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(54) **Electroforming method for producing objects with a high degree of accuracy**

(57) The present invention provides a method for producing, by electroplating, a metal object which has at least one continuous opening, which opening is delimited by metal dykes (16). Instead of applying complete islands of electrically insulating material to the electroforming die (10), only a boundary (20) of electrically insulating material is applied, this boundary corresponding to the periphery of the opening that is to be formed in the product. Therefore, a part (22) of the elec-

troforming die is also uncovered within the boundary (20). During the deposition of metal from an electroplating bath on the uncovered electrically conductive parts (14, 22) of the die, metal overgrowth takes place over the boundary (22), with the result that the periphery of the opening that is to be formed is accurately defined. The metal growth (24) which has grown from the central region (22) is removed from the semi-finished product in order to produce the finished product with a continuous opening.

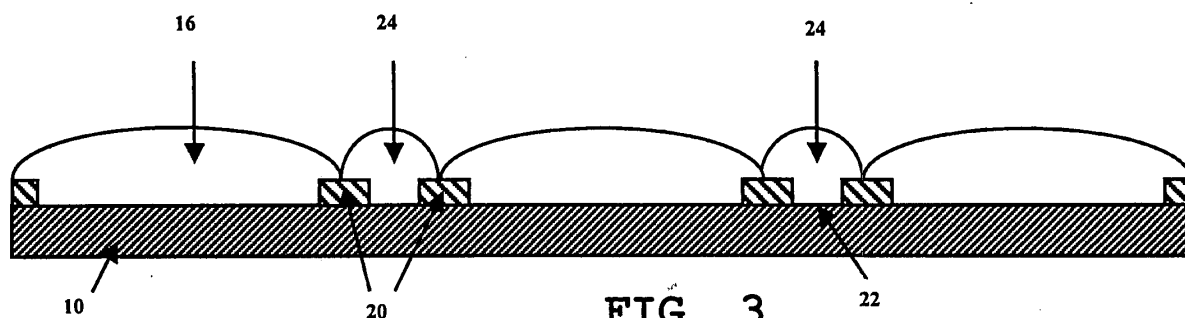


FIG. 3

Description

[0001] The present invention relates to a method for producing, by electroplating, a metal object which has at least one continuous opening that is delimited by metal dykes.

[0002] It is known in the art to produce a wide range of precision metal products by the electroplating route, also known as electroforming. Examples of products of this type, having one or generally more continuous openings, include, inter alia, screens, solar cells, collectors, vapour deposition masks, etc.

[0003] An electroforming method generally comprises the creation of an electroforming die produced from an electrically conducting material. The electroforming die may be of any desired shape, but is often a flat plate or a cylinder. A layer of electrically insulating material, such as photoresist, is applied to the electroforming die. This layer is then exposed through a film, so that after developing "full" islands or regions of insulating material remain in place and define the opening or openings to be formed in the object. Therefore, the electroforming die comprises uncovered metal tracks which are connected to one another, and separate islands of insulating material. The die which has been prepared in this way is placed in an electroplating bath and connected as cathode. Then, metal from the electroplating bath is deposited on the electrically conductive regions of the die (i.e. the regions that are not covered by insulating material). During the deposition of metal from the electroplating bath on the electrically conductive parts of the electroforming die, the conditions are often selected in such a manner that not only metal is deposited on the uncovered tracks of the electroforming die, so as to fill up the space between the regions of electrically insulating material with the metal deposit that is formed, but also this deposit is produced under conditions that are such that the metal partially grows over the islands of electrically insulating material.

[0004] One of the drawbacks of this known method is that it is not accurately known to what extent the metal grows over the islands of electrically insulating material. The reasons for this are the spread in the bath properties through the bath, and to a lesser extent also the spread in the thickness and surface dimensions in the islands made from electrically insulating material. Consequently, the end products have a relatively high degree of inaccuracy, both within a single product and among a series of products produced in succession using the same die. This can lead to a product scrap rate of the order of magnitude of 20 to 30%, i.e. products which do not comply with the required specifications.

[0005] Any spread in the bath conditions resulting from the electroplating bath used manifests itself in variations in the thickness of the product over the surface thereof. Two important parameters which are responsible for a spread of this nature are the temperature of the bath liquid and the spacing (geometry) between anode

and cathode. The thickness of the islands of electrically insulating material, as has been stated, play a less important role, and consequently a spread in the thickness of this material in the range from 1-2 micrometres has scarcely any influence on the final accuracy of the end product.

[0006] It is an object of the present invention to provide a method for producing, by electroplating, objects with very low tolerances, in other words an improved electroforming method.

[0007] The method of the type described in the preamble according to the invention for this purpose comprises the steps of:

- a) applying a boundary formed from an electrically insulating material to an electroforming die corresponding to the periphery of the abovementioned at least one continuous opening that is to be formed, so that the boundary leaves uncovered an exposed central region, located within the boundary, of the electroforming die;
- b) depositing metal on uncovered electrically conductive parts of the electroforming die in an electroplating bath;
- c) removing the metal deposit from the die; and
- d) removing the metal growth that has been deposited in the central region in order to obtain the object with at least one continuous opening.

[0008] In the method according to the invention, in a first step a boundary of an electrically insulating material, such as photoresist, is applied to the electroforming die, which boundary is positioned so as to correspond to the periphery of the opening that is to be formed. The boundary forms a continuous border. In this process, a central region where the electrically conductive material of the electroforming die is uncovered remains inside a continuous border of this type which defines an opening. In other words, instead of a full or solid island of insulating material, in the method according to the invention only the contour of the opening that is to be obtained is applied to the die, in the form of a frame. Consequently, the overgrowth of metal over the boundary made from electrically insulating material during step b) takes place from two directions, namely from the tracks which surround the boundary of an opening and from the central region, so that the final metal border of the opening is always located at the same position, namely in this case in the centre of the boundary as seen in the width direction of the dyke between central region and track. This position of the border of the opening is always identical. Consequently, the method according to the invention is self-regulating with regard to the position of the border. Errors in the dimensions of the resist, which are generally symmetrical, have no influence on this position of the border. The influence of the spread in the bath properties on the position of the border of the opening is very low or absent altogether in the method according to the

invention. This leads to products with a high degree of accuracy and consequently to a low product scrap rate. The metal deposits which grow over the boundary of electrically insulating material from two directions touch one another but have only very poor bonding to one another, since the bath liquid is scarcely refreshed at that location. In addition, the nature of the electroplating bath, such as the additives, including brightener(s), plays a role.

[0009] The metal deposit which has grown on the electroforming die from within the central region as defined above can easily be removed from the semi-finished product obtained, for example by being pressed out, since there is only a weak join. However, this does not represent any risk to the tolerances of the final product. After the abovementioned metal growth, also referred to below as the filler piece, has been removed, the result is an end product with very accurate dimensions of the opening or openings present therein. The abovementioned adhesion between metal deposits which grow towards one another is determined by the width of the boundary of electrically insulating material. For the same final thickness of a product, the adhesion will be lower if the width of the boundary increases.

[0010] The type of metal from which the object is produced is not critical. Examples of suitable metals include, inter alia, nickel, chromium, nickel-palladium alloy and copper. Nickel is particularly preferred. Examples of suitable electroplating baths for nickel include what is known as a Watts bath (NiSO_4), a sulphamate bath, and examples of suitable electroplating baths for copper include a copper sulphate bath. For accurate deposition, the bath preferably comprises a brightener belonging to class 1, cf. for example Modern Electroplating, Frederic A. Lowenheim; 3rd edition 1973, John Wiley & Sons and Nickel and Chromiumplating, J.K. Dennis and T.E. Such Butterworth, 2nd edition, 1986.

[0011] The method according to the invention can be used to produce products with a thickness of up to a few millimetres in a single step. In embodiments of the method according to the invention, a tolerance of less than $\pm 5 \mu\text{m}$ is achieved for a product with an opening of 30 mm, and a tolerance of less than $\pm 1 \mu\text{m}$ is achieved for an opening of 2 mm.

[0012] To simplify the removal of the filler piece, i.e. the metal deposit which has grown from the central region, the electroforming die can be designed in such a manner that the walls of the metal deposits on the tracks and from the central region do not grow vertically on the surface of the electroforming die, but rather grow slightly obliquely. As a result of these sloping surfaces, the growth pieces can easily be removed from the semi-finished product after steps b) and c).

[0013] More particularly, in the method according to the invention, for this purpose during step a) one or more islands of electrically insulating material are likewise applied within the abovementioned boundary made from electrically insulating material. The effect of the pres-

ence of these islands of electrically insulating material within the abovementioned boundary, in other words on the central region, is that the deposition of metal from this central region produces a filler piece which is thicker than the thickness of the end product which is deposited on the electrically conductive parts between the boundaries of different openings. Moreover, the filling piece widens out in the height direction, as seen from the die. The border of the opening is, as it were, forced back towards the product. The reason for this is that a higher current is obtained between the islands of insulating material inside the boundary.

[0014] As has already been stated above, examples of products which can be produced with the aid of the method according to the invention include screens, solar cells, collectors, vapour deposition masks, etc. The openings in products of this type have to have a high level of accuracy, and the method according to the invention is eminently suitable for this purpose. The locations where the adhesion between the product and a filler piece has been broken in an opening that is to be formed leave behind a visible indication that the product has been produced using the method according to the present invention. Electron microscopy may be a useful tool in this respect.

[0015] The present invention is explained further on the basis of the appended drawing, in which:

Fig. 1 illustrates an electroforming method according to the prior art on the basis of a cross section through an electroforming die with metal deposit;

Fig. 2 shows a plan view of the electroforming die used in Fig. 1 prior to metal deposition;

Fig. 3 illustrates an embodiment of the method according to the invention;

Fig. 4 shows a plan view of an electroforming die which is used in the method illustrated in Fig. 3;

Fig. 5 shows a modification of the method according to the invention; and

Fig. 6 shows a plan view of an electroforming die which is used in the modified method shown in Fig. 5.

[0016] Fig. 1 shows an electroforming die 10 made from an electrically conductive metal. A layer of photoresist is applied to the die 10 and is then exposed and developed through a film. This provides resist islands 12 on the die, corresponding to the openings in the object that is to be formed. Therefore, uncovered electrically conductive regions 14 of the die 10 are left between the islands 12. Then, the die 10 that has been prepared in this way is placed in an electroplating bath, for example a nickel sulphamate bath, and connected as cath-

ode. When current is passed through, nickel from the electroplating bath is deposited on the uncovered parts 14 of the die 10. This deposition is continued until the desired thickness of the product has been reached. The metal deposit is to some extent also allowed to grow over the islands 12. After the metal deposit has been removed from the die 10, the result is a product which comprises metal dykes 16 delimiting continuous openings, the dimensions of which correspond to the periphery of the resist islands minus the abovementioned overgrowth which has occurred over the resist islands 12. In Fig. 1, the position of the border of a metal dyke 16 which delimits the abovementioned opening is denoted by P. In this method according to the prior art, the variation in the final position P is primarily dependent on the spread in bath parameters of the electroplating bath used. Within one and the same product, this means that the position of point P may vary for the openings. If the same die is used to produce objects by means of series production, this position P may also differ considerably from series to series.

[0017] Fig. 2 shows a plan view of an example of a die which can be used in the method according to the prior art. The die 10, in this case a flat plate, is covered with a number of resist islands 12, in this case hexagonal in shape, with parts 14 of the die 10 uncovered between the resist islands 12. During electroforming, as has been stated above, metal growth takes place on these parts.

[0018] Fig. 3 shows the principle of the invention. This figure uses the same reference numerals as in Figures 1 and 2 for the same components. In a first step, a layer of photoresist is applied to the die 10 made from electrically conductive material, and this layer of photoresist is then exposed and developed in the usual way. However, in the film used for the exposure step, the pattern of openings that are to be formed is different from that used in the prior art. This is because the pattern only comprises the boundary of an opening or openings to be formed, so that after the photoresist has been developed no solid photoresist islands result, but rather the result is only a boundary comprising a continuous border with an open central region. In Fig. 3 and 4, this boundary is denoted by reference numeral 20, and the central region by 22. If the die prepared in this way is connected as cathode in an electroplating bath, as described above, metal growth takes place not only on the uncovered parts 14 of the die but also in the central region 22 which is delimited by the boundary 20 of photoresist for each opening that is to be formed. Therefore, in addition to the metal dykes 14, metal filler pieces 24 (cf. Fig. 3) are also deposited on the die 10. After the product formed in this way has been detached from the die, these filler pieces 24 can easily be removed from the metal dykes 16, since there is only a very small amount of adhesion between the filler pieces 24 and the metal dykes 16. In this method according to the invention, the overgrowth over the boundary 20 takes place

both from the uncovered electrically conductive parts 16 of the die and from the central region 22 of the boundary, so that the point P is always located in the centre of the boundary 20 made from photoresist. Consequently, it is possible to produce products with very accurate dimensions of the openings formed therein. Fig. 4 illustrates an embodiment of an electroforming die 10 which is used for this purpose and to which the boundary 20 of an electrically insulating material, such as photoresist, corresponding to the contour of the openings to be formed in the product, has been applied. Within the continuous border 20 is the central region 22 of the die 10, which is likewise uncovered.

[0019] Fig. 5 and 6 show a modified embodiment of the method according to the invention. To improve the removal of the filler pieces 24 from the product, small resist islands 30 have also been applied in the central region 22 within the boundary 20 of an opening that is to be formed during the preparation phase of the die. During the deposition of metal, the higher i value will cause the filler piece 24 to grow more quickly and to reach a greater height than the metal dykes 16. Furthermore, as a result the side walls of the filler piece 24 will be oblique, which facilitates the removal of the filler piece 24.

Example

[0020] A coarse 5 mesh screen with a pitch of 5000 micrometres and a hole size of 5 mm is produced. The resist boundary has a width of 150 micrometres and is 5 micrometres thick. After deposition of metal to a height of 80 micrometres from a Watts bath (sulphate) at 60°C, the metal dykes 16 and the filler piece 24 touch one another at point P in the centre of the resist. The deposition of metal is continued until the metal dykes 16 have reached a thickness of 100 micrometres. This means that metal webs 16 and filler piece 24 will grow onto one another over a distance of approx. 20 micrometres. However, this growth of the parts onto one another can easily be broken. The tolerance achieved for the openings in this coarse screen is ± 2 micrometres.

Claims

1. Method for producing, by electroplating, a metal object which has at least one continuous opening that is delimited by metal dykes (16), which method comprises the steps of:

a) applying a boundary (20) formed from an electrically insulating material to an electroforming die (10) corresponding to the periphery of the abovementioned at least one continuous opening that is to be formed, so that the boundary (20) leaves uncovered a central region (22) of the electroforming die (10);

b) depositing metal on uncovered electrically conductive parts (14, 22) of the electroforming die (10) in an electroplating bath;

c) removing the metal deposit from the die (10);
and

d) removing the metal growth (24) which has been deposited in the central region (22) from the metal deposit in order to obtain the object with a continuous opening.

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2. Method according to claim 1, **characterized in that** during step a) one or more islands (30) of electrically insulating material are also applied within the boundary (20).

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3. Method according to one of the preceding claims, **characterized in that** the electroplating bath comprises a brightener belonging to class 1.

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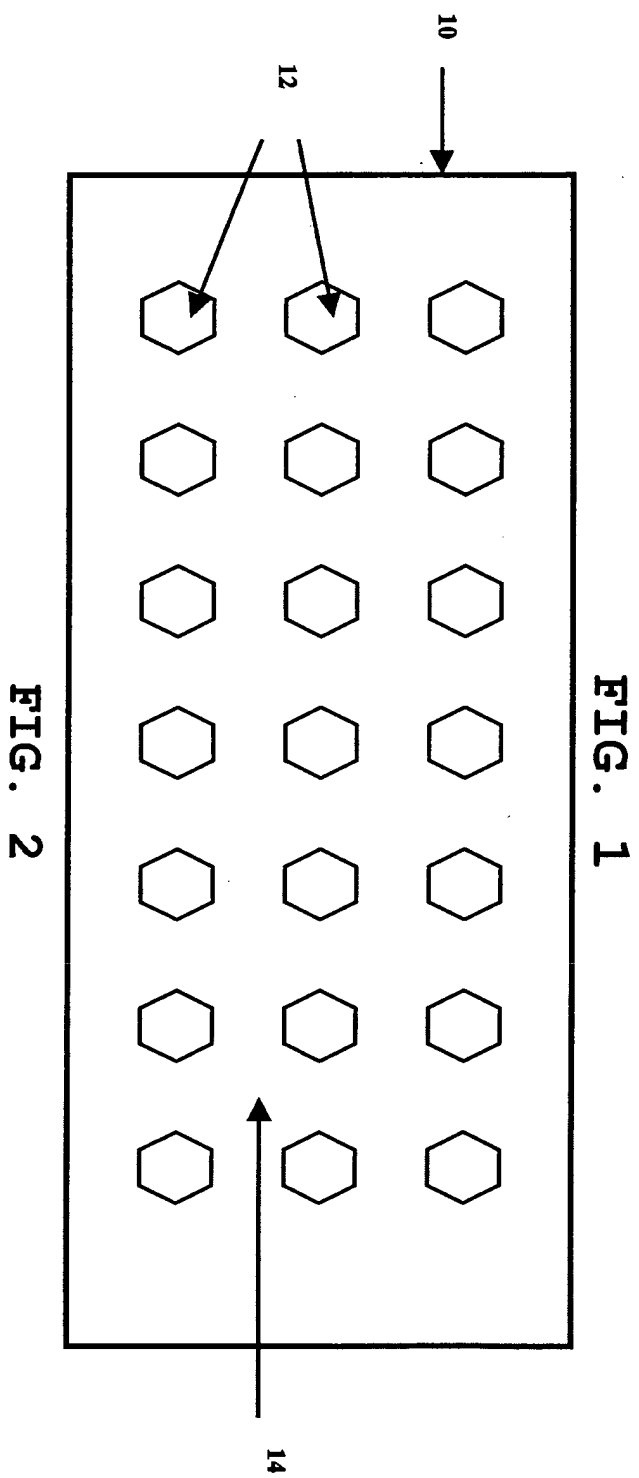
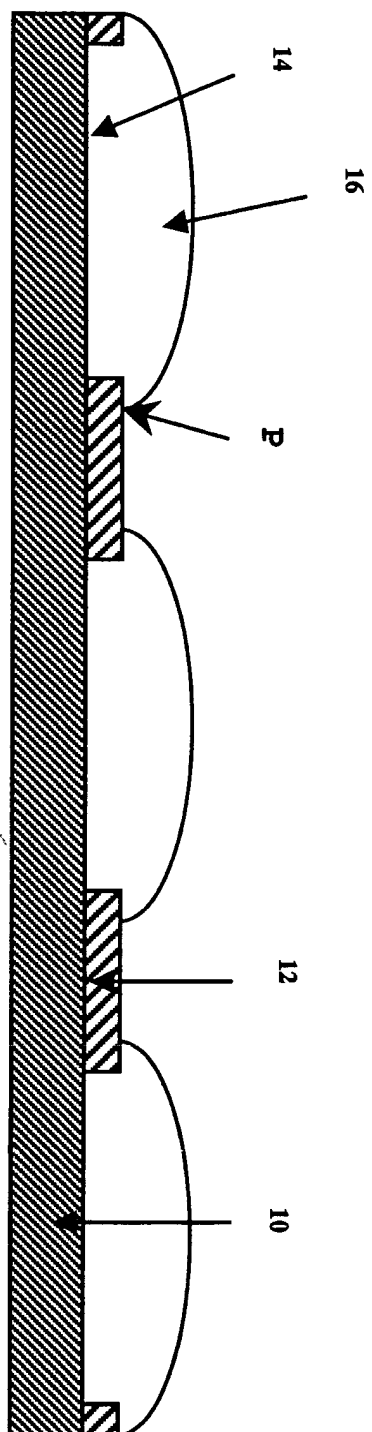
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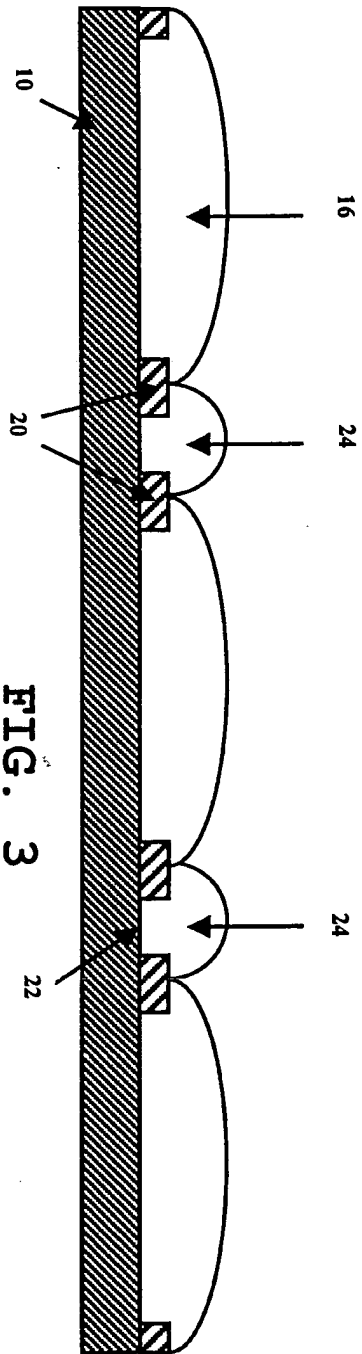


FIG. 3

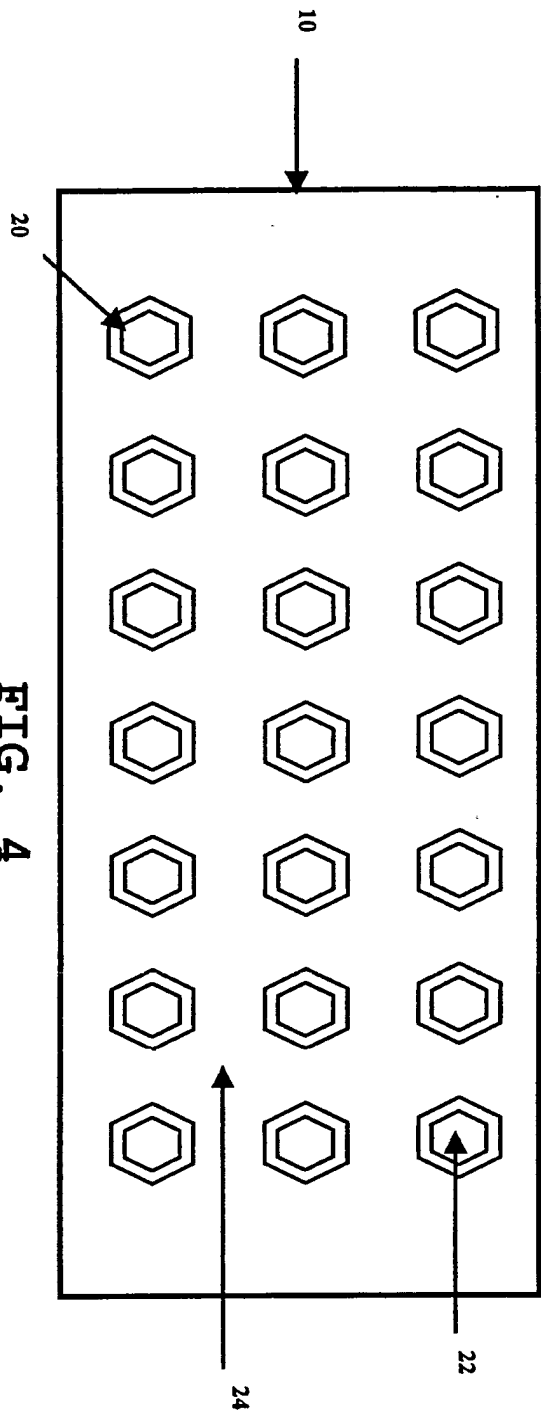


FIG. 4

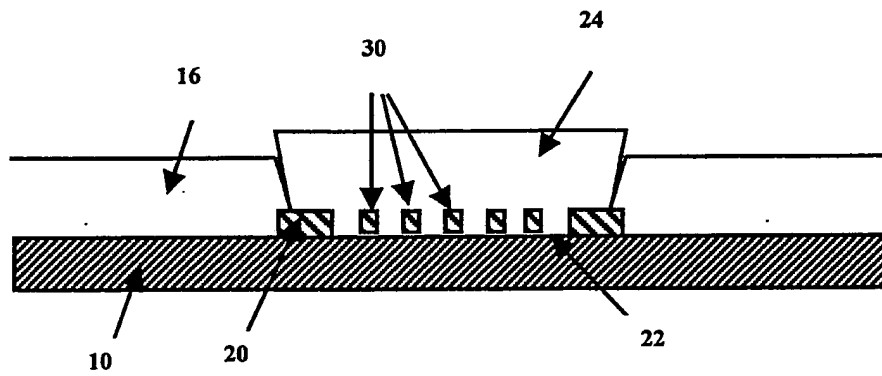


FIG. 5

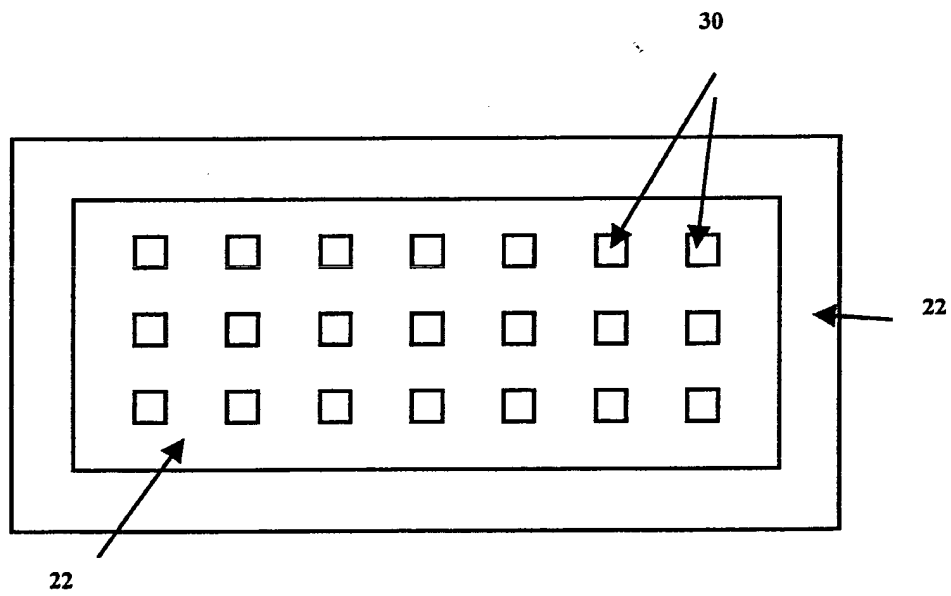


Fig. 6