METHOD FOR MANUFACTURING LOW WORK FUNCTION SURFACES

Methods for fabricating nano-structured surfaces having geometries in which the passage of elementary particles through a potential barrier is enhanced are described. The methods use combinations of electron beam lithography, lift-off, and rolling, imprinting or stamping processes.
FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

<table>
<thead>
<tr>
<th>AL</th>
<th>Albania</th>
<th>BA</th>
<th>Bosnia and Herzegovina</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>Armenia</td>
<td>BB</td>
<td>Barbados</td>
</tr>
<tr>
<td>AT</td>
<td>Austria</td>
<td>BE</td>
<td>Belgium</td>
</tr>
<tr>
<td>AU</td>
<td>Australia</td>
<td>BF</td>
<td>Burkina Faso</td>
</tr>
<tr>
<td>AZ</td>
<td>Azerbaijan</td>
<td>BG</td>
<td>Bulgaria</td>
</tr>
<tr>
<td>BA</td>
<td>Bosnia and Herzegovina</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BB</td>
<td>Barbados</td>
<td>BE</td>
<td>Belgium</td>
</tr>
<tr>
<td>BF</td>
<td>Burkina Faso</td>
<td>BG</td>
<td>Bulgaria</td>
</tr>
<tr>
<td>BJ</td>
<td>Benin</td>
<td>BR</td>
<td>Brazil</td>
</tr>
<tr>
<td>BY</td>
<td>Belarus</td>
<td>CA</td>
<td>Canada</td>
</tr>
<tr>
<td>CF</td>
<td>Central African Republic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CG</td>
<td>Congo</td>
<td>CH</td>
<td>Switzerland</td>
</tr>
<tr>
<td>CI</td>
<td>Côte d'Ivoire</td>
<td>CM</td>
<td>Cameroon</td>
</tr>
<tr>
<td>CN</td>
<td>China</td>
<td>CU</td>
<td>Cuba</td>
</tr>
<tr>
<td>CZ</td>
<td>Czech Republic</td>
<td>DE</td>
<td>Germany</td>
</tr>
<tr>
<td>DK</td>
<td>Denmark</td>
<td>EE</td>
<td>Estonia</td>
</tr>
<tr>
<td>ES</td>
<td>Spain</td>
<td>FI</td>
<td>Finland</td>
</tr>
<tr>
<td>FR</td>
<td>France</td>
<td>GB</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>GE</td>
<td>Georgia</td>
<td>GH</td>
<td>Ghana</td>
</tr>
<tr>
<td>GN</td>
<td>Guinea</td>
<td>GR</td>
<td>Greece</td>
</tr>
<tr>
<td>HU</td>
<td>Hungary</td>
<td>IL</td>
<td>Israel</td>
</tr>
<tr>
<td>IE</td>
<td>Ireland</td>
<td>IS</td>
<td>Iceland</td>
</tr>
<tr>
<td>IT</td>
<td>Italy</td>
<td>JP</td>
<td>Japan</td>
</tr>
<tr>
<td>KE</td>
<td>Kenya</td>
<td>KG</td>
<td>Kyrgyzstan</td>
</tr>
<tr>
<td>KP</td>
<td>Democratic People's Republic of Korea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KR</td>
<td>Republic of Korea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KZ</td>
<td>Kazakhstan</td>
<td>LC</td>
<td>Saint Lucia</td>
</tr>
<tr>
<td>LI</td>
<td>Liechtenstein</td>
<td>LK</td>
<td>Sri Lanka</td>
</tr>
<tr>
<td>LR</td>
<td>Liberia</td>
<td>LS</td>
<td>Lesotho</td>
</tr>
<tr>
<td>LT</td>
<td>Lithuania</td>
<td>LU</td>
<td>Luxembourg</td>
</tr>
<tr>
<td>LV</td>
<td>Latvia</td>
<td>MC</td>
<td>Monaco</td>
</tr>
<tr>
<td>MD</td>
<td>Republic of Moldova</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MG</td>
<td>Madagascar</td>
<td>MK</td>
<td>The former Yugoslavia</td>
</tr>
<tr>
<td>ML</td>
<td>Mali</td>
<td>MN</td>
<td>Mongolia</td>
</tr>
<tr>
<td>MR</td>
<td>Mauritania</td>
<td>MW</td>
<td>Malawi</td>
</tr>
<tr>
<td>MX</td>
<td>Mexico</td>
<td>NE</td>
<td>Niger</td>
</tr>
<tr>
<td>NL</td>
<td>Netherlands</td>
<td>NO</td>
<td>Norway</td>
</tr>
<tr>
<td>NZ</td>
<td>New Zealand</td>
<td>PL</td>
<td>Poland</td>
</tr>
<tr>
<td>PT</td>
<td>Portugal</td>
<td>RO</td>
<td>Romania</td>
</tr>
<tr>
<td>RU</td>
<td>Russian Federation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>Sudan</td>
<td>SE</td>
<td>Sweden</td>
</tr>
<tr>
<td>SG</td>
<td>Singapore</td>
<td>SI</td>
<td>Slovenia</td>
</tr>
<tr>
<td>SK</td>
<td>Slovakia</td>
<td>SN</td>
<td>Senegal</td>
</tr>
<tr>
<td>SZ</td>
<td>Swaziland</td>
<td>TD</td>
<td>Chad</td>
</tr>
<tr>
<td>TG</td>
<td>Togo</td>
<td>TJ</td>
<td>Tajikistan</td>
</tr>
<tr>
<td>TM</td>
<td>Turkmenistan</td>
<td>TR</td>
<td>Turkey</td>
</tr>
<tr>
<td>TT</td>
<td>Trinidad and Tobago</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UA</td>
<td>Ukraine</td>
<td>UG</td>
<td>Uganda</td>
</tr>
<tr>
<td>US</td>
<td>United States of America</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UZ</td>
<td>Uzbekistan</td>
<td>VN</td>
<td>Viet Nam</td>
</tr>
<tr>
<td>YU</td>
<td>Yugoslavia</td>
<td>ZW</td>
<td>Zimbabwe</td>
</tr>
</tbody>
</table>
Method for manufacturing low work function surfaces

Technical Field

The present invention is concerned with methods for fabricating elementary particle-emitting surfaces, which could be used as cathodes or anodes, and embodiments of the same.

Background Art

The present invention is related to U.S. Pat. Appl. No. 09/020,654, filed 1998 February 9, entitled "Method for Increasing Tunneling through a Potential Barrier", which is incorporated herein by reference in its entirety.

In Edelson's disclosure, filed 1995 March 7, titled "Electrostatic Heat Pump Device and Method", serial number 08/401,036, now abandoned, incorporated herein by reference in its entirety, two porous electrodes were separated by a porous insulating material to form an electrostatic heat pump. In said device, evaporation and ionization of a working fluid in an electric field provided the heat pumping capacity. The use of electrons as the working fluid is disclosed in that application.

In WO97/02460, incorporated herein by reference in its entirety, Edelson discloses an improved device and method for the use of electrons as the working fluid in a heat-pumping device. In this invention, a vacuum diode is constructed using a low work function cathode.

In U.S. Pat. No. 5,722,242, incorporated herein by reference in its entirety, Edelson further discloses that the work function of the anode should be lower than the work function of the cathode in order to optimize efficient operation.

In WO99/10695, incorporated herein by reference in its entirety, Edelson and Cox disclose an improvement to the Vacuum Diode Heat Pump, wherein a particular material and means of construction was disclosed to further improve upon previous methods and devices.

The Vacuum Diode at the heart of Edelson's Vacuum Diode Heat Pump may also be used as a thermionic generator: the differences between the two devices being in the operation of the diode, the types and quantities of external energy applied to it, and the provisions made for drawing off, in the instance of the thermionic converter, an electrical current, and in the instance of the Vacuum Diode Heat Pump, energy in the form of heat.
Many attempts have been made to find materials with low work function for use as cathodes. Uses for such materials include amplifiers, vacuum diodes, flat panel displays, thermionic energy converters, and now thermionic heat pumps.

It is well known from Quantum Mechanics that elementary particles have wave properties as well as corpuscular properties. The density of probability of finding an elementary particle at a given location is $|\psi|^2$ where $\psi$ is a complex wave function and has form of the de Broglie wave:

$$\psi = A \exp\left\{ -i2\pi/\hbar (Et - px) \right\}$$  \hspace{1cm} (1)

Here $\psi$ is wave function; $\hbar$ is Planck's constant; $E$ is energy of particle; $p$ is impulse of particle; $x$ is a vector connecting initial and final locations; $t$ is time.

There are well known fundamental relationships between the parameters of this probability wave and the energy and impulse of the particle:

$$E = \frac{p^2}{2m}$$ \hspace{1cm} (2)

Here $k$ is the wave number of probability wave. The de Broglie wavelength is given by:

$$\lambda = \frac{2\pi}{k}$$ \hspace{1cm} (3)

If time, $t$, is set to 0, the space distribution of the probability wave may be obtained. Substituting (2) into (1) gives:

$$\psi = A \exp(ikx)$$ \hspace{1cm} (4)

Figure 1 shows an elementary particle wave moving from left to right perpendicular to a surface 7 dividing two domains. The surface is associated with a potential barrier, which means the potential energy of the particle changes it passes through it.

Incident wave 1 $A\exp(ikx)$ moving towards the border will mainly reflect back as reflected wave 3 $B\exp(-ikx)$, and only a small part leaks through the surface to give transmitted wave 5 $A(x)\exp(ikx)$ ($B=1>>A$). This is the well-known effect known as quantum mechanical tunneling. The elementary particle will pass the potential energy barrier with a low probability, depending on the potential energy barrier height.

Usagawa in U.S. Pat. No. 5,233,205 discloses a novel semiconductor surface in which interaction between carriers such as electrons and holes in a mesoscopic region and the potential field in the mesoscopic region leads to such effects as quantum interference and resonance, with the result that output intensity may be changed. Shimizu in U.S. Pat. No. 5,521,735
discloses a novel wave combining and/or branching device and Aharonov-Bohm
type quantum interference devices which have no curved waveguide, but utilize
double quantum well structures.

Mori in U.S. Pat. No. 5247223 discloses a quantum interference semiconductor
device having a cathode, an anode and a gate mounted in vacuum. Phase
differences among the plurality of electron waves emitted from the cathode
are controlled by the gate to give a quantum interference device operating as
an AB type transistor.

Other quantum interference devices are also disclosed by Ugajin in U.S. Pat.
No. 5,332,952 and Tong in U.S. Pat. No. 5,371,388.

Referring now to Figure 2, two domains are separated by a surface 17 having
an indented shape, with height a.

An incident probability wave 11 is reflected from surface 17 to give
reflected probability wave 13, and from the bottom of the indent to give
reflected probability wave 21. The reflected probability wave will thus be:

$$A\beta \exp(-ikx) + A\beta \exp(-ik(x+2a))$$

$$= A\beta \exp(-ikx)(1+\exp(-ik2a))$$ (5)

When $k2a=\pi$, $\exp(-i\pi) = -1$ and equation (5) will equal zero.

Physically this means that for $k2a = (2\pi/\lambda)2a = \pi$ and correspondingly $a=(\lambda/4)$,
the reflected probability wave equals zero. Further this means that the
particle will not reflect back from the border. Leakage of the probability
wave through the barrier will occur with increased probability and will open
many new possibilities for different practical applications.

Indent on the surface should have dimensions comparable to de Broglie
wavelength of electron. In particular indent height should be

$$a = n\lambda + \lambda/4$$ (6)

Here $n = 0, 1, 2, \ldots$

And the indent width should be of order of $2\lambda$.

If these requirements are satisfied then elementary particles will accumulate
on the surface.

For semiconductor material, the velocities of electrons in the electron cloud
is given by the Maxwell-Boltzmann distribution:

$$F(v)dv = n(m/2\pi k_BT)(-mv^2/2 k_BT)dv$$ (7)
where $F(v)$ is the probability of an electron having a velocity between $v$ and $v+dv$.

The average velocity of the electrons is

$$V_n = \left(3 \frac{K_B T}{m}\right)^{1/2}$$  \hspace{1cm} (8)

and the de Broglie wavelength corresponding to this velocity, calculated using formulas (2), (3) and the classical approximation $p=mv$ is:

$$\lambda = \frac{h}{(3m K_B T)^{1/2}} = 62 \text{ Å for } T=300K.$$  \hspace{1cm} (9)

This gives a value for $a$ of $\frac{76}{4} = 19$ Å. Indents of this depth may be constructed on a surface by a number of means known to the art of micro-machining. Alternatively, the indented shape may be introduced by depositing a series of islands on the surface.

For metals, free electrons are strongly coupled to each other and form a degenerate electron cloud. Pauli’s exclusion principle teaches that two or more electrons may not occupy the same quantum mechanical state: their distribution is thus described by Fermi-Dirac rather than Maxwell-Boltzmann.

In metals, free electrons occupy all the energy levels from zero to the Fermi level ($\epsilon_F$).

Referring now to Figure 3, electron 1 has energy below the Fermi level, and the probability of occupation of these energy states is almost constant in the range of $0-\epsilon_F$ and has a value of unity. Only in the interval of a few $K_B T$ around $\epsilon_F$ does this probability drop from 1 to 0. In other words, there are no free states below $\epsilon_F$. This quantum phenomenon leads to the formal division of free electrons into two groups: Group 1, which comprises electrons having energies below the Fermi level, and Group 2 comprising electrons with energies in the interval of few $K_B T$ around $\epsilon_F$.

For Group 1 electrons, all states having energies a little lower or higher are already occupied, which means that it is quantum mechanically forbidden for them to take part in current transport. For the same reason electrons from Group 1 cannot interact with the lattice directly because it requires energy transfer between electron and lattice, which is quantum mechanically forbidden.

Electrons from Group 2 have some empty energy states around them, and they can both transport current and exchange energy with the lattice. Thus only electrons around the Fermi level are taken into account in most cases when properties of metals are analyzed.
For electrons of group 1, two observations may be made. The first is that it is only these electrons which have wavelengths comparable to dimensions achievable by current fabrication techniques: 50-100 Å corresponds to about 0.01ε_f (E-E0)~(1/λ)^2. Group 2 electrons of single valence metals on the other hand, where ε_f = 2-3 eV, have a de Broglie wavelength around 5-10 Å which is difficult to fabricate using current techniques.

The second is that for quantum mechanical interference between de Broglie waves to take place, the main free path of the electron should be large. Electrons from group 1 satisfy this requirement because they effectively have an infinite main free path because of their very weak interaction with the lattice.

Referring again to Figure 3 electron 1, which is a group 1 electron, has k_0 = π/2a and energy ε_0, and is moving to the indented surface 17. As discussed above, this particular electron will not reflect back from the surface due to interference of de Broglie waves, and will leave the metal. Consider further that the metal is connected to a source of electrons, which provides electron 2, having energy close to ε_f (group 2). As required by the thermodynamic equilibrium electron 2 will lose energy to occupy state ε_0, losing energy ε_f - ε_0, for example by emission of a photon with energy ε_p (ε_f - ε_0). If this is absorbed by electron 3, electron 3 will be excited to a state having energy ε_f + ε_p = 2ε_f - ε_0.

Thus as a consequence of the loss of electron 1, electron 3 from the Fermi level is excited to a state having energy 2ε_f - ε_0, and could be emitted from the surface by thermionic emission. The effective work function of electron 3 is reduced from the value of φ to φ - ε_f + ε_0 = φ - (ε_f - ε_0). In another words, the work function of electron 3 is reduced by ε_f - ε_0.

Thus indents on the surface of the metal not only allow electron 1 to be emitted into the vacuum with high probability by interference of the de Broglie wave, but also results in the enhanced probability of emission of another electron (electron 3) by ordinary thermionic emission.

This approach will decrease the effective potential barrier between metal and vacuum (the work function).

This approach has many applications, including cathodes for vacuum tubes, thermionic converters, vacuum diode heat pumps, photoelectric converters, cold cathode sources, and many other in which electron emission from the surface is used.
In addition, an electron moving from vacuum into an anode electrode having an 
indented surface will also experience de Broglie interference, which will 
promote the movement of said electron into said electrode, thereby increasing 
the performance of the anode.

Electronic Engineering Times 23rd February 1998 page 43 and following reports 
that several groups have reported approaches to building single-electron 
memory cells where the active region is measured in nanometers rather than 
microns. These new devices are based on silicon and operate at room 
temperature. Stephen Chou has devised a process called nano-imprint 
lithography which offers the possibility of sub 0.1-micron circuit 
fabrication. Three fundamental approaches are being adopted: micromechanical 
manipulation based on scanning-probe microscopy, chemical self assembly and 
electron beam patterning.

Scanning-probe techniques are able to move and position individual atoms on a 
substrate. Noel MacDonald and Calvin Quate have extended this to probe-array 
technology allowing positioning operations to be conducted in parallel. 
Other molecular self-assembly techniques have shown the ability to quickly 
define or assemble regular arrays. However, for the methods to yield a 
practical circuit fabrication technique, some way must be found to create 
arbitrary circuit patterns under a designer’s direction. Direct patterning 
of a conjugated polymer by exposing thin films of the material with a 50 kV 
electron beam is one approach. This modifies the molecular structure of parts 
of a special polymer spin-coated onto a wafer. The polymer is then developed 
in a solution that dissolves either the modified or the unmodified molecules, 
leaving a wafer with a patterned plastic surface. The pattern may then be 
transferred to the wafer by an etching process. Often the polymer resists the 
etching process, hence etching will affect only the exposed areas of the 
wafer. Alternatively, the polymer is etchable, and since it comprises an 
additional layer on the wafer, a constant-rate etch process will remove the 
exposed areas of the wafer before the areas covered with the polymer, thereby 
transferring the pattern to the wafer.

Stephen Chou and others are developing an electron beam approach applicable 
to mass production. A mold or stamper, produced as described above, is used 
to imprint a pattern into a polymer which has been spin-coated onto a wafer. 
The resulting variation in thickness means that a constant rate etch process 
will remove the shallow areas first, leaving a pattern of exposed substrate 
which can be processed further.
Disclosure of Invention

Broadly the present invention is a method for fabricating surface structures which enhance the passage of elementary particles through a potential energy barrier by utilizing interference of de Broglie waves to increase the probability of emission.

In a preferred embodiment, the surface structure is created using electron beam lithography followed by etching or lift-off processes. Other embodiments include the use of oxygen atom beams to selectively oxidize the surface of a metal.

In a particularly preferred embodiment, the surface structure is mass-produced by using a replica surface, which is stamped into a resist layer. Constant rate etching techniques result in the facile and economic production of the nano-structured surfaces. In a further preferred embodiment, a "negative", or relief, of the surface required is created according to the above embodiments and used to mass-produce the surface structure in a softer material by a stamping, printing or rolling process.

The present invention provides new and improved methods and for fabricating particle-emitting surfaces having a geometrical shape for causing de Broglie interference, which have one or more of the following objects or advantages:

An object of the present invention is to provide a method for fabricating a surface having indents, the depth of which are chosen so that the probability wave of the elementary particle reflected from the bottom of the indent interferes destructively with the probability wave of the elementary particle reflected from said surface adjacent to the indents.

An advantage of the present invention is that a finely-structured surface is produced.

An advantage of the present invention is that an indented surface is produced having a lower effective work function than the unmodified surface.

An object of the present invention is to provide a method for fabricating molds, stampers or rollers which carry the geometrical shape need to cause de Broglie interference in relief, or "negative" form.

An advantage of the present invention is that the nano-structured surfaces may be easily and economically mass-produced.
**Brief Description of Drawings**

Figure 1 shows in diagrammatic form, an incident probability wave, a reflected probability wave and a transmitted probability wave interacting with a substantially planar surface.

Figure 2 shows in diagrammatic form, an incident probability wave, two reflected probability waves and a transmitted probability wave interacting with a surface having a series of indents.

Figure 3 shows in a diagrammatic form, the behavior of an electron in a metal.

Figure 4 is a diagrammatic representation of an electron beam lithographic method for manufacturing a low work function surface.

Figure 5 is a diagrammatic representation of a lift off method for manufacturing a low work function surface.

Figure 6 is a diagrammatic representation of an oxygen atom beam lithographic method for manufacturing a low work function surface.

Figure 7 is a diagrammatic representation of an oxygen beam lithographic method for manufacturing a low work function surface, in which the surface is smooth.

Figure 8 is a diagrammatic representation of a mass-production, stamper-based method for manufacturing a low work function surface.

**Reference Numerals in the Drawings**

11. Incident probability wave

13. Reflected probability wave

15. Transmitted probability wave

17. Surface

19. Indented surface

21. Reflected probability wave

40. Substrate

42. Resist layer

44. Electron source

46. Electron beam
**Detailed Description of the Invention**

Referring now to Figure 4, which shows in diagrammatic form a preferred process for making an elementary particle emitting surface having a geometrical shape for causing de Broglie interference, a substrate 40 is coated with a thin layer of resist 42 (step (a)). In a preferred embodiment, the surface is coated with a layer of resist of between 10 nm and 2 microns thickness by spin-coating and baking. In step (b), a pattern is "written" onto the surface of resist 48 by means of electron beam 46 emitted by an electron source 44, a process well-known in the art as electron beam lithography. This process changes the physical properties of resist 42, forming areas 48 which may be soluble or insoluble in an appropriate developer. In step (c) the resist-coated substrate is treated with a
developing agent. In one embodiment, exposed areas 48 are soluble, and the developer removes that part of the resist exposed to the electron beam. In step (d) substrate 40 having a pattern of resist 42 on its surface, is exposed to an etching agent which etches exposed areas of the substrate, to form a series of pits 49. In step (e), the resist 42 is removed to give a substrate, whose surface is patterned with a series of pits 49 giving the surface a geometrical shape which causes de Broglie interference. In a preferred embodiment, the substrate is silica. In another preferred embodiment, the substrate is diamond. In yet another embodiment, the substrate is gallium arsenide (GaAs).

Referring now to Fig. 5, which shows in diagrammatic form another preferred process for making an elementary particle emitting surface having a geometrical shape for causing de Broglie interference, a substrate 50 having a pattern of resist 52 is made using electron beam lithography as described above in Fig. 4, steps (a) to (c). In step (b) a material 54, preferably a metal, is deposited onto the substrate using vapor deposition techniques well known in the art. Material 54 covers at least the exposed areas of substrate 50 as defined by the pattern. In step (c) the pattern is transferred to a substrate by removing pattern 52 and the parts of the second material 54 which lie above the pattern, whereby some of the second material 54 remains in a pattern of the shape of the spaces of the original pattern. Thus substrate 50 is exposed to a developing agent, which lifts off or dissolves remaining areas of the resist, and with this, is lifted off material 54 on top of resist 52, leaving raised areas 56 of material 54, giving the surface of substrate 50 a geometrical shape which causes de Broglie interference.

In a preferred embodiment, the substrate is silica. In another preferred embodiment, the substrate is diamond. In yet another embodiment, the substrate is gallium arsenide (GaAs).

Referring now to Fig. 6, which shows in diagrammatic form a further preferred process for making an elementary particle emitting surface having a geometrical shape for causing de Broglie interference, a metal substrate 60 is exposed to an oxygen atom beam 68 from oxygen atom source 66, which creates a pattern of oxide 62 in the surface of the substrate (step (a)). In step (b) anisotropic etching of the oxide pattern 62 yields a series of pits 64, giving the surface of substrate 60 a geometrical shape which causes de Broglie interference.

Referring now to Fig. 7, which shows in diagrammatic form a yet further preferred process for making an elementary particle emitting surface having a geometrical shape for causing de Broglie interference, a metal substrate 70
is exposed to an oxygen atom beam 68 from oxygen atom source 66, which
creates a pattern of oxide 72 in the surface of the substrate (step (a)).
This pattern is approximately twice the depth required for causing de Broglie
interference. In step (b) isotropic oxidation of the surface yields a flat
surface having indented oxide regions 74. The different energy distribution
of oxide electrons creates a potential energy barrier of the sort described
above, leading to the enhanced emission of electrons from the surface.

Any of the patterned substrates described above can be used as an electrode,
or in a particularly preferred embodiment, the pattern on the substrate is
created as the relief or "negative" of the pattern needed to cause de Broglie
interference and used as a mold, stamper or roller for preparing large
numbers of patterned substrates. This process is illustrated in Fig. 8.

Referring now to Fig. 8, step (a) shows a patterned substrate 40 produced
according the process shown in Fig 4, and a substrate 80 which has been
coated with a resist layer 82 as shown in Fig. 4, step (a). Any of the other
patterned substrates produced as described above may also be used. In step
(b), patterned substrate 40 is used as the stamper or mold and is pressed
into the surface of resist layer 82. In step (c), patterned substrate 40 is
removed, leaving a pattern in resist layer 82. In step (d), substrate 80 is
treated with a constant-rate etchant, which causes the formation of a pattern
in the surface of substrate 80 giving the surface of substrate 80 a
geometrical shape which causes de Broglie interference.

**Industrial Applicability**

Thus the method for fabricating elementary particle-emitting surfaces
described above produces surfaces in which the passage of elementary
particles through a potential barrier is enhanced.

The invention should not be construed as limited to the specific embodiments
and methods described above but should be seen to include equivalent
embodiments and methods. For example, the polymer described above could be
replaced by many materials that are affected by electron beams. Furthermore,
the use of beams to create the required pattern can be implemented in many
ways and not only as specifically described above. Etching may or may not
take place, depending on the required method of transferal of the pattern
"written" onto the polymer. The patterned substrate may form an electrode
itself, or the pattern on it may be transferred to another material which may
serve as an electrode, or may act as a mold from which electrodes are formed,
or may even act as a mold for which molds to make electrodes are formed.
Alternatively the mold is made of a higher melt material which is then stamped or rolled into a heated, softened lower melt material. Preferred materials are silica for the higher melt material and gold for the lower melt material.

Etching and lift-off methods as described above may be used for transferal of the pattern "written" into the resist to a substrate, or any technologies obvious in the art of pattern transferal. The substrate onto which resist is mounted when the pattern is "written" may or may not be the surface to which the pattern is transferred.

A yet further approach is to use a metal ion beam to build up surface structures.
Claims

We claim:

1. A process for making an elementary particle emitting surface having a geometrical shape for causing de Broglie interference between said elementary particles, comprising the steps of:
   a. positioning into the path of a particle beam a layer of material whose molecules are modified when exposed to an electron beam,
   b. directionally focusing the particle beam on the material in a pattern that comprises the two-dimensional features of a cross-section of said geometrical shape, whereby the structure of those molecules exposed to the beam is modified,
   c. developing said material to remove molecules of one type of structure from the material, whereby a pattern is left,
   d. transferring said pattern to a surface of a substrate whereby said geometrical shape is created on said substrate.

2. The process of claim 1 wherein said particle beam is an electron beam.

3. The process of claim 2 including the step of mounting said material on a substance prior to exposure to said electron beam.

4. The process of claim 3 wherein the step of mounting the material on said substance is done by spin coating a polymer onto said substance.

5. The process of claim 4 wherein the step of transferring said pattern is done by transferring said pattern to a surface of said substance beneath said polymer.

6. The process of claim 5 wherein the step of transferring said pattern to said substance beneath said polymer is done by etching.

7. The process of claim 6 wherein the etching step is done by etching means selected from the group consisting of: chemical etching, isotropic etching, and anisotropic etching.

8. The process of claim 2 wherein the step of transferring said pattern to a substrate is done by etching away said material and said substrate on
which the material is mounted, so that the etching etches deeper into said substrate in places not covered by said material.

9. The process of claim 8 wherein the etching step is done by etching means selected from the group consisting: of chemical etching, isotropic etching, and anisotropic etching.

10. The process of claim 2 including the step of depositing a second material on said material on said substrate, to cover at least the exposed areas of said substrate as defined by the pattern, prior to transferring said pattern.

11. The process of claim 10 wherein the step of transferring the pattern to a substrate is done by removing the pattern and the parts of the second material which lie above the pattern, whereby some of the second material remains in a pattern of the shape of the spaces of the original pattern.

12. The process of claim 11 wherein the removing step is done by a means selected from the group consisting of: chemical etching, isotropic etching, anisotropic etching, evaporating and dissolving means.

13. The process of claim 1 wherein said particle beam is an oxygen atom beam.

14. The process of claim 13 wherein the step of transferring said pattern to a substrate is done by isotropically oxidizing said surface of said substrate.

15. The process of claim 1 additionally comprising the steps of:
   i providing a second substrate coated with a polymer coat,
   ii pressing said surface having said geometrical shape against said polymer coat on said second substrate,
   iii etching said second substrate using a constant rate etchant to yield a predetermined pattern on the surface of said second substrate.

16. The process of claim 1 additionally comprising the steps of:
i bringing said surface having said geometrical shape into contact with a second substrate,

ii applying pressure to said surface having said geometrical shape, to cause said second substrate to have a surface having impressions opposite to those of said surface having a geometrical shape.

17. The process of claim 16 additionally comprising the step of heating said second substrate, said second substrate having a melting temperature lower than said surface having said geometrical shape, whereby said second substrate is softened.

18. The process of claim 16 additionally comprising the step of treating said second substrate with a hardening agent, whereby said second substrate is hardened after said impressions have been formed.

19. A process for preparing an elementary particle emitting surface having a geometrical shape for causing de Broglie interference between said elementary particles, comprising the steps of:

a. providing a metal substrate,

b. etching said metal substrate by oxygen atom beam etching means to give an oxide pattern,

c. dissolving said oxide to give a substrate having said predetermined lattice pattern.

20. A process for preparing an elementary particle emitting surface having a geometrical shape for causing de Broglie interference between said elementary particles, comprising the steps of:

a. providing a metal substrate,

b. etching said metal substrate by oxygen atom beam etching means to give an oxide pattern,

c. subjecting the substrate to isotropic oxidation, yielding a flat surface having indented oxide regions, which provide a potential energy barrier causing de Broglie interference between said elementary particles.
Figure 2
Figure 3

\[ \epsilon \]

\[ \epsilon_f + \varphi \]

\[ 2\epsilon_f - \epsilon_0 \]

\[ \epsilon_f \]

\[ \epsilon_0 \]

\[ 0 \]

1 2 3
Figure 4

(a)

(b)

(c)

(d)

(e)
Figure 5

(a)  

(b)  

(c)
Figure 7

(a)

(b)
Figure 8

(a) 

(b) 

(c) 

(d)
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
   IPC(6) : Please See Extra Sheet.
   US CL : Please See Extra Sheet.
   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)

   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 practicable, search terms used)
   Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>X,P</td>
<td>US 5,772,905 A (CHOU) 30 June 1998 (30-06-98), see: abstract; figures 1 and 5; col. 1, lines 19-25; col.2, lines 19-44; col. 4, lines 33-67; col. 5, lines 10-14, 43-45, 55; column 6, lines 13-18.; col. 7, lines 1-5.</td>
<td>1-12, 15-18</td>
</tr>
<tr>
<td>Y</td>
<td>US 5,119,151 A (ONDA) 02 June 1992 (02-06-92), see: abstract; col. 1, lines 39-48; col. 6, lines 41-47, 64-68; col.7, lines 10-35.</td>
<td>1-12, 15-18</td>
</tr>
<tr>
<td>Y</td>
<td>US 4,983,540 A (YAMAGUCHI et al.) 08 January 1991 (08-01-91), see abstract; col. 1, lines 6-11; col. 3, line 65 - col. 4, line 62.</td>
<td>13, 14, 18, 19</td>
</tr>
<tr>
<td>A</td>
<td>US 4,958,201A (MIMURA) 18 September 1990 (18-09-90).</td>
<td>1-20</td>
</tr>
</tbody>
</table>

[X] Further documents are listed in the continuation of Box C.  [ ] See patent family annex.

Date of the actual completion of the international search
29 JUNE 1999

Date of mailing of the international search report
16 JUL 1999

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. (703) 305-3230

Authorized officer
[Signature]
Telephone No. (703) 308-0661

Form PCT/ISA/210 (second sheet)(July 1992)*
<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>US 5,229,320 A (UGAJIN) 20 July 1993 (20-07-93).</td>
<td>1-20</td>
</tr>
</tbody>
</table>
A. CLASSIFICATION OF SUBJECT MATTER:
 IPC (6):
G03F 7/35, 7/26, 7/34, 7/38

A. CLASSIFICATION OF SUBJECT MATTER:
US CL:
430/199, 291, 296, 311, 313, 322, 323, 324, 325; 216/11, 13, 40, 52, 54, 66, 67

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):
APS: search terms: de Broglie with (wave or interference), interference wave, (oxygen or ion or electron or e) with beam lithography, elementary or electron emitting device, quantum with (effects or wires), spin coating, etching