are two principal methods of manufacturing such an epitaxial layer 1.

The first is to mask an area of the substrate 2 when forming an epitaxial layer 1, such that an epitaxial layer of a first thickness 3 is formed on only one part of the substrate 2 with the remainder of the substrate 2 having no epitaxial layer. Then a further area of the substrate 2 is left unmasked while the first thickness 3 is also masked. This allows for growth of a second thickness of the epitaxial layer 4. Then both the first thickness 3 and second thickness 4 are masked, and a further thickness of the epitaxial layer 5 is grown.

This method lends itself well to using different materials for each respective layer as they are isolated from each other.

The skilled person will appreciate that a similar effect in appearance (but potentially greatly differing in application) could be produced by using multiple different types of growth from

different precursors in a hybrid form of heterotopotaxy. The skilled person will also appreciate that if an epitaxial layer had already been formed, one or more portions could be removed resulting in one or more different thicknesses. Such removal could be effected by a variety of methods, in one embodiment of the invention this is by chemical etching of the epitaxial layer, in another embodiment by the physical removal of one or more portion(s) of the epitaxial layer by mechanical devices such as by grinding or using cutting methods.

The second principal method of manufacturing such an epitaxial layer 1 is shown as part of figure 5 in an embodiment of the invention that lends itself well to a "graduated" epitaxial layer which may be used for example for x-ray analysis. In this embodiment a first thickness epitaxial layer 8 is grown as a complete layer extending across the whole substrate at a desired thickness. Then when this has grown, a portion of the first thickness epitaxial layer 8 is masked, and a second thickness epitaxial layer 9 is grown as a layer on top of the first thickness epitaxial layer 8 aside from the masked portion of course to form a second thickness epitaxial layer 9, which is thus thicker than the first thickness epitaxial layer 8 which in this embodiment is used to detect higher levels of x-ray energy detection through that portion. Following this both the first thickness epitaxial layer 8 and a portion of the second thickness epitaxial layer 9 can be masked and a third thickness epitaxial layer 10 is grown, which being thicker than the second layer 9, allows for even higher levels of x-ray energy detection through that portion.

Further maskings of the thicknesses can take place to allow for further thickness growths as the user requires. The skilled reader will appreciate an alternative is for growth of each thickness in isolation (rather than this "layered" technique), as the user may require.

In a further embodiment of this second method, rather than having separate maskings and separate layered growth, a suitable inhibitor such as a die, a stamp or the like, is located above the growth during the growing process and typically one growth process takes place. Other embodiments are possible in which there are at least two growths. The inhibitor is constructed so as to deliberately limit growth in specified areas resulting in multiple different thicknesses of the epitaxial layer 1. This embodiment provides the advantage that only one growth phase occurs so there is no possibility of distortion between layers from finished surfaces once they are formed.

The skilled reader will appreciate photolithography will suit as a method of masking surfaces in these embodiments, which includes 3-dimensional printing.

The user could thus employ the invention for any application they require, such as using a first thickness of the epitaxial layer 3 which may be optimised for absorbing photons in the x-ray range and a second thickness of the epitaxial layer 4 optimised for absorbing photons in the ultra-violet range, and further thicknesses of the epitaxial layer 5 optimised for absorbing visible light. This is of particular use when subjects to be analysed are expensive or rare, or where ensuring any x-ray or ultra-violet assessment is critically “right first time”. This is the case when x-ray tubes are experimental in nature and it is only after the event that success is known. In such an example of employing the invention being able to use visible or ultra-violet photons for a “trial run” before revealing a sensitive or expensive subject to x-ray photons is hugely valuable, as is the case for example with cobalt, which is an expensive subject to prepare. Thus when a user can test their system using visible or ultra-violet photons before deploying x-rays on the subject itself, they can have increased confidence that tests will yield the results they seek.

Having multiple thicknesses of an epitaxial layer 1 allows for many possibilities, such as when aligning optical imaging elements for particular applications. In several applications, for example, it is desirable to ensure a subject is precisely aligned with an x-ray tube, and certain materials may be adversely affected by repeated bombardment with x-rays, or as in the example above with cobalt which requires preparation of an expensive material, deploying the invention increases a users confidence their tests will be worthwhile.

Figure 3 shows that if one or more areas of the epitaxial layer 6 absorbed light in the visible spectrum alone (with other thicknesses of the epitaxial layer 7 suitable for x-ray receipt), it is possible to align a subject by directing only visible light at it in the first instance, ensuring that the known areas of the epitaxial layer 6 that react wholly to light in the visible spectrum are appropriately aligned with designated targets. Similarly both x-ray and ultra-violet photons can be used to do the same, or indeed to assess different parts of a subject using different frequencies of light.

Of particular use is the embodiment in which different thicknesses of an epitaxial layer are aligned with the alternative or adjacent pixels of a receiving optical device. This is possible because all receiving devices are divided into discrete units called pixels, and photons that are absorbed (fully or partially) by an epitaxial layer will be aligned with only one of these pixels. As such it is possible to determine the location of these, and configure an epitaxial layer in accordance with them. Doing so allows a user to obtain coherent images, simultaneously, of a scene of interest, in at least two different frequency resolutions, for example both in ultra-violet as well as x-ray ranges, by using both sources of photons either simultaneously or at separate times on the same subject. Having aligned the epitaxial layer with chosen pixels, in this embodiment an image comprising just ultra-violet or just x-ray photons can be constructed. Naturally the granularity of each individual image

is lower than if all pixels are used, however the utility of being able to take more than one image of the same subject in two different frequency resolutions outweighs this, and known software can be used to estimate the information required to create complete composite images should the user so require.

This effect can be achieved with any pattern or effect a user so desires depending on the nature of the subject they are assessing, where for example as shown in figure 4 a first thickness of the epitaxial layer 6 which reacts wholly to light in the visible spectrum alone is arranged such that it is aligned with individual pixels of related receiving apparatus, with other thicknesses of the epitaxial layer 7 suitable for x-ray receipt aligned with adjacent or alternate pixels of receiving apparatus (not shown) resulting in a "checkerboard" appearance. Alternatively pixels can form larger groups, such that at least one portion of the epitaxial layer is at one thickness, while the remainder comprises a plurality of thicknesses which may be immediately (but not necessarily) adjacent or alternative to each other.

In another embodiment a similar effect is achieved by not altering the physical thicknesses of the epitaxial layer 1, but by applying different levels of doping or by growing different types of crystal to form a multi-purpose epitaxial layer.

Using such an epitaxial layer 1 allows for the same precise optical/ x-ray imaging that can be achieved using a conventional imager (for example spatial linearity, ease of calibration and dynamic range), yet with far more utility to the user. The skilled person will appreciate the invention relates to every possible combination of building a complete optical sensing system, from providing the epitaxial layer 1 alone, to a sensor such as a CCD, CMOS or CID comprising an epitaxial layer 1 according to the invention, to complete enclosed off-

the-shelf sensing systems such as for example; optical oscilloscopes, streak camera tubes, image intensifiers, arrays, x-ray detectors and night-vision apparatus among others, all of which comprise an epitaxial layer 1 according to the invention.

A further embodiment of the invention combines both different physical thicknesses of the epitaxial layer 1 with different levels of doping (across different physical thicknesses of the epitaxial layer 1) or by growing different types of crystal on different physical thicknesses of the epitaxial layer 1.

According to the second aspect of the invention shown in figure 6 there is provided an epitaxial layer of continuous or reasonably continuous thickness 11 (which may or may not have a supporting substrate 12 of the material or materials the epitaxial layer is made from, and the users requirements and circumstances dictate) which is provided with at least two frequency ranges of photons allowing images comprising electrons/ photoelectrons in at least two frequency ranges to be constructed. Thus rather than using two or more thicknesses of epitaxial layer to absorb (wholly or partially) photons in at least two frequency ranges (which may thus overlap), the properties of a single epitaxial layer of continuous or reasonably continuous thickness 11 are exploited to achieve the same effect. This is as a result of the inherent properties of the material used for the epitaxial layer, which in this embodiment is silicon having an absorption depth of circa 10 μm , which absorbs wavelengths at both 1nm which is in the soft x-ray range and also at around 650nm which is in the visible range. Thus in this embodiment an epitaxial layer of continuous or reasonably continuous thickness 11 is required when used in conjunction with at least one source of x-ray photons 13 and at least one source of visible photons 14 both of which can be received by the epitaxial layer of continuous or reasonably continuous thickness 11 in the direction of arrows 15 generally indicated in Figure 6, to

allow conversion by known related apparatus (not shown) in to electrons and/ or photoelectrons. Thus as a result a user can have a complete composite picture of the same subject in two different frequency ranges. The skilled person will appreciate that the embodiments described should not be taken as limiting the scope of the invention. Further embodiments may make use of different materials for the epitaxial layer which exhibit properties similar to silicon but for different applications, the material being selected based on the frequency ranges a user is interested in.

Claims

1: An epitaxial layer comprising at least two different thicknesses in which a first thickness is configured to detect a first frequency range of incident photons and a second thickness is configured to detect a second frequency range of incident photons.

2: An epitaxial layer according to claim 1 in which at least one of the first and second thicknesses is configured to detect photons in the visible range.

3: An epitaxial layer according to claims 1 or 2 in which at least one of the first and second thicknesses is configured to detect photons in the x-ray range.

4: An epitaxial layer according to claims 1 or 2 in which at least one of the first and second thicknesses is configured to detect photons in the ultra-violet range.

5: An epitaxial layer according to any preceding claim in which different thicknesses are aligned to adjacent pixels on a receiving sensor.

6: An epitaxial layer according to any of claims 1- 4 in which different thicknesses are aligned to alternate pixels on a receiving sensor.

7: An epitaxial layer of continuous thickness is configured to detect at least two frequency ranges of photons allowing images comprising electrons/ photoelectrons in at least the same two frequency ranges to be constructed.

8: An epitaxial layer according to any preceding claim in which a plurality of doping levels are used to achieve required photon detection depths.

9: An epitaxial layer according to any preceding claim in which a plurality of materials are used to form the layer to achieve required photon detection depths.

10: A CCD comprising an epitaxial layer according to any preceding claim.

11: A CMOS comprising an epitaxial layer according to any of claims 1-9.

12: A CID comprising an epitaxial layer according to any of claims 1-9.

13: An optical sensing system comprising an epitaxial layer according to any of claims 1-9.

14: A method of aligning an optical device comprising an epitaxial layer according to any of claims 1- 9 which in use different thicknesses of the epitaxial layer are aligned to predetermined pixels on a receiving sensor.

15: A method of manufacturing an epitaxial layer according to any of claims 1- 9 comprising the steps of;

- masking an area of a subject substrate;
- growing a first epitaxial layer to a desired thickness on the unmasked substrate;
- masking the first epitaxial layer and growing a second epitaxial layer on the remainder of the substrate to a different thickness than the first epitaxial layer.

16: A method of manufacturing an epitaxial layer according to any of claims 1- 6 and claims 8 or 9 comprising the steps of;

- growing a first epitaxial layer to a desired thickness;
- masking one or more portions of the first epitaxial layer and growing a further epitaxial layer on the remainder of the first epitaxial layer to a different thickness.

17: A method of manufacturing an epitaxial layer according to any of claims 1- 6 and claims 8 or 9 comprising at least the steps of;

- taking an existing epitaxial layer;
- removing one or more portions of the epitaxial layer resulting in different thickness of the epitaxial layer.

18: A method of manufacturing an epitaxial layer according to any of claims 15, 16 or 17 in which a second epitaxial growth is formed using a different material to a first growth.

19: An epitaxial layer substantially as hereinbefore described with reference to the accompanying figures.

Figure 1

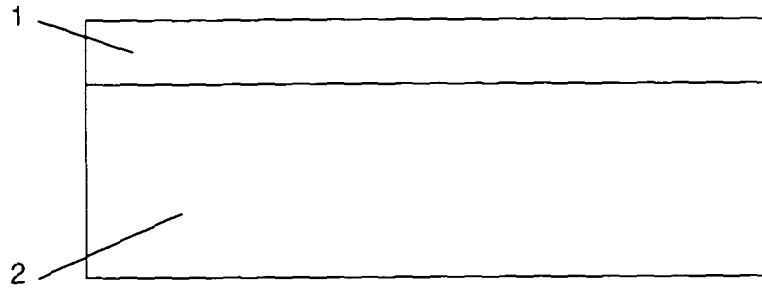


Figure 2

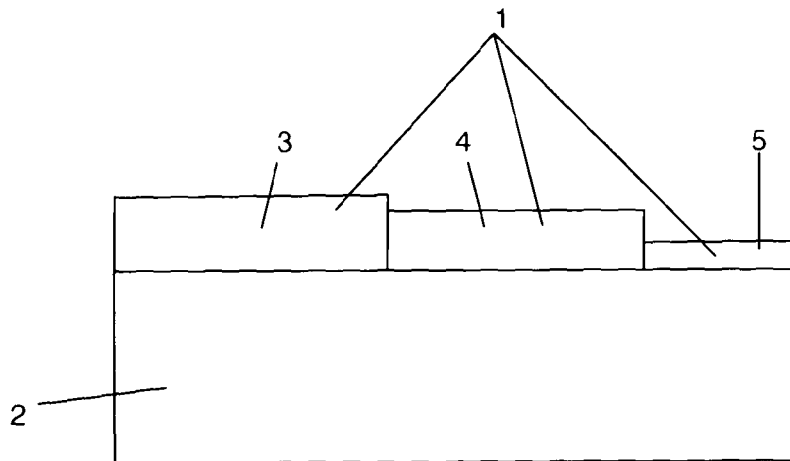


Figure 3

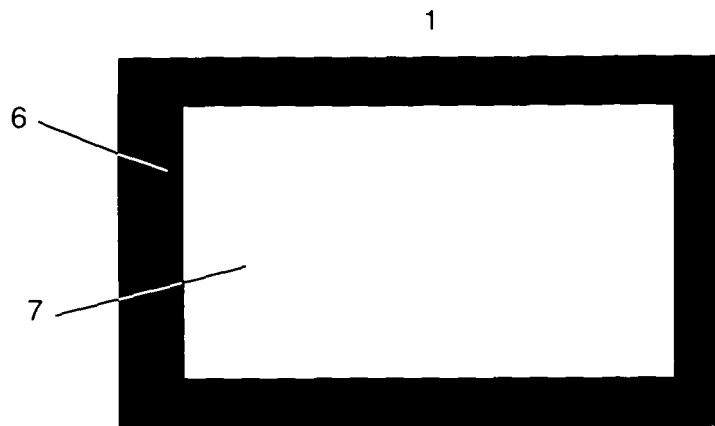


Figure 4

1

6	7	6	7	6	7	6	7	6	7	6
7	6	7	6	7	6	7	6	7	6	7
6	7	6	7	6	7	6	7	6	7	6
7	6	7	6	7	6	7	6	7	6	7
6	7	6	7	6	7	6	7	6	7	6
7	6	7	6	7	6	7	6	7	6	7
6	7	6	7	6	7	6	7	6	7	6

Figure 5

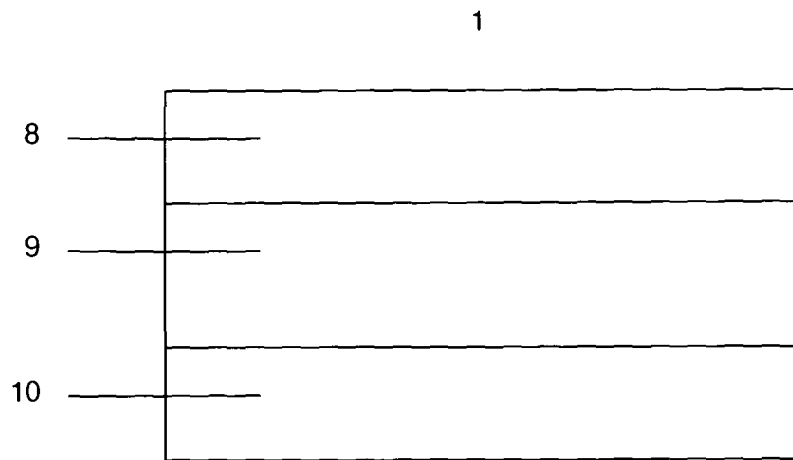


Figure 6

