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| <b>(51) International Patent Classification <sup>6</sup> :</b><br><b>G03F 7/40</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>A1</b> | <b>(11) International Publication Number:</b> <b>WO 97/25653</b><br><b>(43) International Publication Date:</b> 17 July 1997 (17.07.97)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>(21) International Application Number:</b> PCT/GB97/00043<br><b>(22) International Filing Date:</b> 9 January 1997 (09.01.97)<br><b>(30) Priority Data:</b><br>9600469.2 10 January 1996 (10.01.96) GB<br><b>(71) Applicant (for all designated States except US):</b> THE SECRETARY OF STATE FOR DEFENCE [GB/GB]; Defence Evaluation & Research Agency, Ively Road, Farnborough, Hampshire GU14 0LX (GB).<br><b>(72) Inventors; and</b><br><b>(75) Inventors/Applicants (for US only):</b> DUTTON, David, Thomas [GB/GB]; Defence Research Agency, St. Andrews Road, Malvern, Worcs. WR14 3PS (GB). DEAN, Anthony, Brian [GB/GB]; Defence Research Agency, St Andrews Road, Malvern, Worcs. WR14 3PS (GB).<br><b>(74) Agent:</b> SKELTON, Stephen, Richard; D/IPR (DERA) Formalities, Poplar 2a, MOD (PE) Abbey Wood #19, P.O. Box 702, Bristol BS12 7DU (GB). |           | <b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).<br><br><b>Published</b><br><i>With international search report.</i><br><i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i> |
| <b>(54) Title:</b> THREE-DIMENSIONAL ETCHING PROCESS<br><br><b>(57) Abstract</b><br><br>A method of forming three-dimensional structures on a substrate by a single reactive ion etch run whereby a mask is formed on said substrate before a series of iterations are carried out, each iteration including a mask etch and a substrate etch, so that successive iterations give rise to reduction in the mask area and exposure of further areas of substrate.                                                                                                                                                                                                                                                                                                                                                                                                   |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

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Three Dimensional Etching Process.

The current invention relates to the production of three dimensional structures on a substrate by Reactive-Ion Etching. It can be applied to materials such as semiconductor, glass, polyimide or any other which can be etched using a reactive ion plasma.

Three dimensional semiconductor structures are required for optical confinement (for example in visible/infrared lenses, emitters or detectors) and electromagnetic confinement (eg microwave inductors, detectors or sources).

A number of techniques are known for the fabrication of optical confining structures such as microlenses. For example, Hutley et. al. teach the formation of small discs of photoresist which, on heating to melt, are drawn into the shape of small lenses by surface tension. (Physics World, July 1991 pp27-32).

Liau et. al. teach the formation of a stepped structure by repeated applications of photolithography and bromine-methanol etching. Mass transport within this structure to form a lens shape is then effected, again by heating to melt (see Appl. Phys. Lett. 55 (2) 10 July 1989; The Lincoln Laboratory Journal, Volume 3, Number 3, 1990).

Other methods of forming microlens arrays are detailed in "Micro-optics has macro potential" Laser Focus World June, 1991. Methods which involve reactive ion etching typically involve repeated applications of photoresist and etch runs. This makes the fabrication process cumbersome.

According to this invention, a method of producing or modifying a three dimensional surface profile on a substrate comprises the steps of

(i) forming a mask of resist on the substrate such that some area of the substrate is protected by the mask and some area is exposed and

(ii) subjecting the substrate to a plurality of iterations

wherein each iteration comprises at least one resist etch and at least one substrate etch, the resist etch being carried out using a suitable resist etchant, which modifies the shape of the mask and hence the area of substrate exposed, and the substrate etch being carried out using a suitable substrate etchant from which the mask affords protection of the substrate, and which removes material from the areas of substrate which are exposed.

In a preferred embodiment, an optical concentrator is formed on the substrate.

In a preferred embodiment the substrate comprises a semiconductor material.

In a preferred embodiment the substrate comprises InSb.

In a further preferred embodiment the substrate etchant comprises a  $\text{CH}_4/\text{H}_2$  plasma.

In a further preferred embodiment the resist etchant comprises an oxygen plasma.

In a further preferred embodiment, a Winston cone is formed in InSb heterostructure material.

The invention will now be described with reference to the following figures in which figures 1a - 1e show representations of the substrate and mask at various stages of a process using the method of the current invention and figures 2a and 2b show scanning electron microscope images of an array of microlenses during two stages of their formation by the method of the current invention.

Referring to figure 1a, a dome or button of photolithographic masking resist 1 is applied to a semiconductor substrate 2. This may be formed by, for example, greyscale lithography (see UK patent application 9310013.9) or resist-reflow methods.

The substrate is then etched using a substrate etchant from which the resist 1 affords protection so that material is removed from areas 3 on the substrate 2. This gives rise to the structure shown in figure 1b.

Referring to figure 1c, the area covered by resist 1 is then reduced, using a suitable resist etchant, so that further areas 4 of substrate 2 are exposed.

Further etching of the substrate using the substrate etchant then removes material from areas 3 and 4 to produce a stepped structure as shown in figure 1d.

Repeated etching of the resist 1 and substrate 2, in a single reactive ion etch run, gives rise to the multi-stepped structure shown in figure 1e.

Detailed three-dimensional structures can be formed by controlling the rate and time for each of the etching steps. The final resolution of the profile is dependent on the number of alternate substrate and resist etch steps over a given structure height.

This technique can also be used to modify structures formed by other techniques.

Referring to figures 2a and 2b, the microlenses shown therein were fabricated using a Surface Technology Systems (STS) Reactive Ion Etching Machine, Model 340PC, and the following etch conditions:

Resist Etch conditions: Gas: O<sub>2</sub>, flow rate 80 standard cubic centimetres per minute(sccm);  
Chamber Pressure: 60 mTorr;  
RF Power: 60W.

Substrate Etch Conditions: Gas: CH<sub>4</sub>, 90 sccm and H<sub>2</sub>, flow rate 10 sccm;  
Chamber Pressure: 90 mTorr;  
RF Power: 50W.

The substrate (InSb) was coated with  $12 \times 10^{-6}$  m of AZ4562 resist and was processed into straight sided cones using greyscale technology and Ion beam milling. (Other methods of effecting this part of the process will be apparent to those skilled in the art). The sample was then resist etched using the above resist etch conditions for 5 minutes. This was followed by a 5 minute InSb etch using the above substrate-etch conditions and then another 5 minute resist etch. Four iterations of 5 minute InSb etching and 2 minute resist etching were then performed to obtain the structure shown in figure 2a.

A further seven steps resulted in the structure shown in figure 2b.

Under some conditions, the exothermic nature of the reactive ion etching process causes the resist to reflow. This gives additional flexibility to the process and may obviate the need for greyscale lithography or ex-situ resist reflow using, for example, a hot plate or oven.

Claims.

1. A method of producing or modifying a three dimensional surface profile on a substrate comprising the steps of

(i) forming a mask of resist on the substrate such that some area of the substrate is protected by the mask and some area is exposed and

(ii) subjecting the substrate to a plurality of iterations

wherein each iteration comprises at least one resist etch and at least one substrate etch, the resist etch being carried out using a suitable resist etchant, which modifies the shape of the mask and hence the area of substrate exposed, and the substrate etch being carried out using a suitable substrate etchant from which the mask affords protection of the substrate, and which removes material from the areas of substrate which are exposed.

2. The method of claim 1 where an optical concentrator is formed in the substrate.

3. The method of claim 1 or 2 where the substrate comprises a semiconductor material.

4. The method of claim 3 where the substrate comprises InSb.

5. The method of claim 4 where the substrate etchant comprises a  $\text{CH}_4/\text{H}_2$  plasma.

6. The method of claim 5 where the resist etchant comprises an oxygen plasma.

7. The method of claim 6 where a Winston cone emitter is formed in InSb heterostructure material.

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Fig.1a.

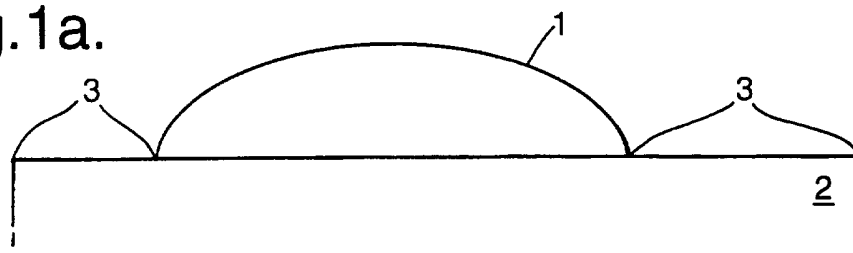


Fig.1b.

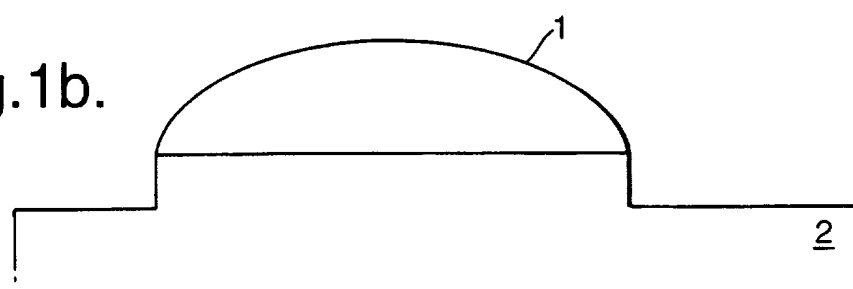


Fig.1c.

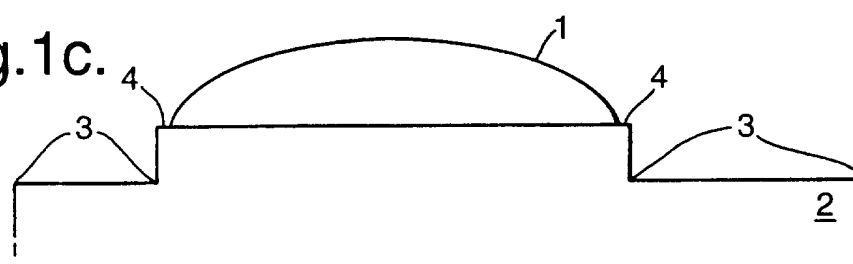


Fig.1d.

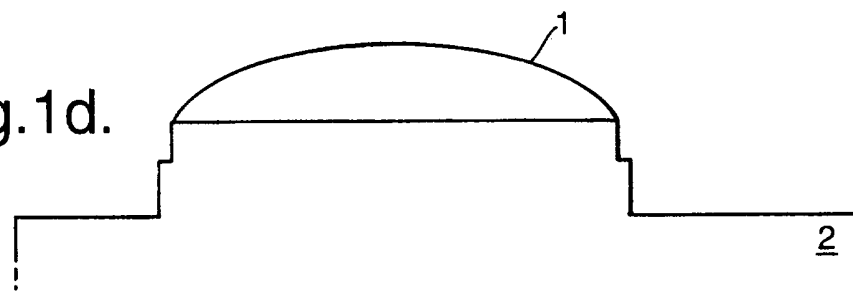
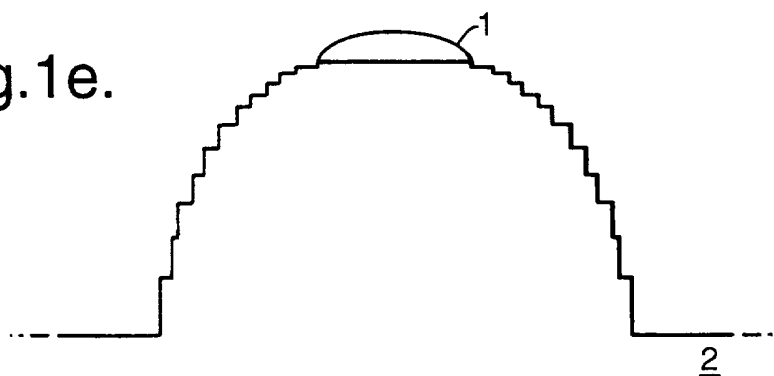


Fig.1e.





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Fig.2a.

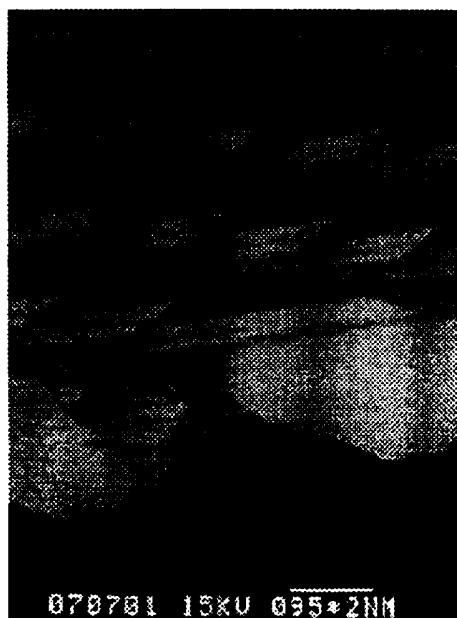
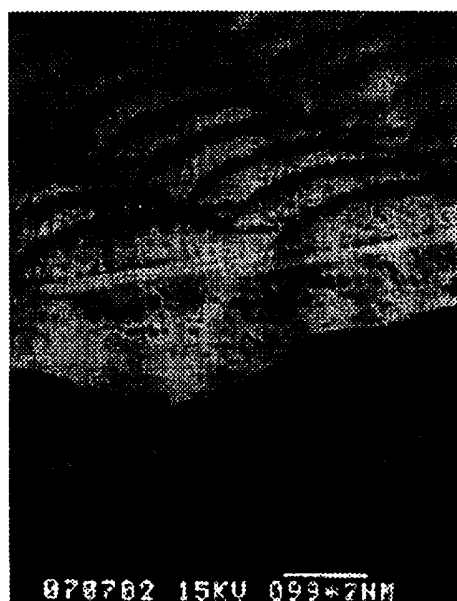


Fig.2b.



# INTERNATIONAL SEARCH REPORT

Internati      Application No  
PCT/GB 97/00043

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6      G03F7/40

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6      G03F      H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                                             | Relevant to claim No. |
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| X          | US 5 286 338 A (FELDBLUM AVI Y ET AL) 15<br>February 1994                                                                                                                                                                                                                                                                      | 1,2,6                 |
| Y          | see the whole document                                                                                                                                                                                                                                                                                                         | 3-5,7                 |
| Y          | ---<br>JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY:<br>PART B,<br>vol. 9, no. 3, 1 May 1991,<br>pages 1421-1432, XP000367925<br>PEARTON S J: "COMPARISON OF CH <sub>4</sub> /H <sub>2</sub> /AR<br>REACTIVE ION ETCHING AND ELECTRON<br>CYCLOTRON RESONANCE PLASMA ETCHING OF<br>IN-BASED III-V ALLOYS"<br>see the whole document | 3-5,7                 |
| A          | ---<br>US 5 456 798 A (KOUMURA TUKASA ET AL) 10<br>October 1995<br>---<br>-/-                                                                                                                                                                                                                                                  |                       |

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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| A          | <p>PATENT ABSTRACTS OF JAPAN<br/> vol. 010, no. 204 (M-499), 17 July 1986<br/> &amp; JP 61 044627 A (PIONEER ELECTRONIC<br/> CORP), 4 March 1986,<br/> see abstract<br/> -----</p> |                       |

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| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
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|                                           |                     | JP 6308302 A               | 04-11-94            |
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