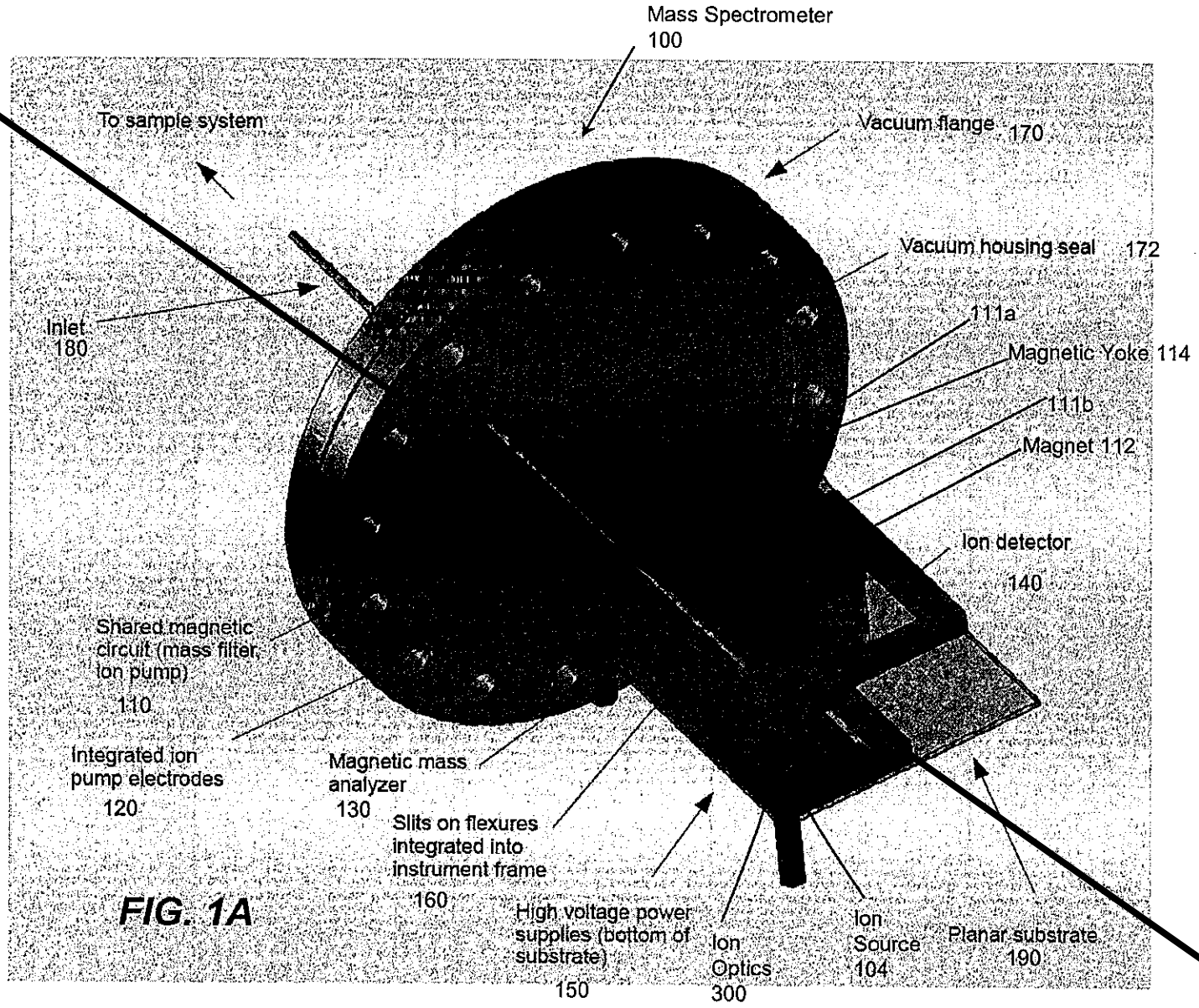

Mass Spectrometer
100
To sample system
Vacuum flange 170
Vacuum housing seal 172
Inlet
180
111a
Magnetic Yoke 114
111b
Magnet 112
Ion detector
140
Shared magnetic
circuit (mass filter,
ion pump)
110
Integrated ion
pump electrodes
120
Magnetic mass
analyzer
130
Slits on flexures
integrated into
instrument frame
160
High voltage power
supplies (bottom of
substrate)
150
Ion
Optics
300
Ion
Source
104
Planar substrate
190

FIG. 1A

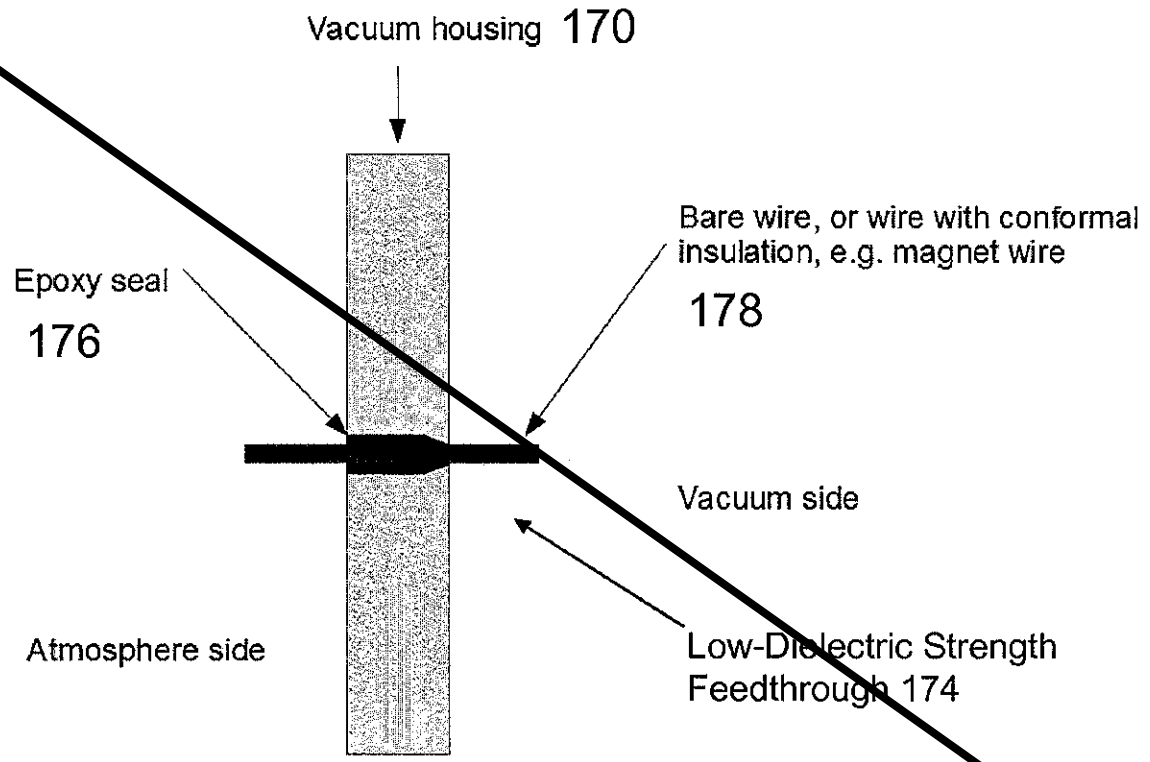

Vacuum housing 170
Bare wire, or wire with conformal insulation, e.g. magnet wire
178
Epoxy seal
176
Vacuum side
Atmosphere side
Low-Dielectric Strength Feedthrough 174

FIG. 1B

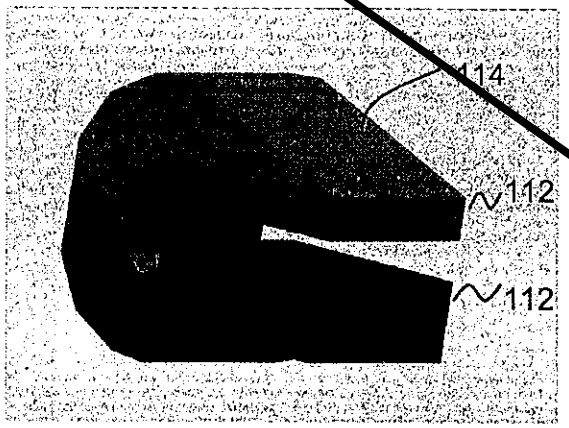

114
112
112

FIG. 1C

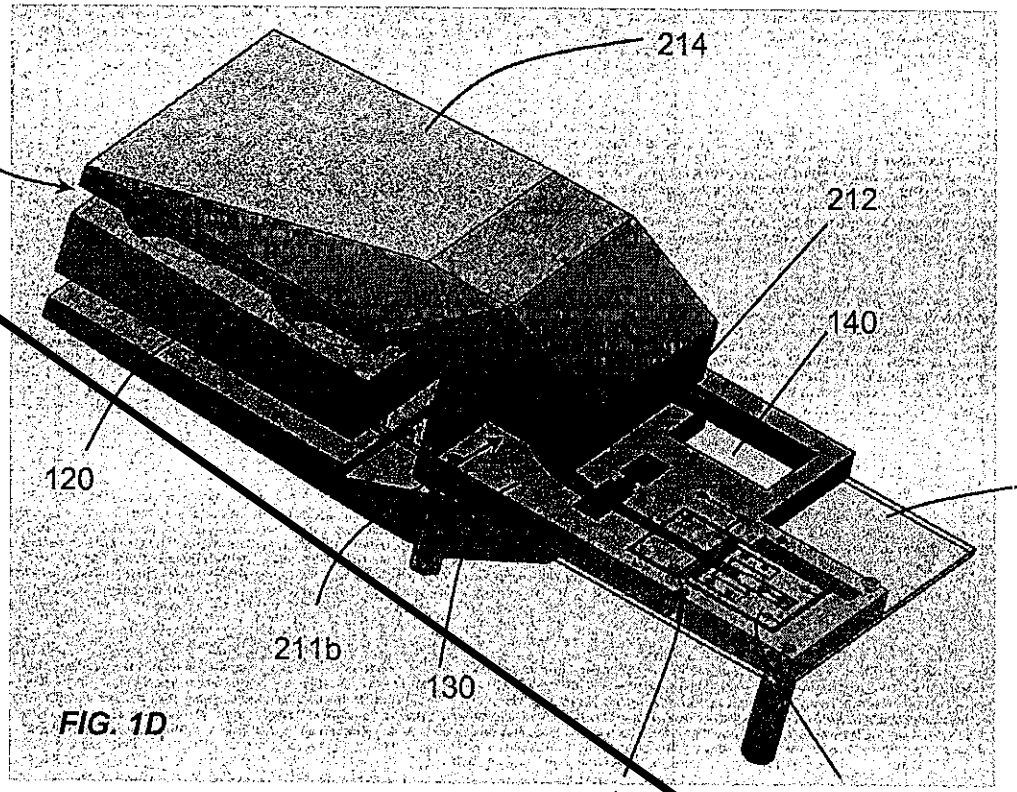

211a
214
212
140
120
190
211b
130
Ion
Optics
300
Ion
Source
104

FIG. 1D

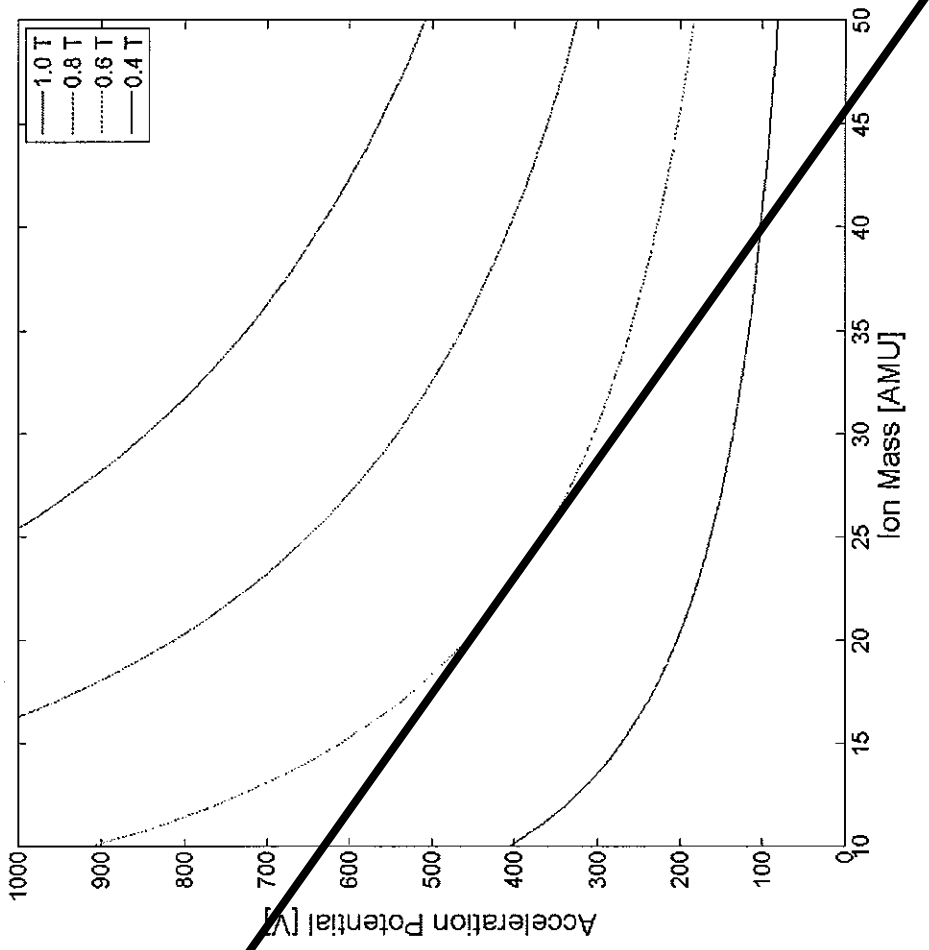

1.0 T
0.8 T
0.6 T
0.4 T
Acceleration Potential [V]
Ion Mass [AMU]
0
100
200
300
400
500
600
700
800
900
1000
10
15
20
25
30
35
40
45
50

FIG. 2

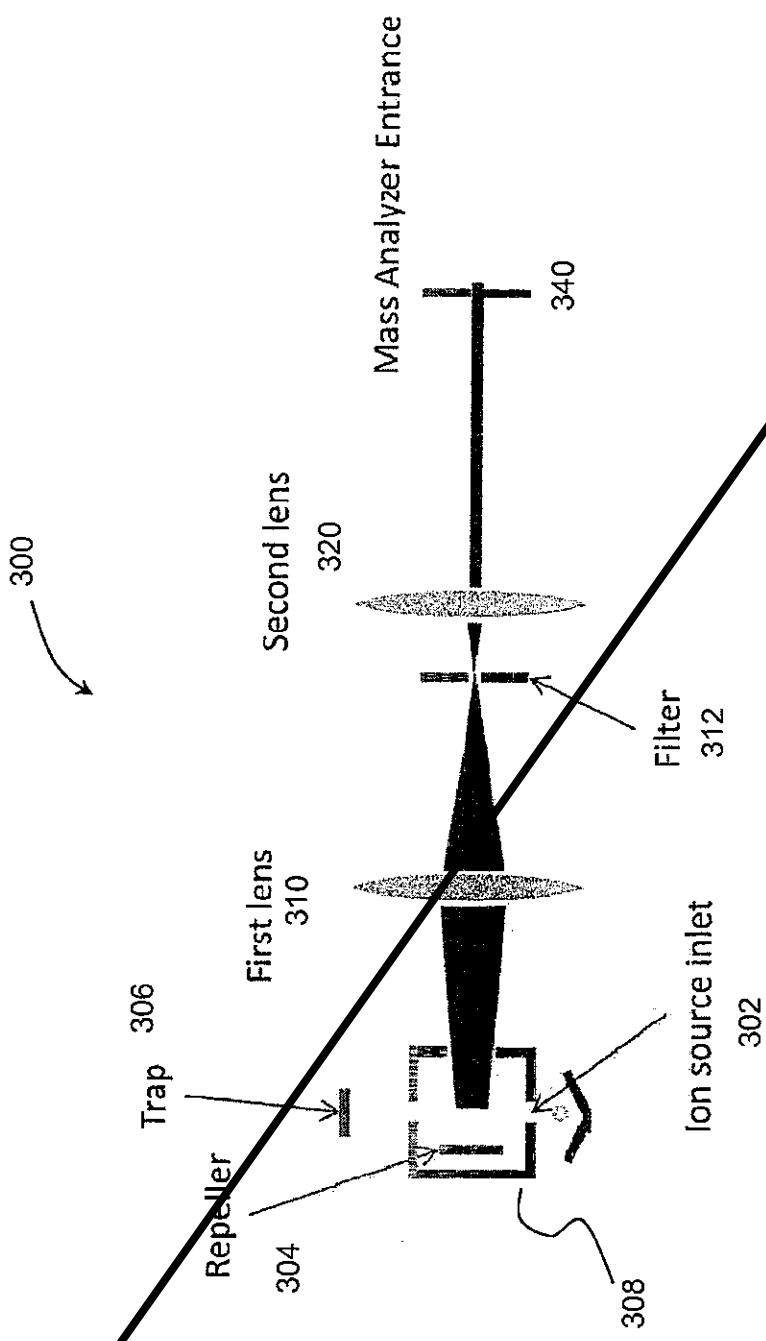

300
Mass Analyzer Entrance
340
Second lens
320
Filter
312
First lens
310
Trap
306
Repeller
304
Ion source inlet
302
308

FIG. 3

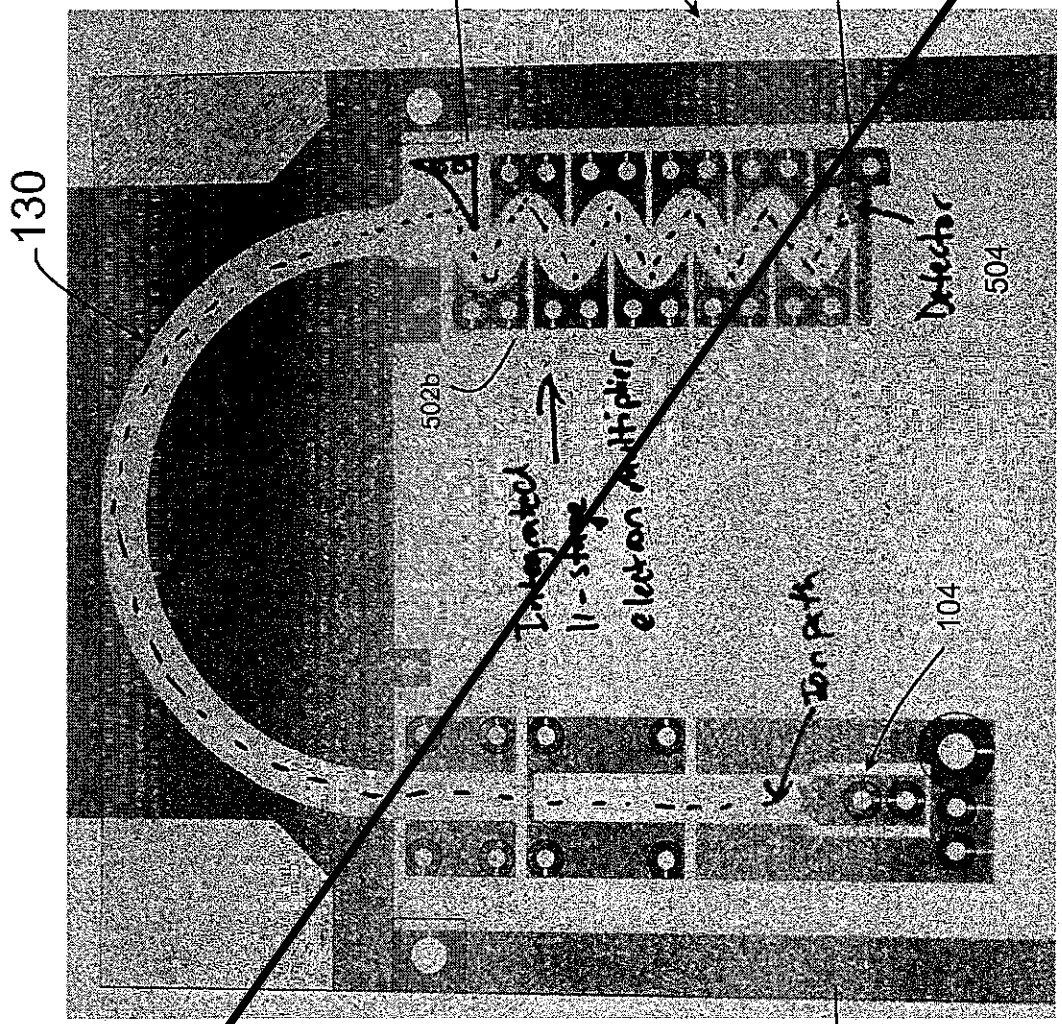


FIG. 4

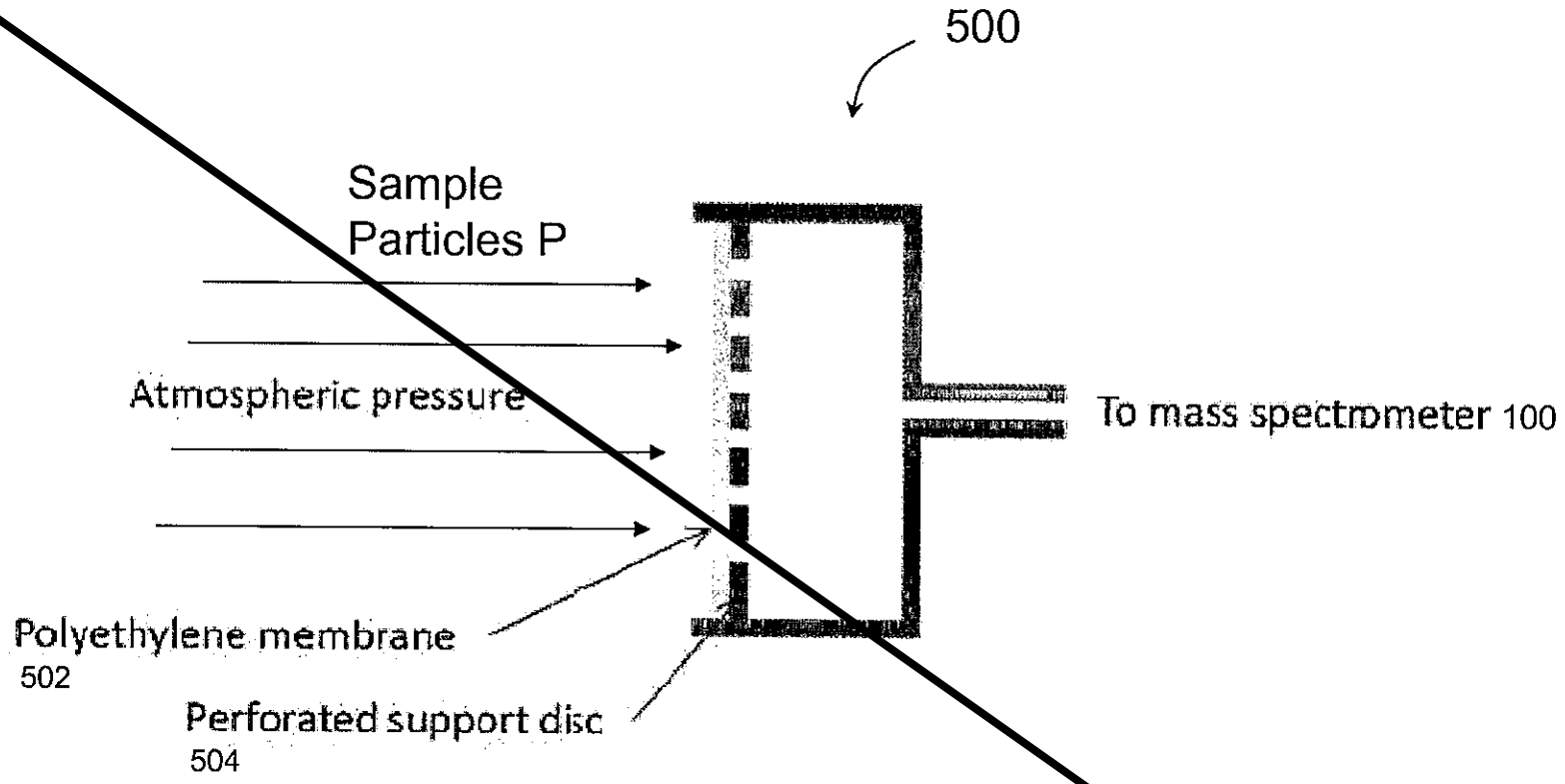

500
Sample
Particles P
Atmospheric pressure
To mass spectrometer 100
Polyethylene membrane
502
Perforated support disc
504

FIG. 5

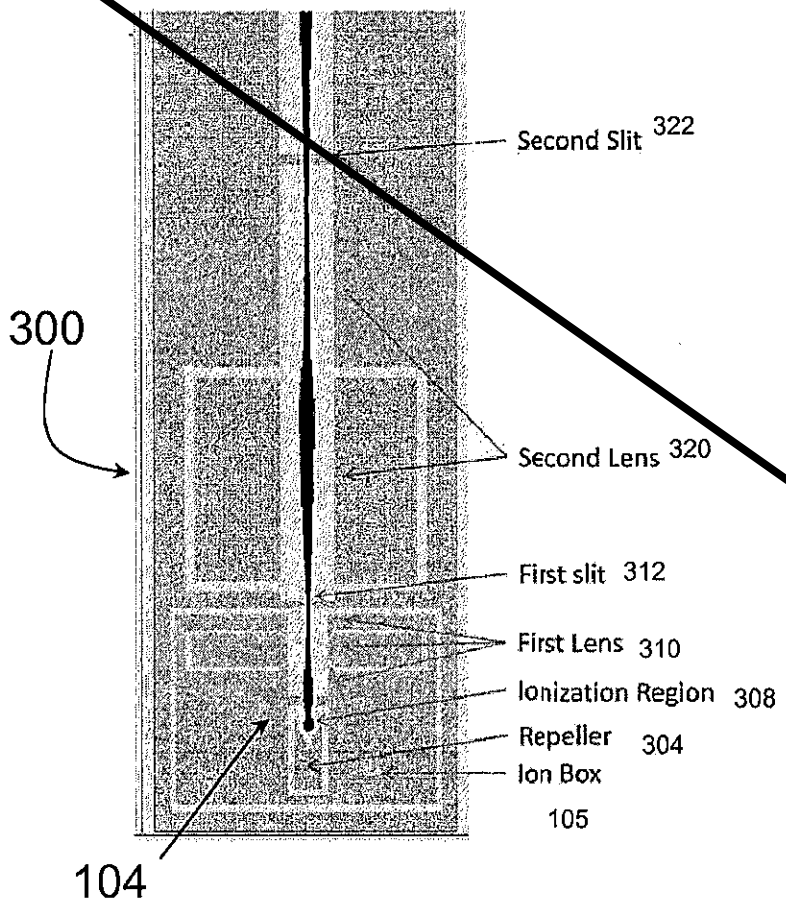

300
Second Slit 322
Second Lens 320
First slit 312
First Lens 310
Ionization Region 308
Repeller 304
Ion Box
105
104

FIG. 6A

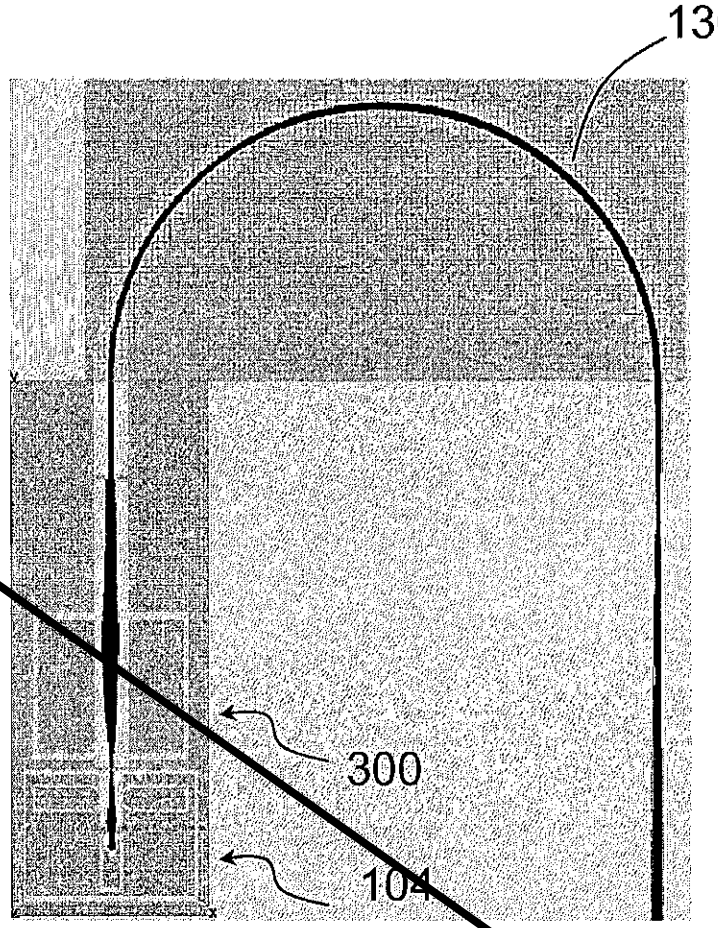

130
300
104

FIG. 6B

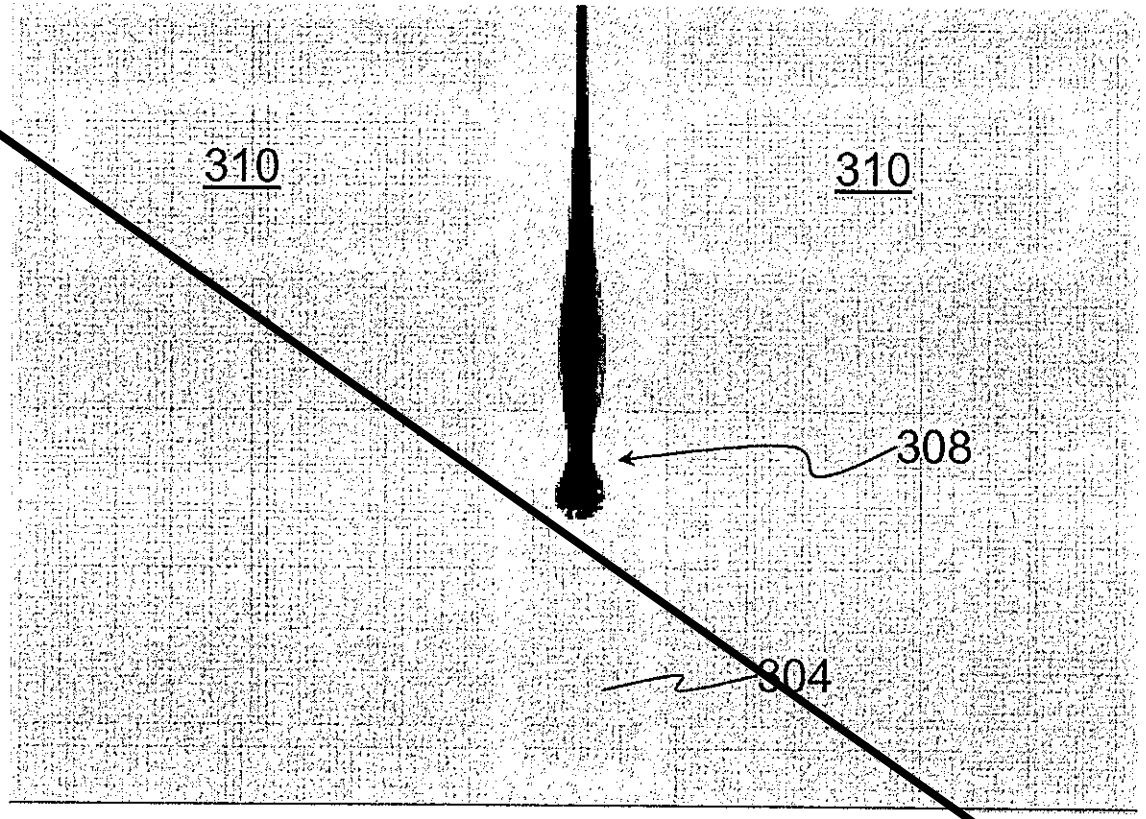


FIG. 6C

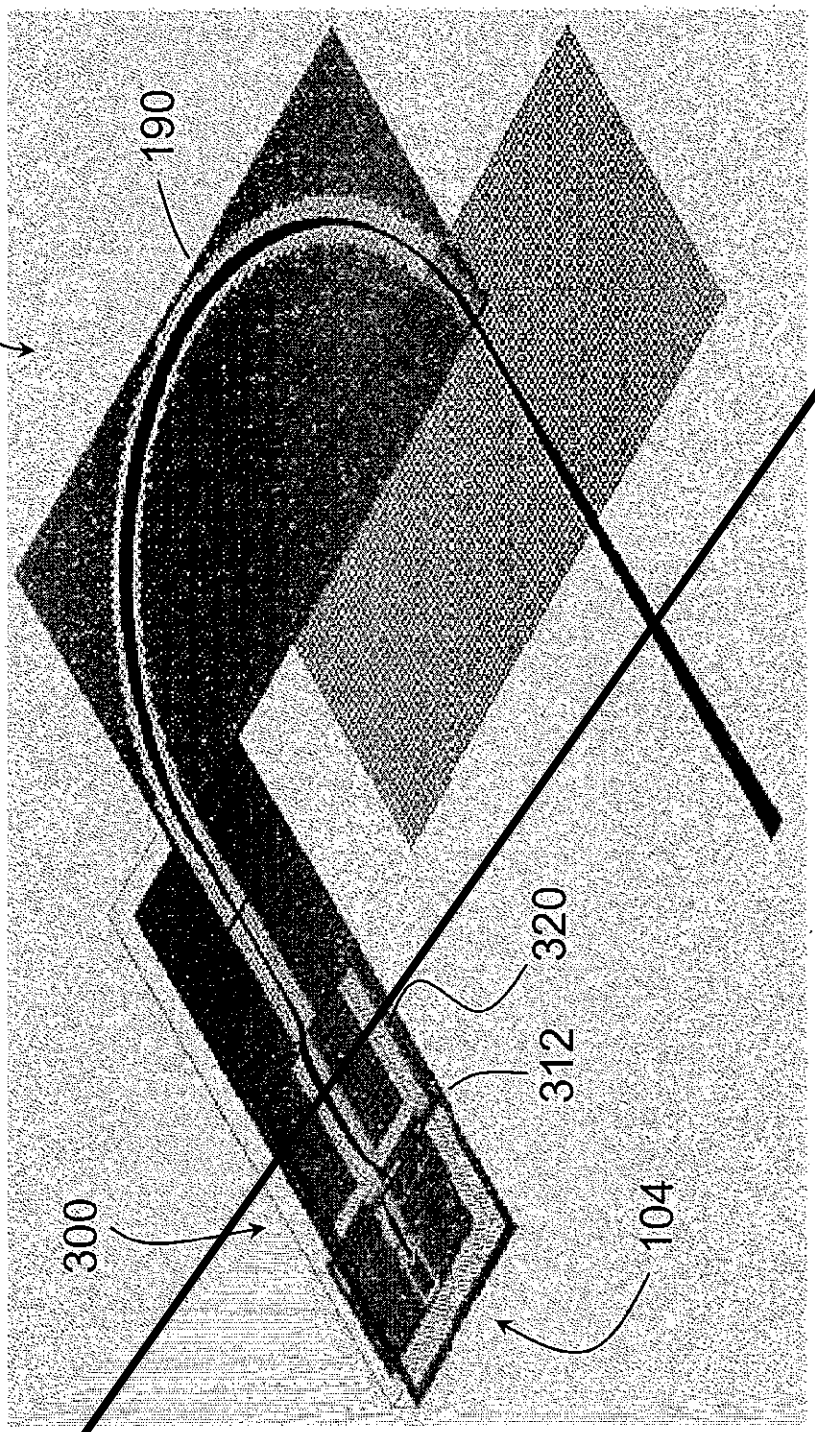


FIG. 7

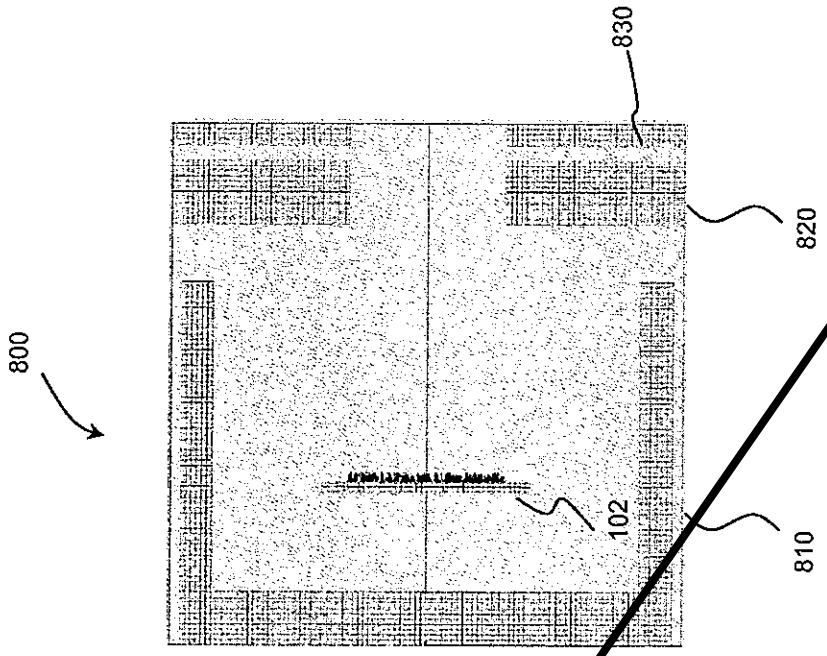


FIG. 9

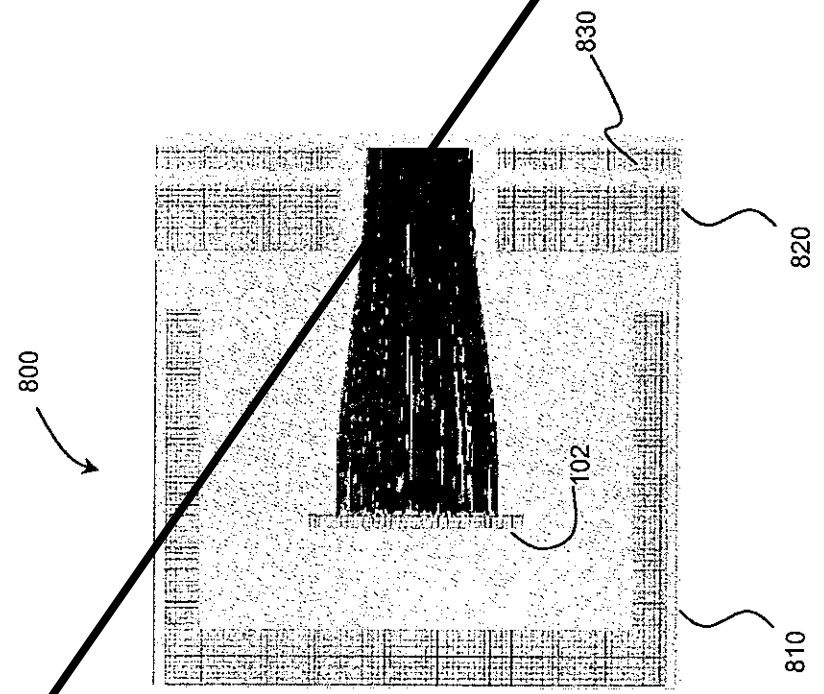


FIG. 8

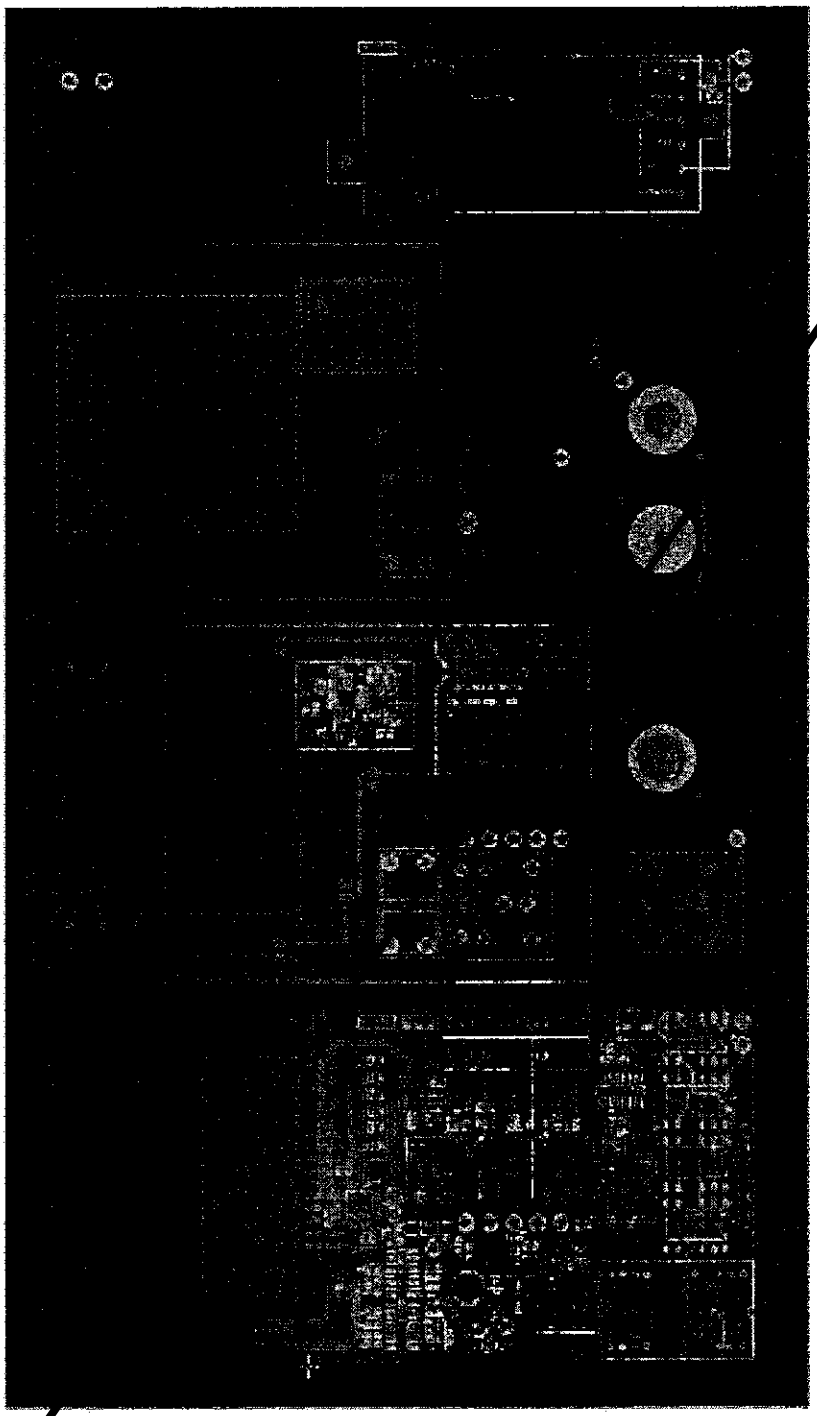


FIG. 10

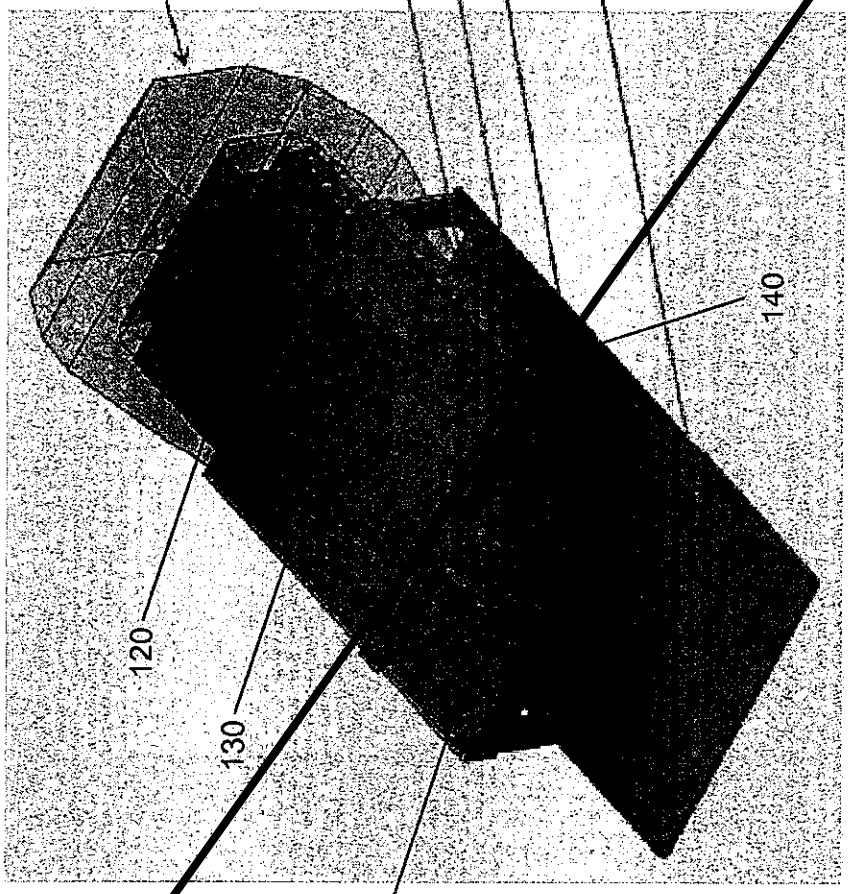

Magnet Yoke 114, 214
Mass Analyzer Assembly 1100
Top Cover 1102
Analyzer Electrode 1110
Bottom Cover 1104
Electronics Board 1120
120
130
140
190

FIG. 11

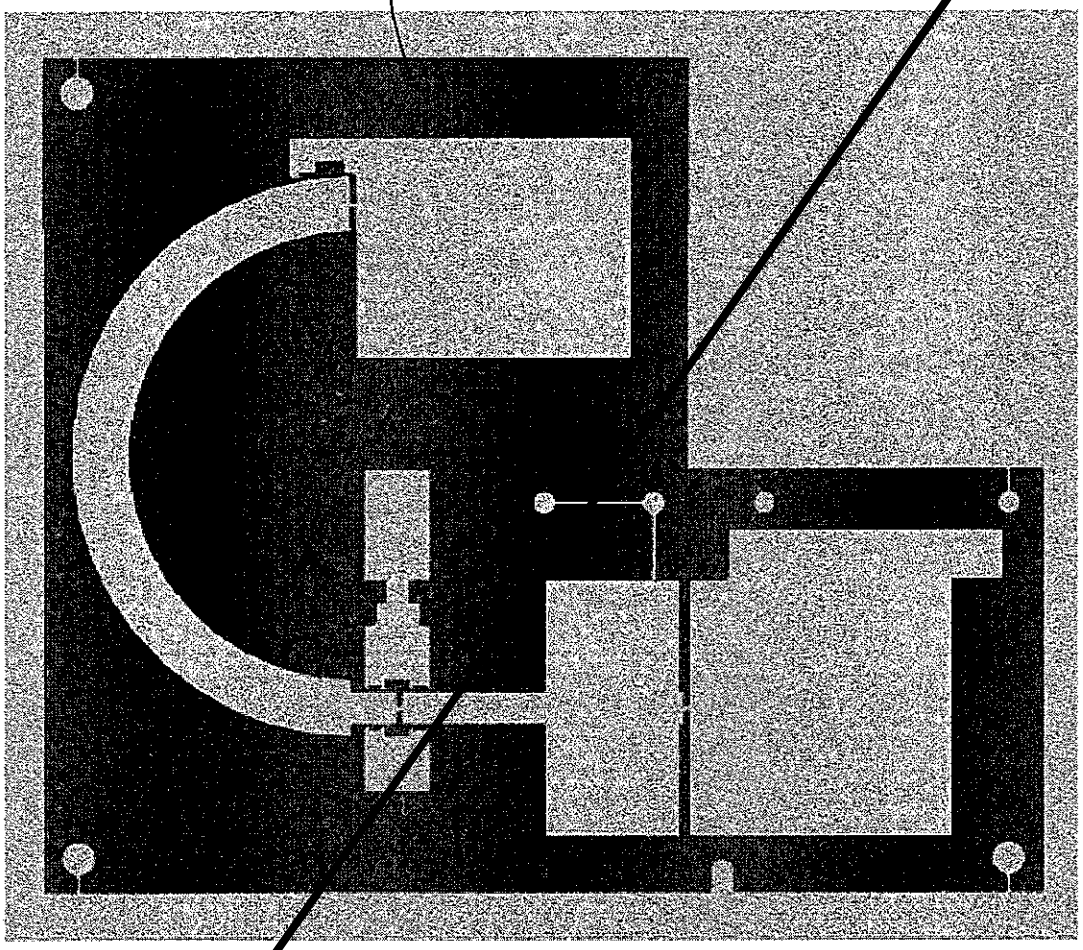


FIG. 12

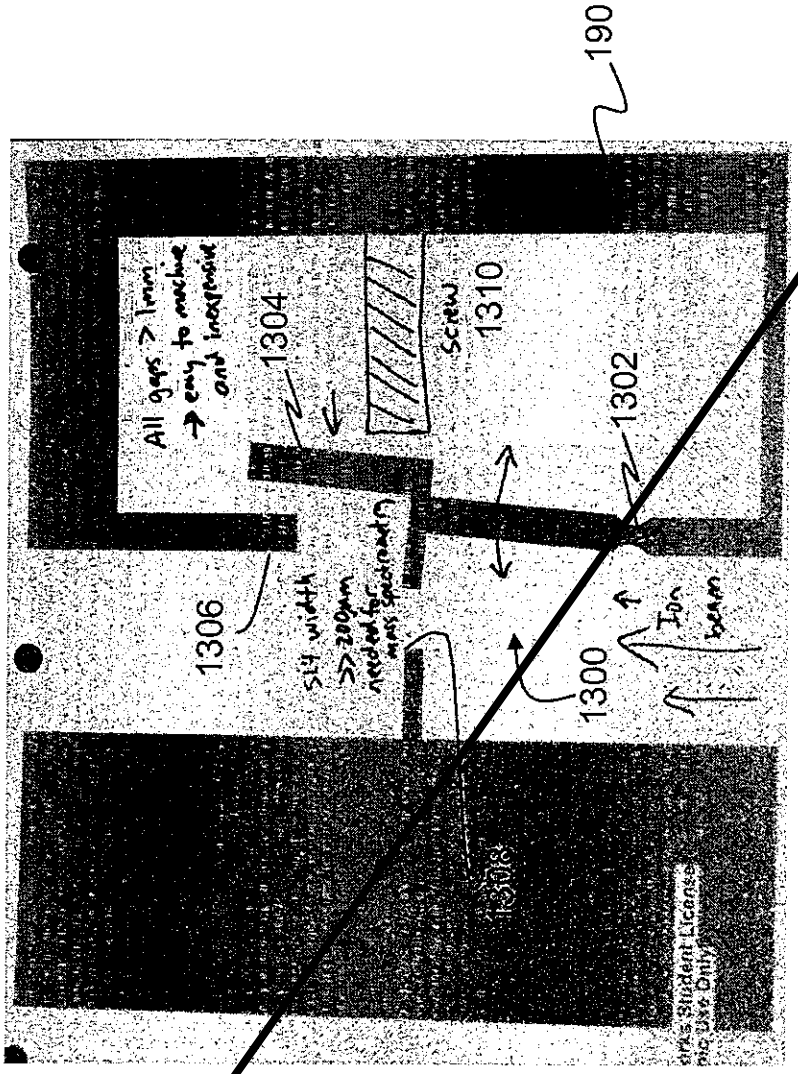

190
All gaps > 1mm
→ easy to machine
and inspect
1304
Screw
1310
1302
1306
Slit width
≥ 280μm
needed for
mass spectrometry
1300
Ion
beam

FIG. 13

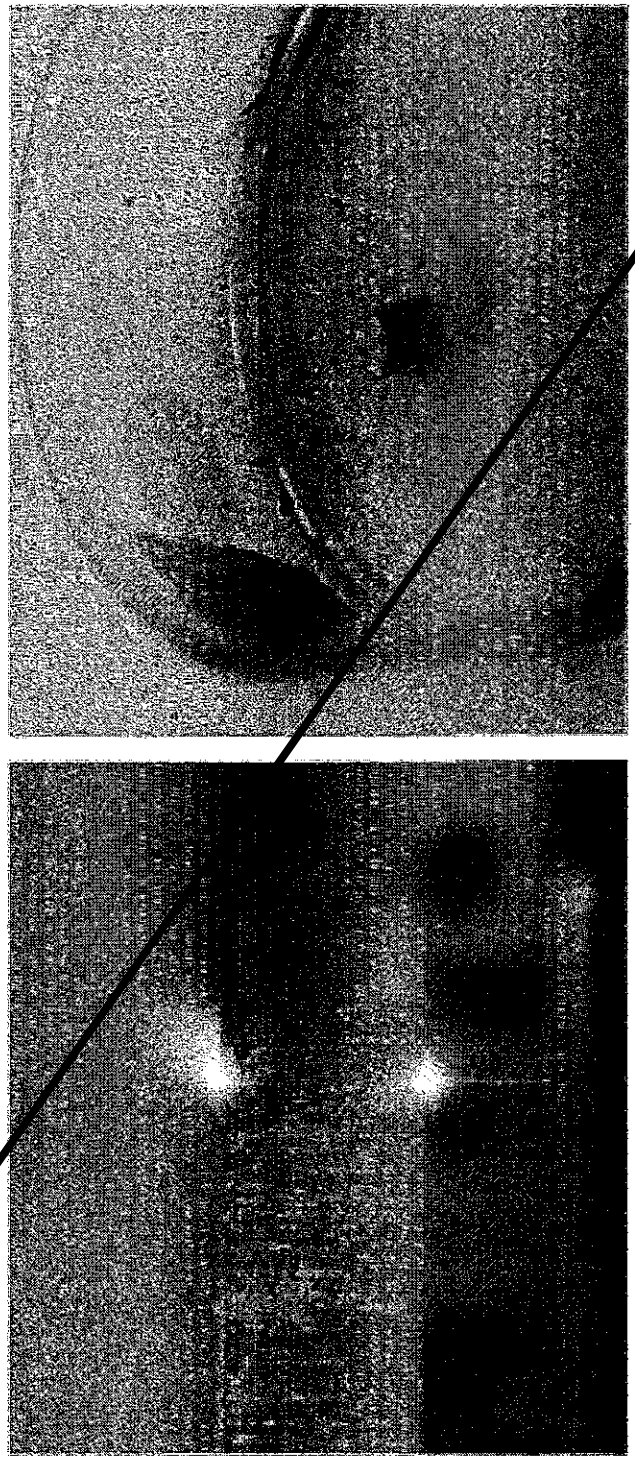


FIG. 14

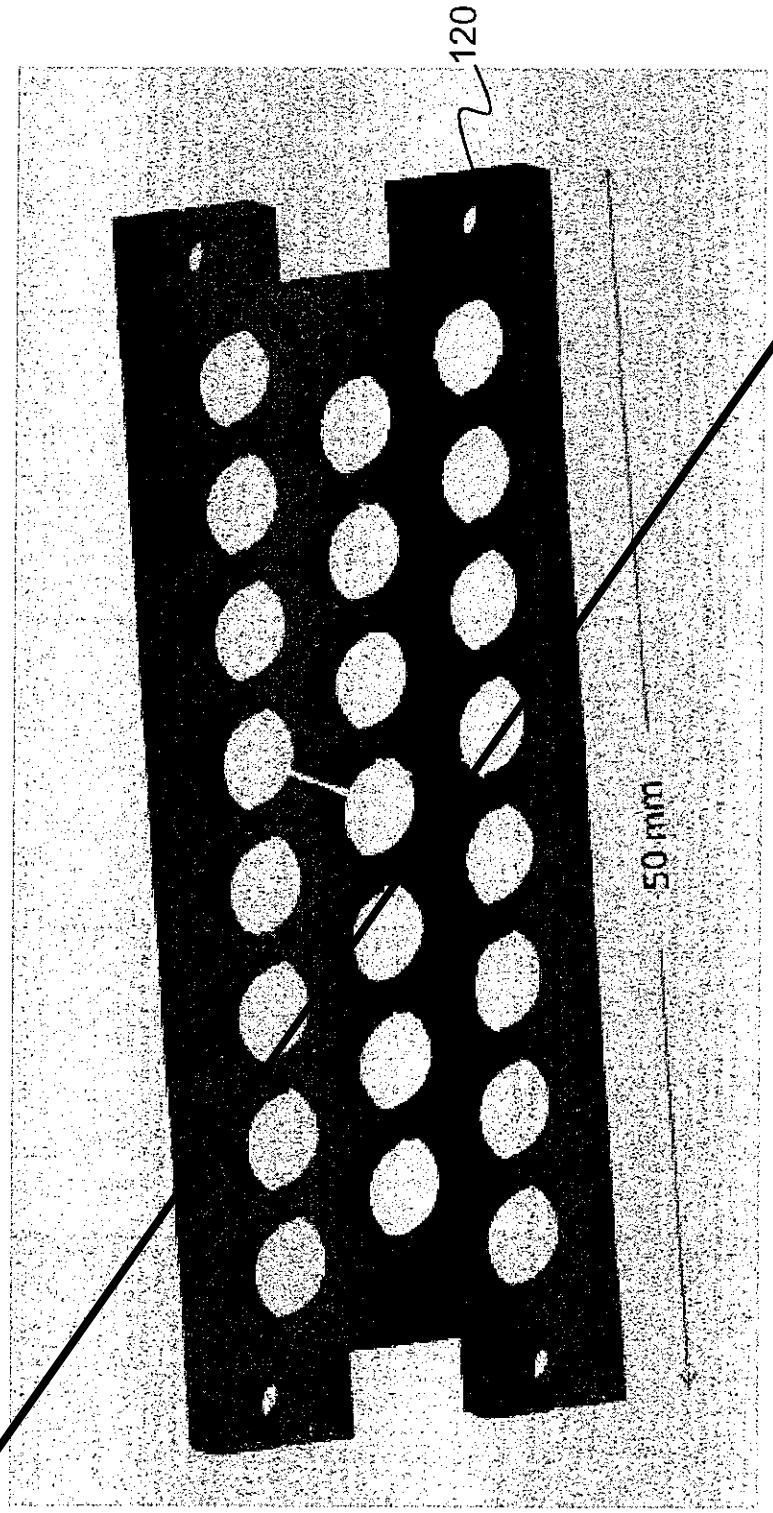


FIG. 15

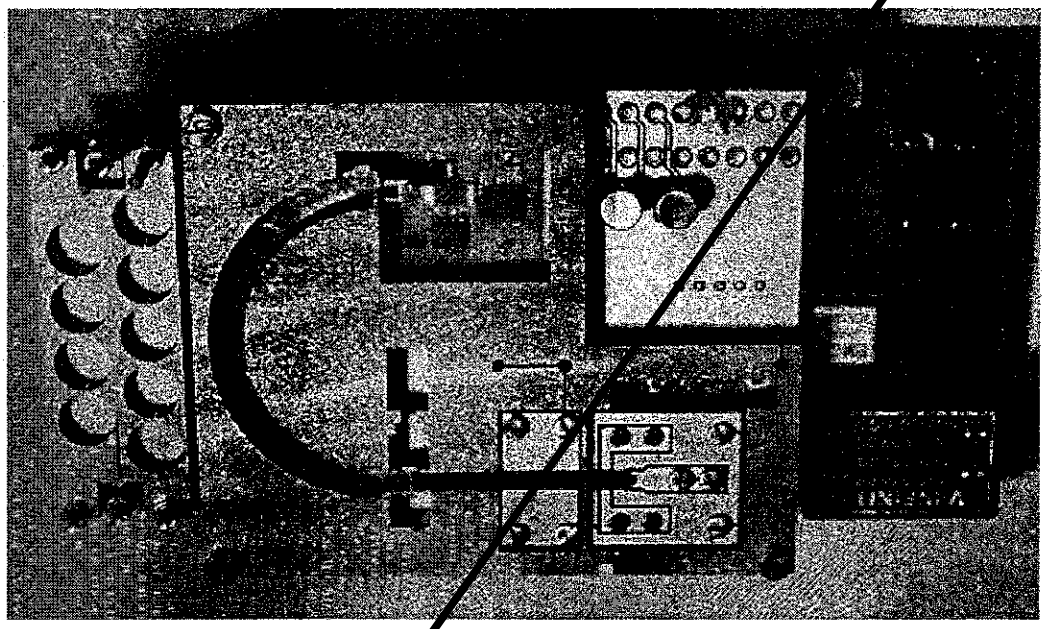


FIG. 16

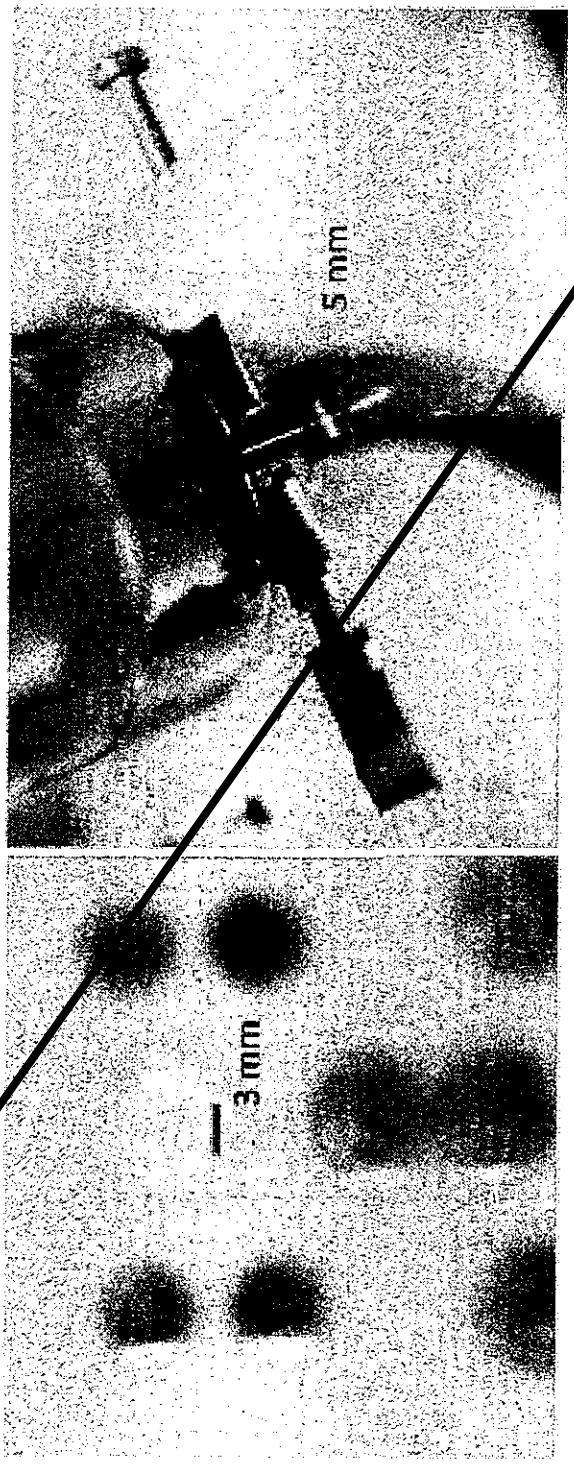


FIG. 17

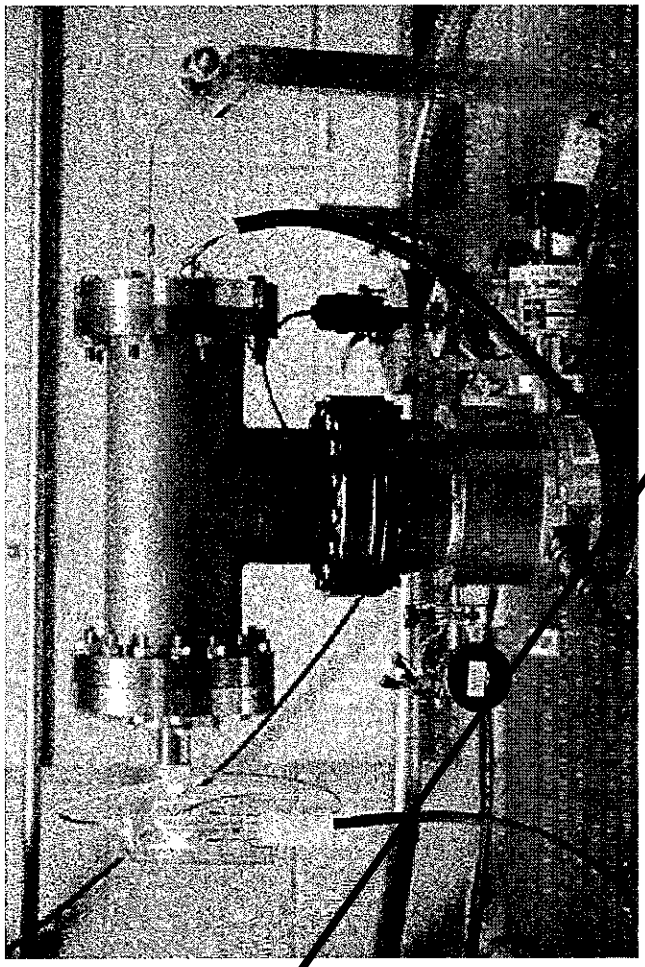


FIG. 18B

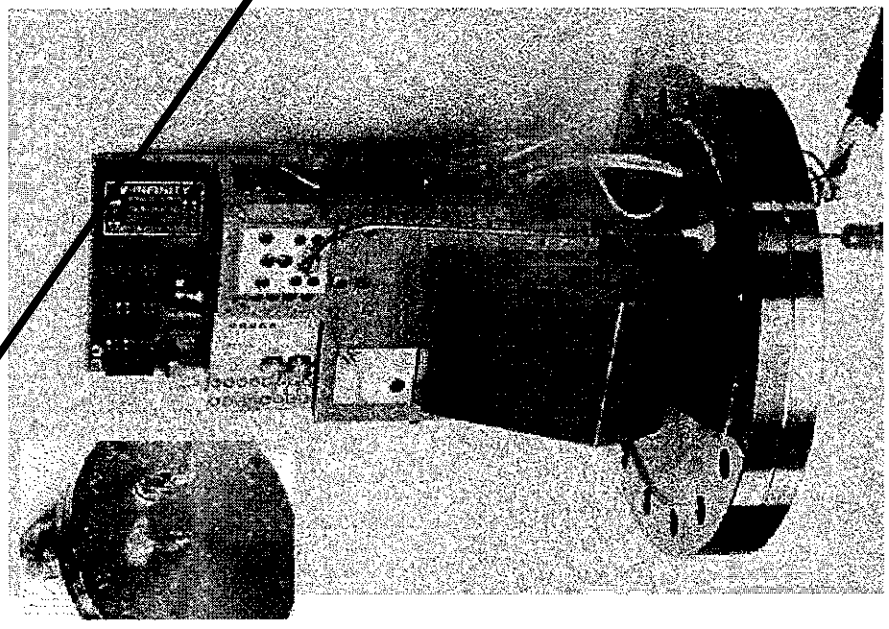


FIG. 18A

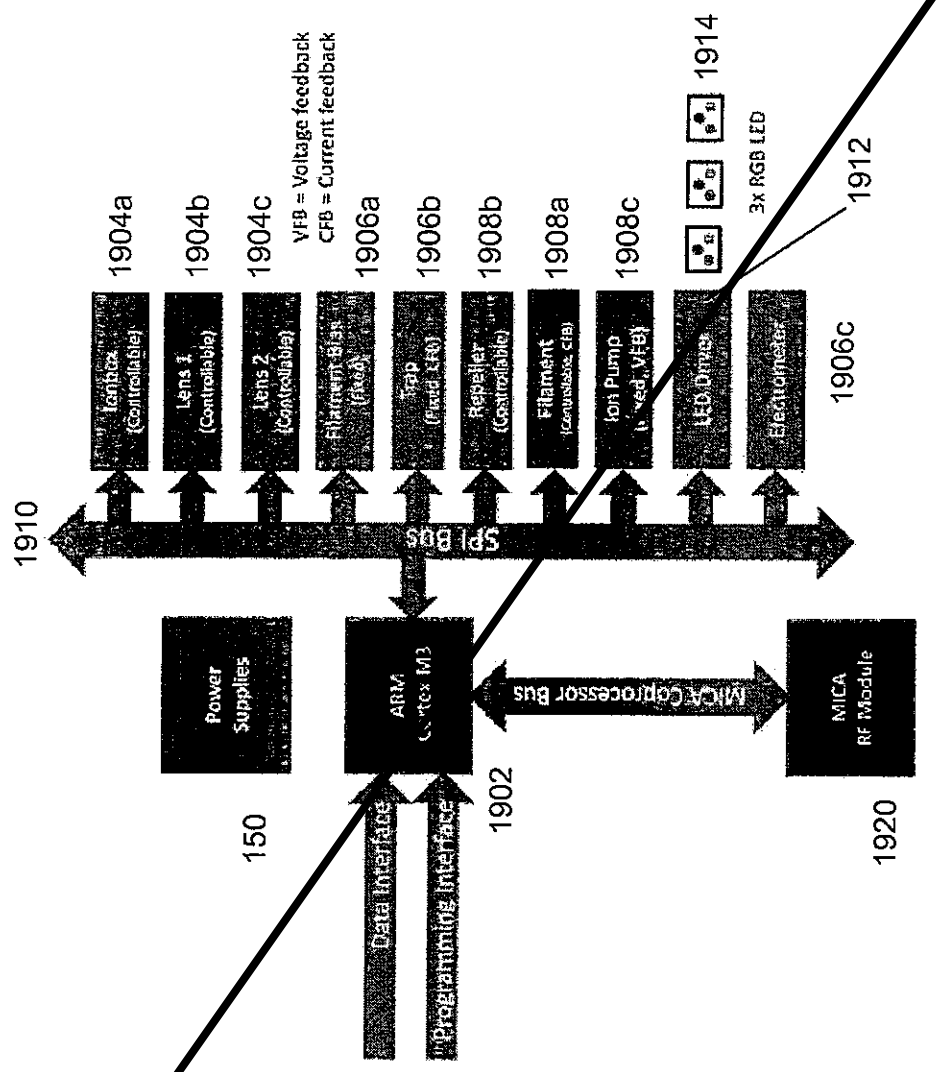

1904a
1904b
1904c
1906a
1906b
1908b
1908a
1908c
1914
1912
1906c
1910
1902
150
1920
VFB = Voltage feedback
CFB = Current feedback
3x RGB LED
Lens 1 (Controllable)
Lens 2 (Controllable)
Trap (Fixed 1.8V)
Repeller (Controllable)
Filament (Controllable, CFB)
LED Driver
Electrometer
SPI Bus
Power Supplies
ARM
MICA
RF Module
MICA coprocessor Bus
Data Interface
Programming Interface

FIG. 19

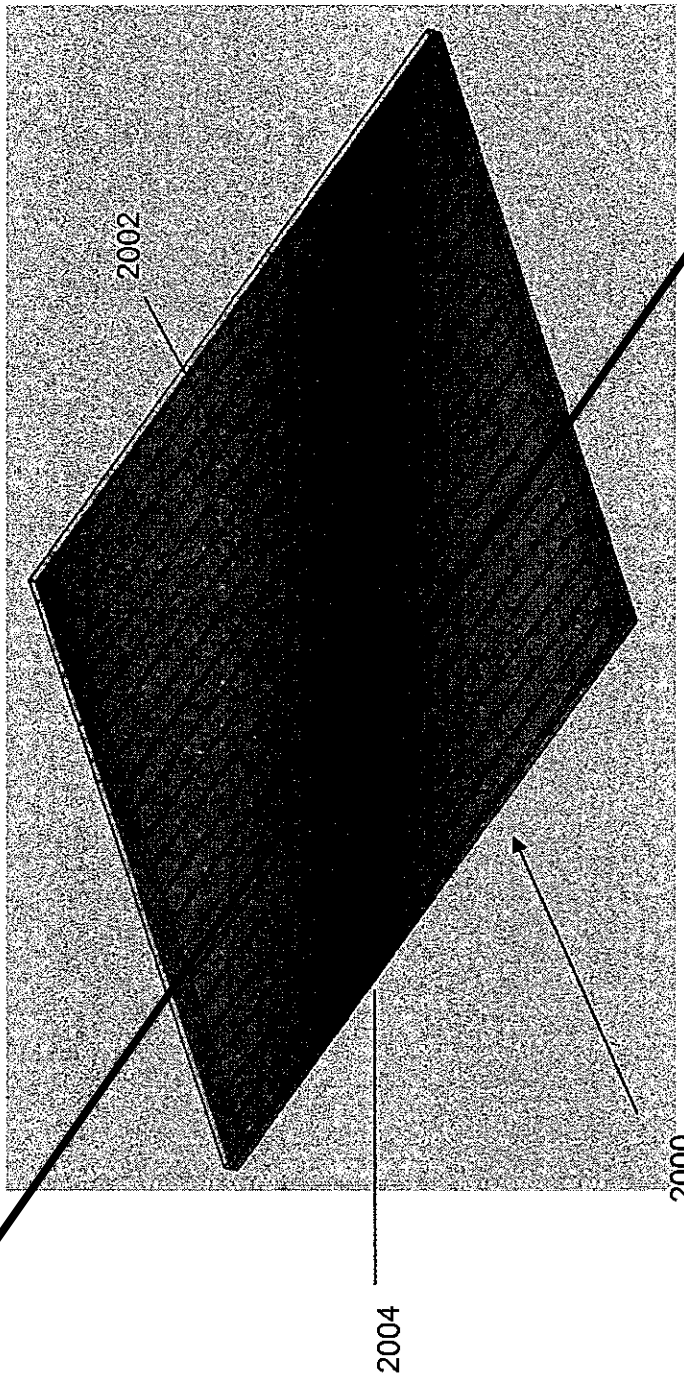


FIG. 20

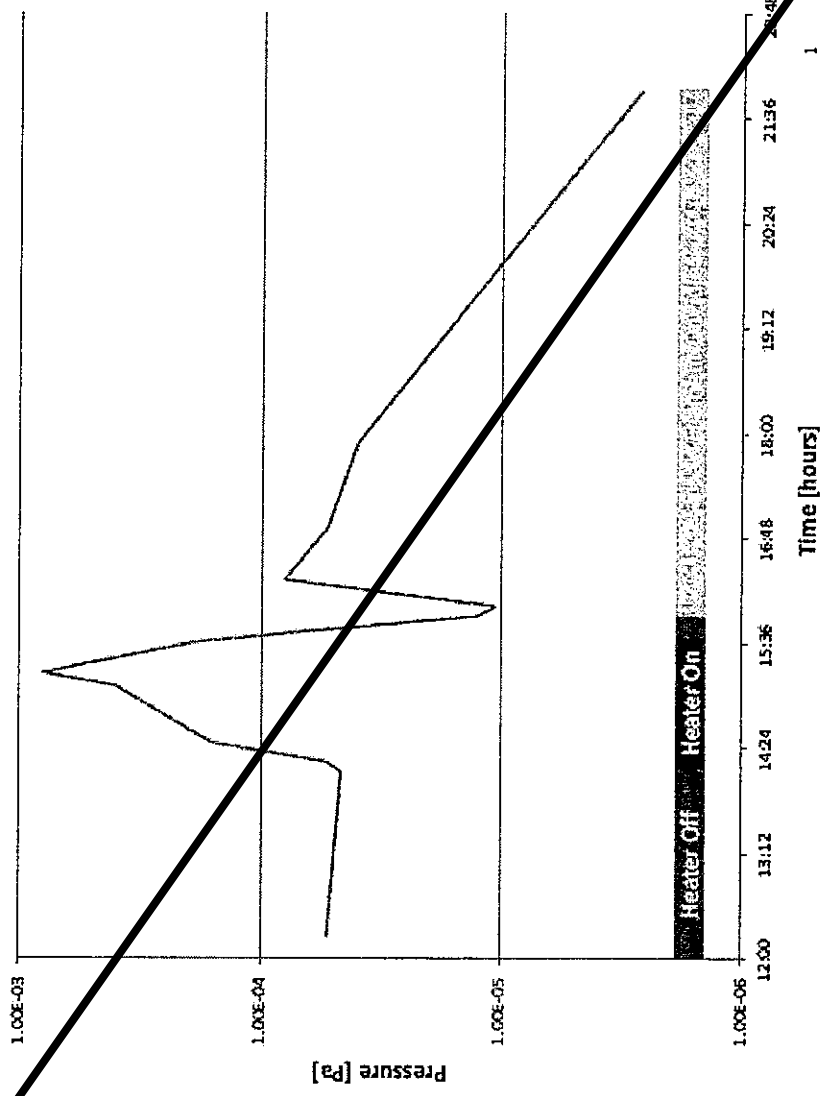

1.00E-03
1.00E-04
1.00E-05
1.00E-06
Pressure [Pa]
Heater Off
Heater On
12:00
13:12
14:24
15:36
16:48
18:00
19:12
20:24
21:36
Time [hours]

FIG. 21

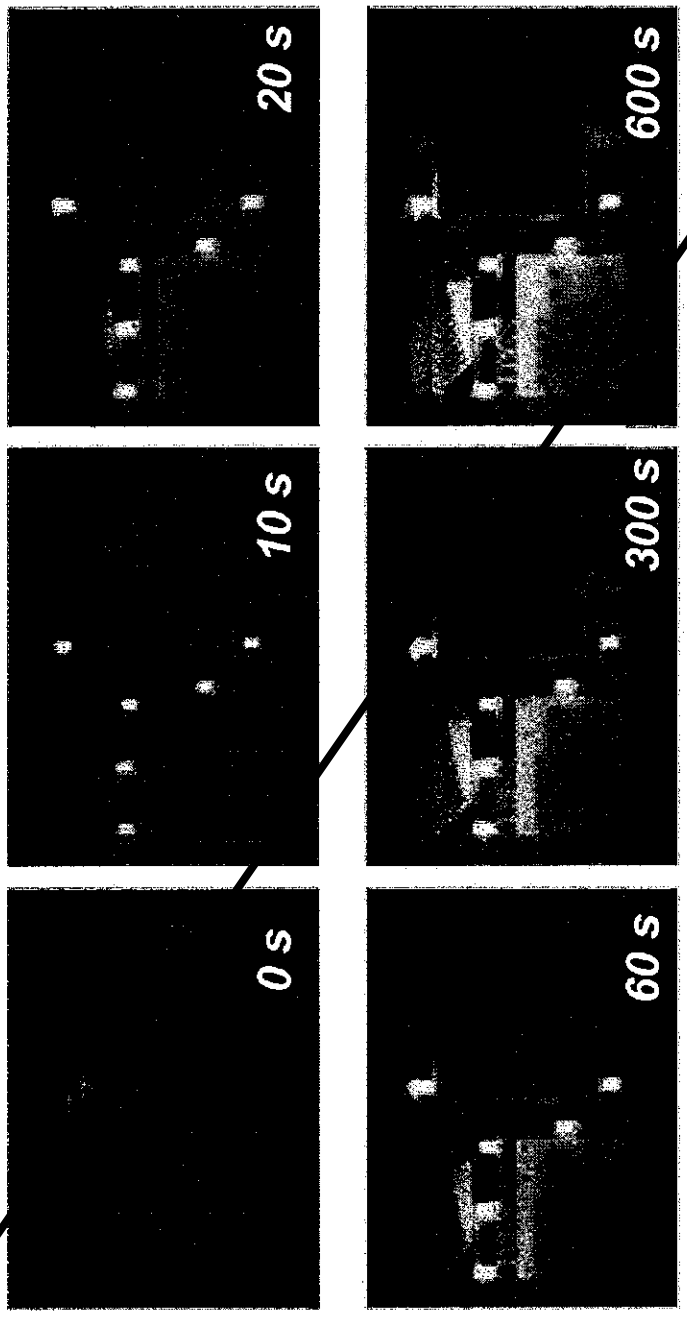


FIG. 22

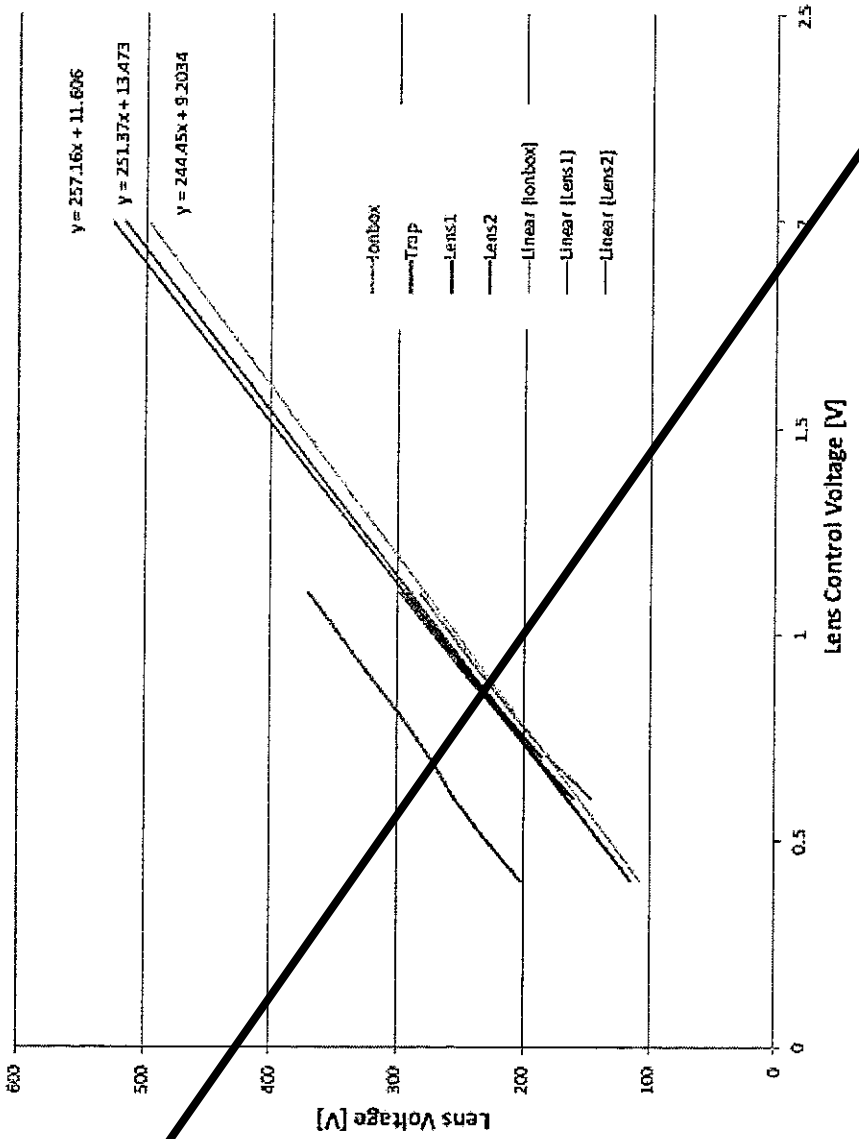

y = 257.16x + 11.606
y = 251.37x + 13.473
y = 244.45x + 9.2034
Ionbox
Trap
Lens1
Lens2
Linear (Ionbox)
Linear (Lens1)
Linear (Lens2)
Lens Voltage [V]
Lens Control Voltage [V]
0
100
200
300
400
500
600
0
0.5
1
1.5
2
2.5

FIG. 23

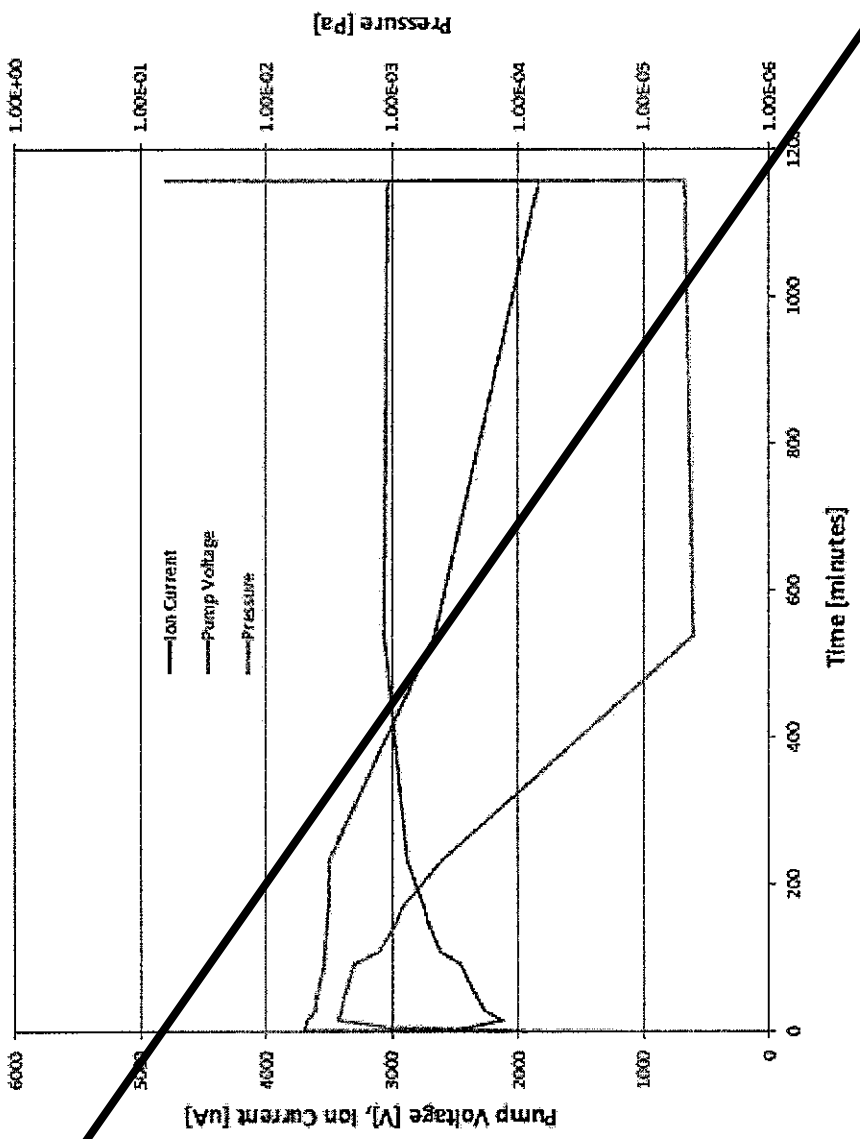

Pressure [Pa]
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
Pump Voltage [V], Ion Current [uA]
6000
5000
4000
3000
2000
1000
0
Time [minutes]
0
200
400
600
800
1000
1200
Ion Current
Pump Voltage
Pressure

FIG. 24

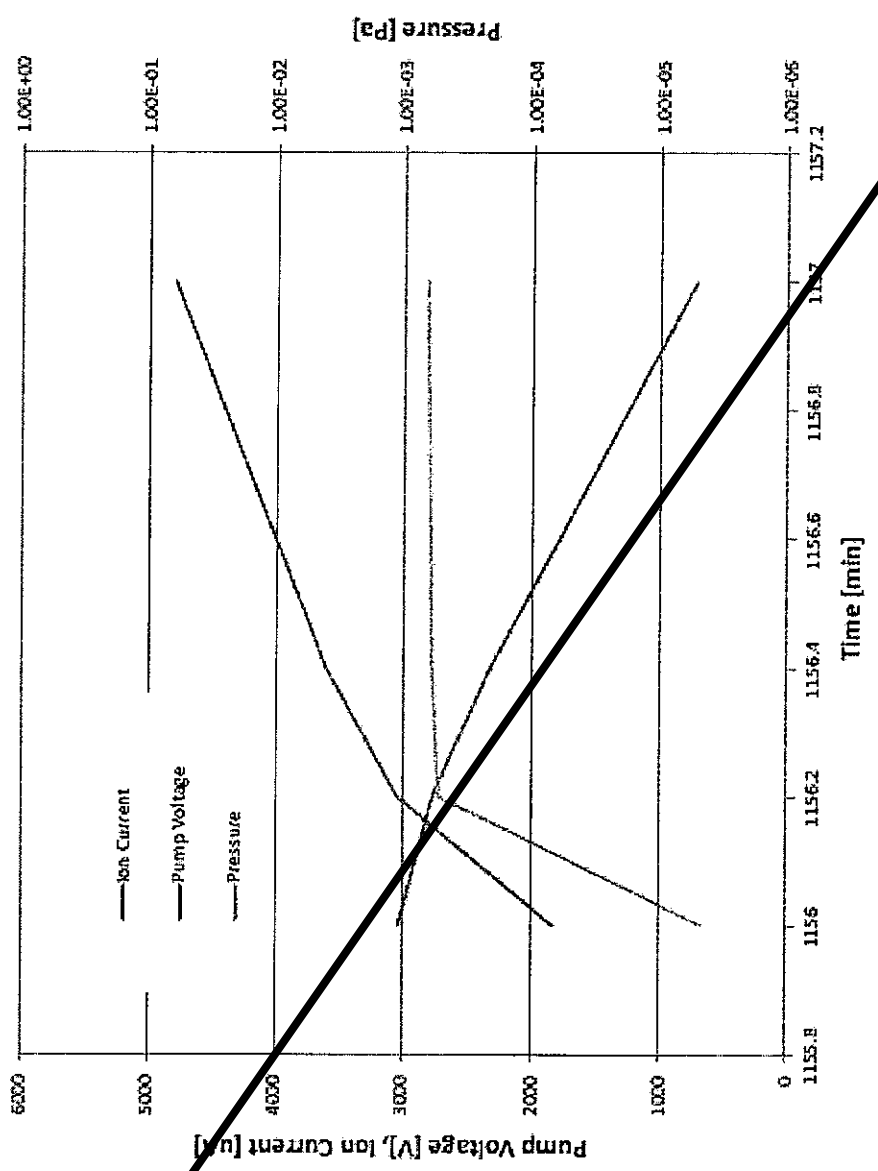

Pressure [Pa]
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
Pump Voltage [V], Ion Current [uA]
6000
5000
4000
3000
2000
1000
0
Ion Current
Pump Voltage
Pressure
1155.8
1156
1156.2
1156.4
1156.6
1156.8
1157.2
Time [min]

FIG. 25

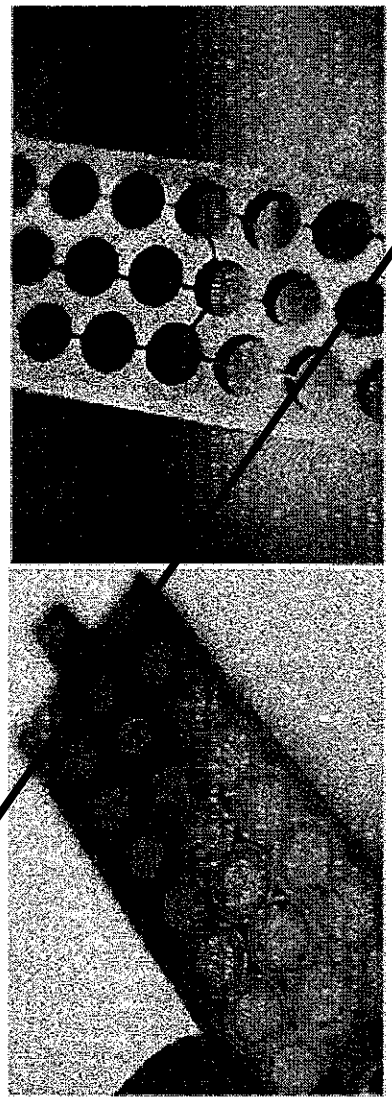


FIG. 28

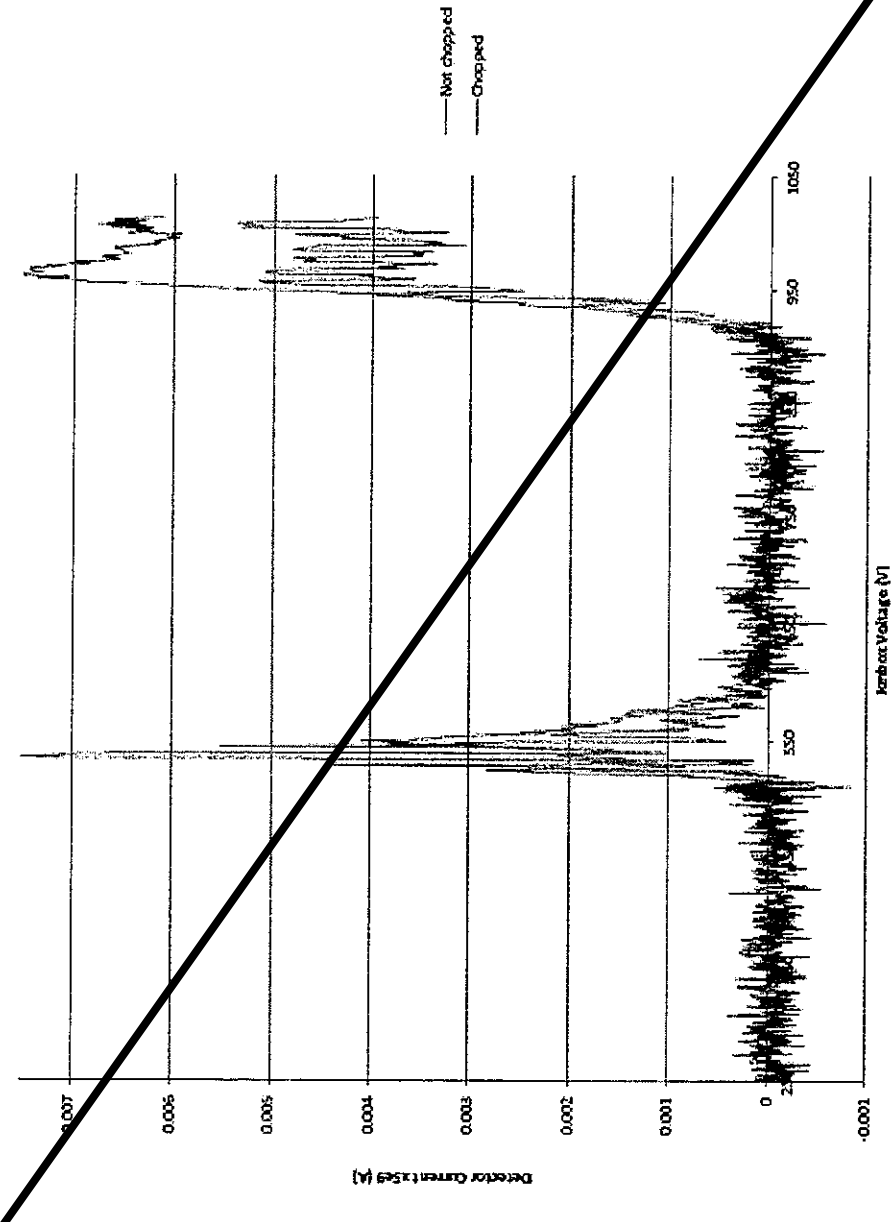

Not chopped
Chopped
Detector Current (1.569 µA)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
-0.001
550
950
1050
Ion Beam Voltage (V)

FIG. 27

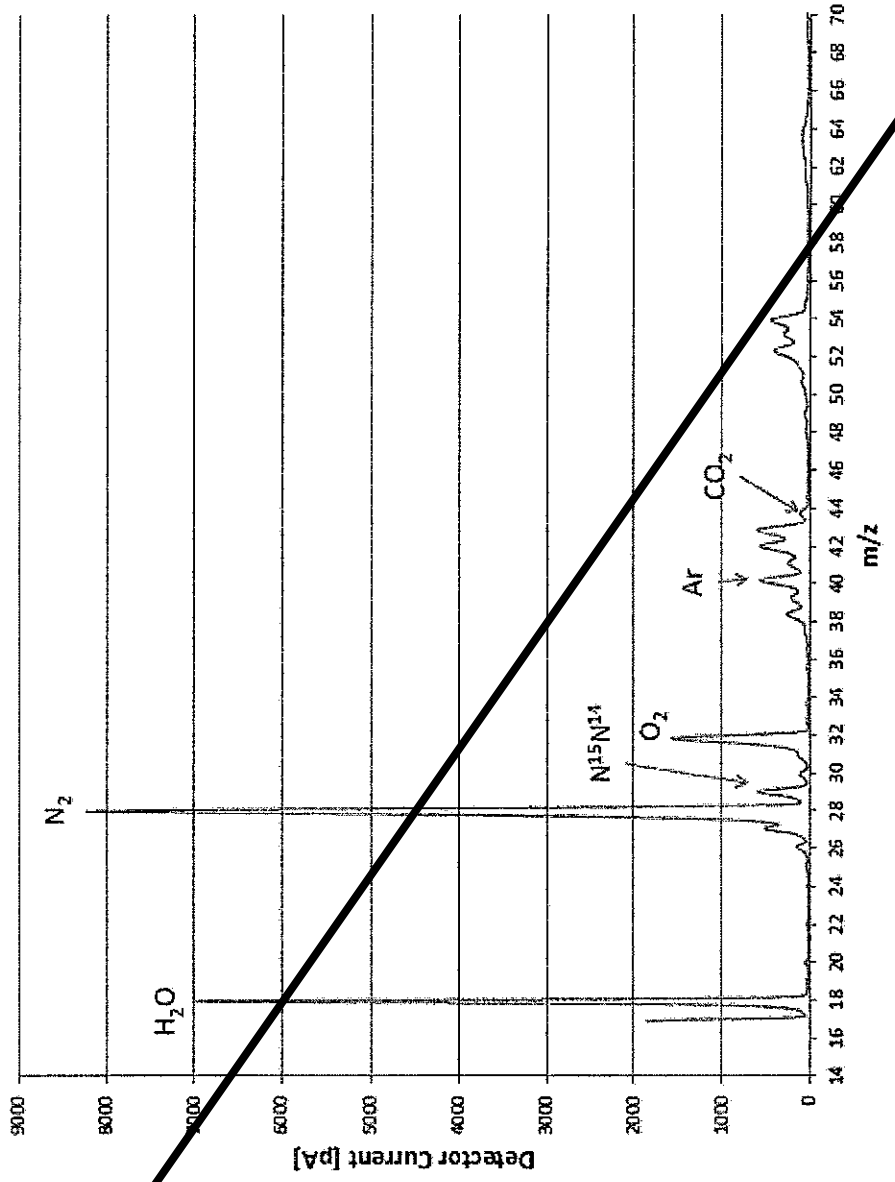

Detector Current [pA]
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
m/z
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70
N_2
H_2O
$N^{15}N^{14}$
O_2
Ar
CO_2

FIG. 28

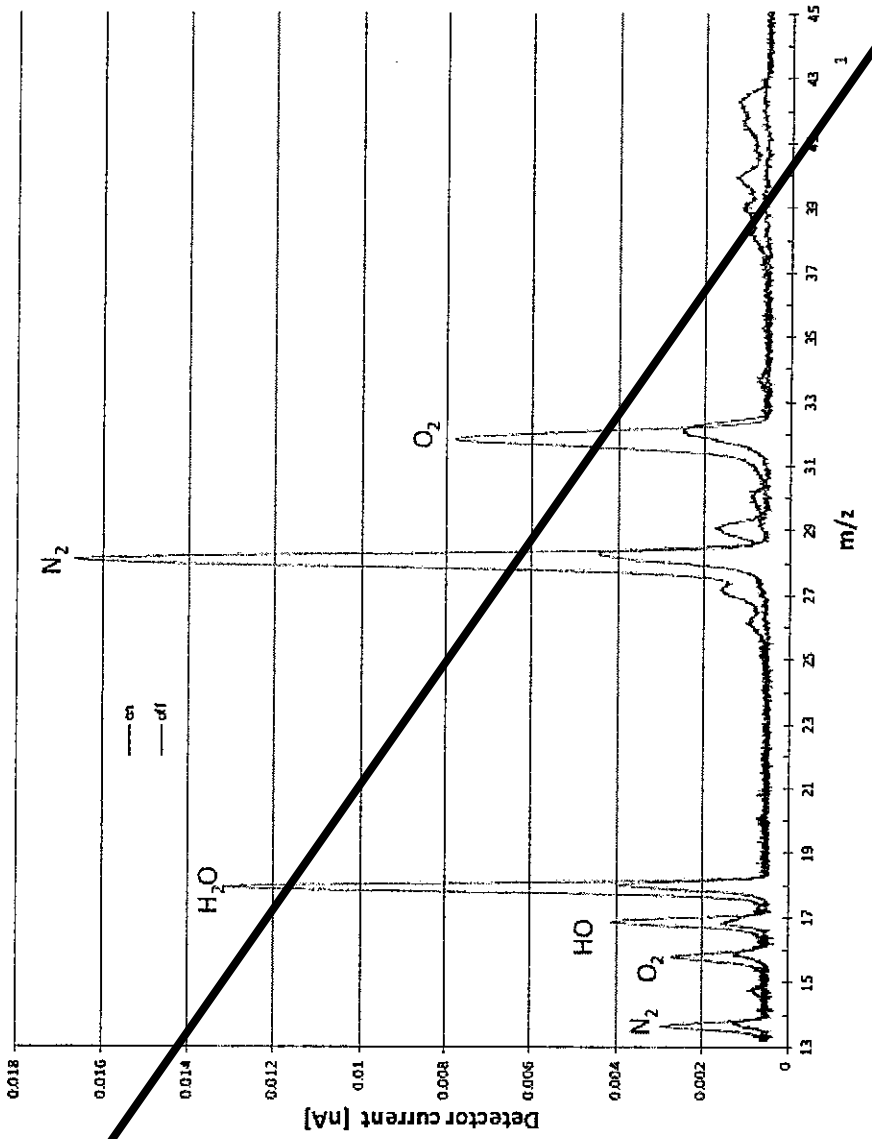


FIG. 29

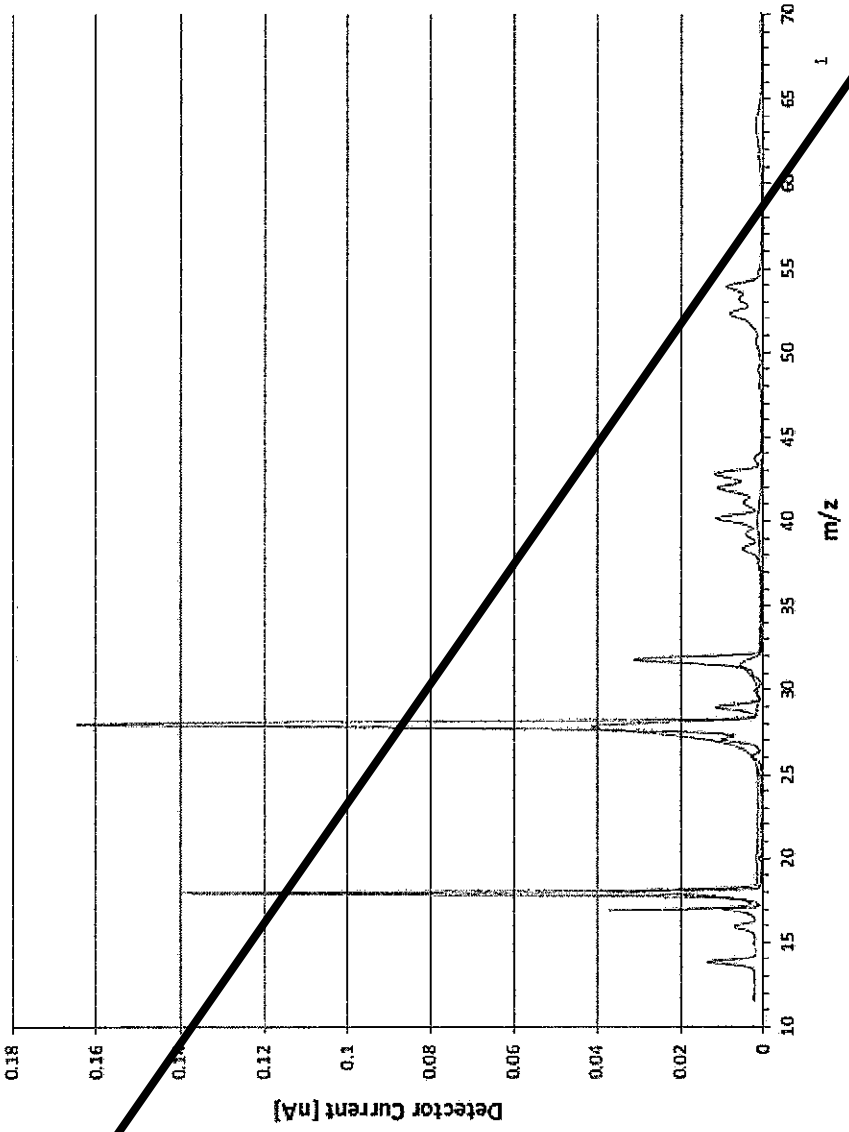

Detector Current [nA]
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
m/z
10
15
20
25
30
35
40
45
50
55
60
65
70

FIG. 30

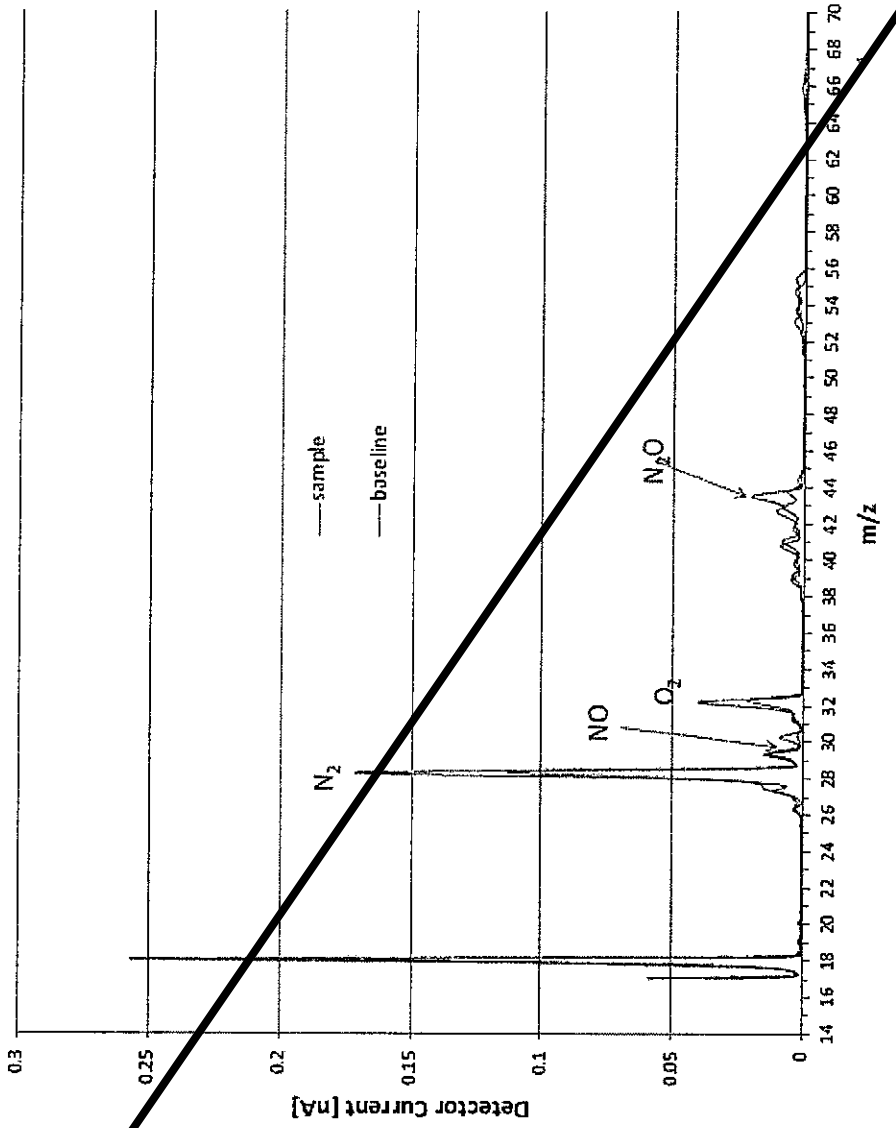

Detector Current [nA]
0.3
0.25
0.2
0.15
0.1
0.05
0
m/z
14 16 18 20 22 24 25 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70
—sample
—baseline
N_2
NO
O_2
N_2O

FIG. 31

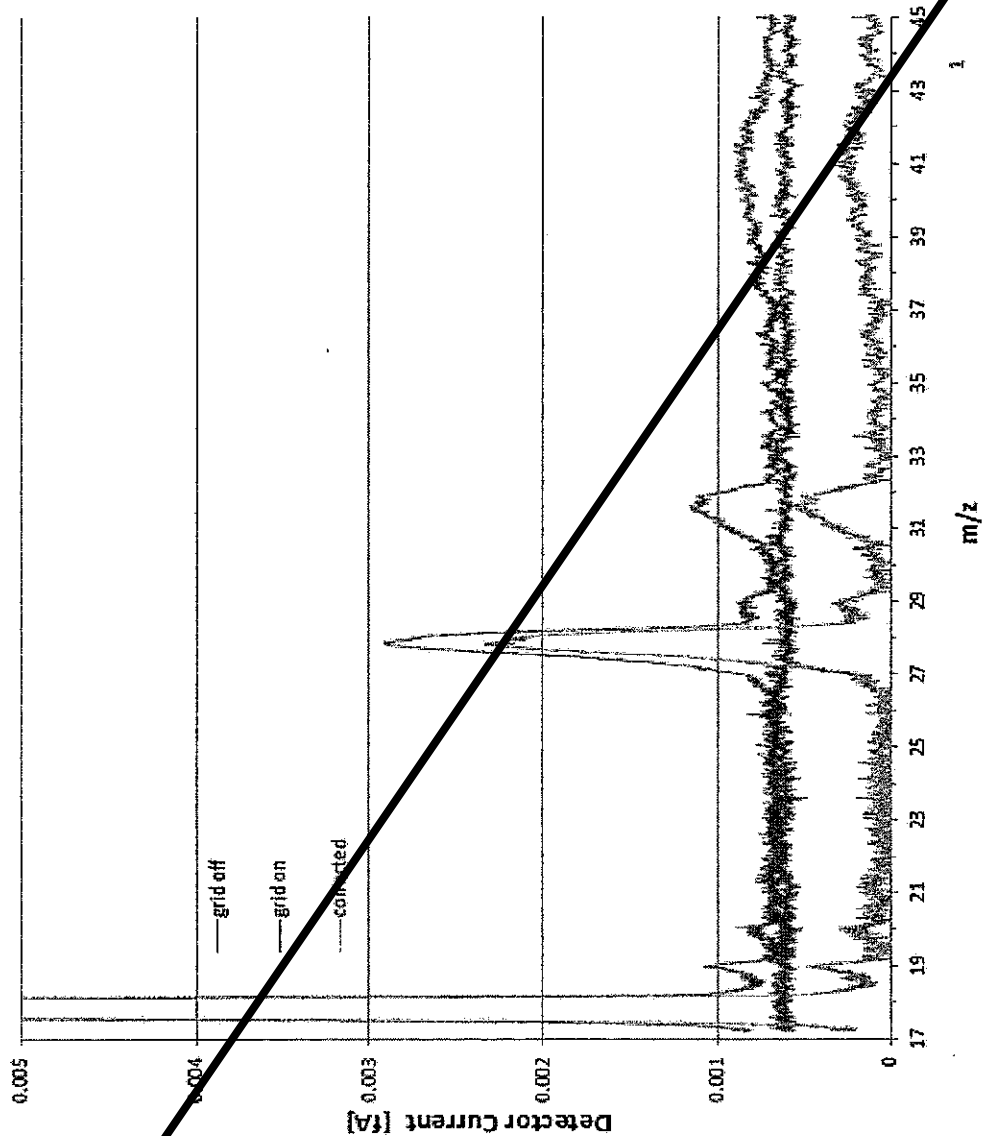

Detector Current [fA]
0.005
0.004
0.003
0.002
0.001
0
grid off
grid on
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
m/z

FIG. 32

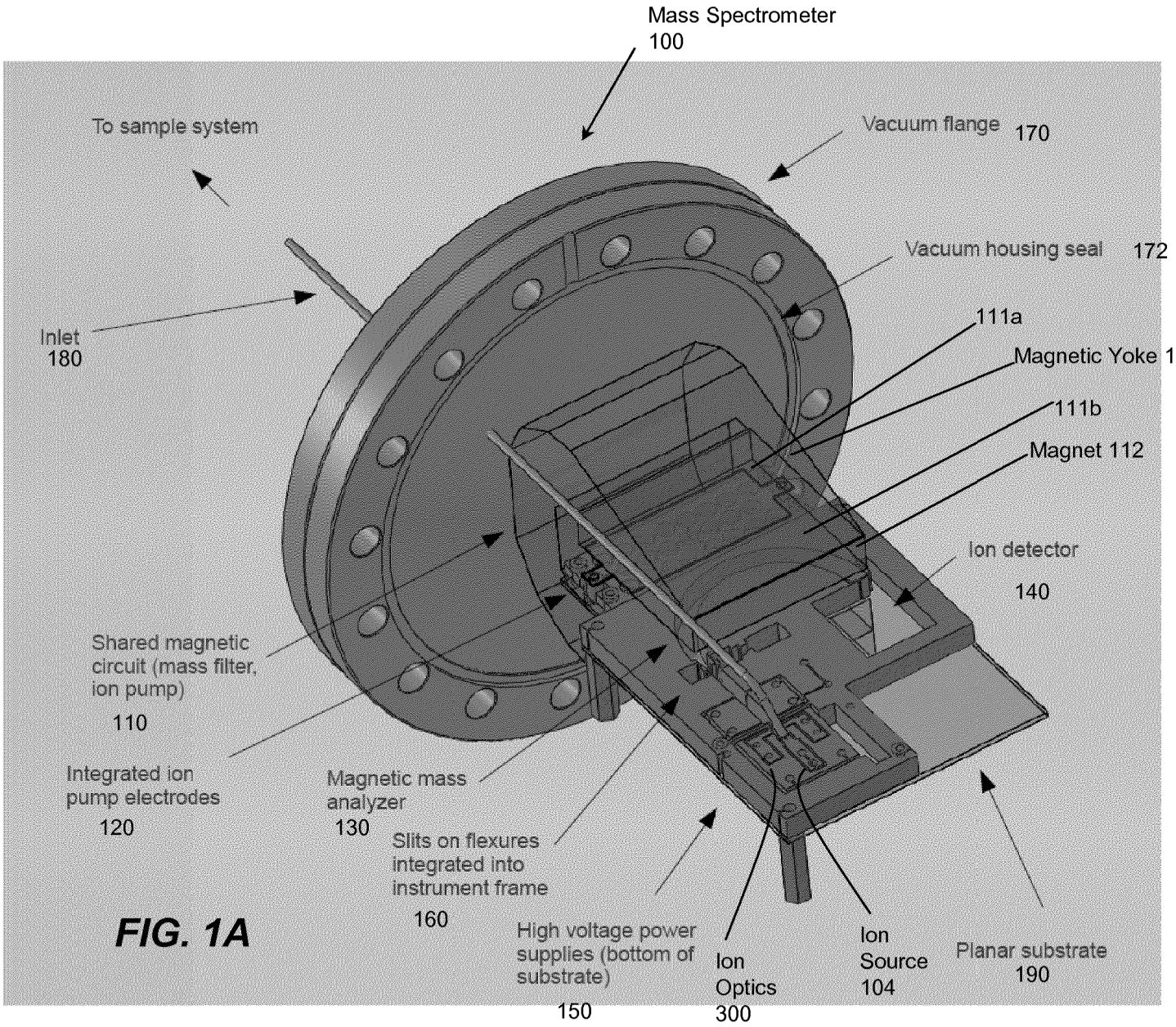

Mass Spectrometer
100
To sample system
Vacuum flange 170
Vacuum housing seal 172
Inlet
180
111a
Magnetic Yoke 114
111b
Magnet 112
Ion detector
140
Shared magnetic
circuit (mass filter,
ion pump)
110
Integrated ion
pump electrodes
120
Magnetic mass
analyzer
130
Slits on flexures
integrated into
instrument frame
160
High voltage power
supplies (bottom of
substrate)
150
Ion
Optics
300
Ion
Source
104
Planar substrate
190

FIG. 1A

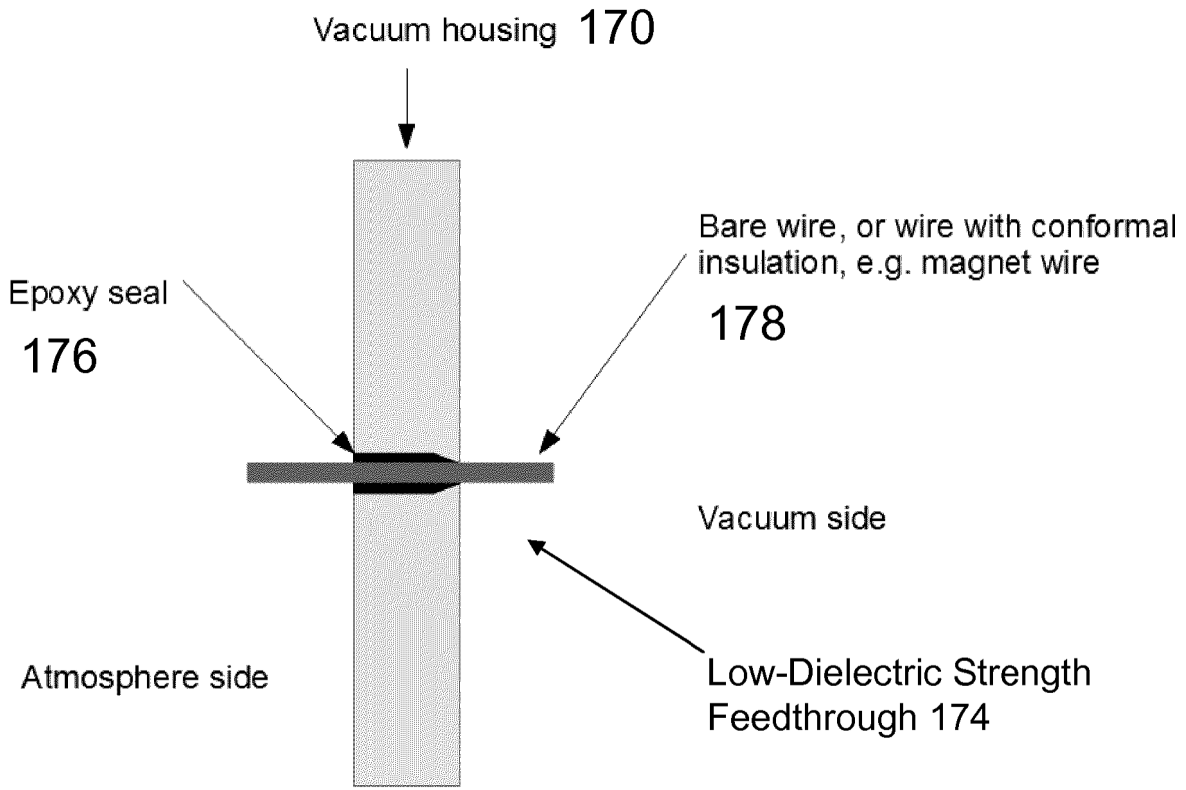

Vacuum housing 170
Bare wire, or wire with conformal insulation, e.g. magnet wire
178
Epoxy seal
176
Vacuum side
Atmosphere side
Low-Dielectric Strength Feedthrough 174

FIG. 1B

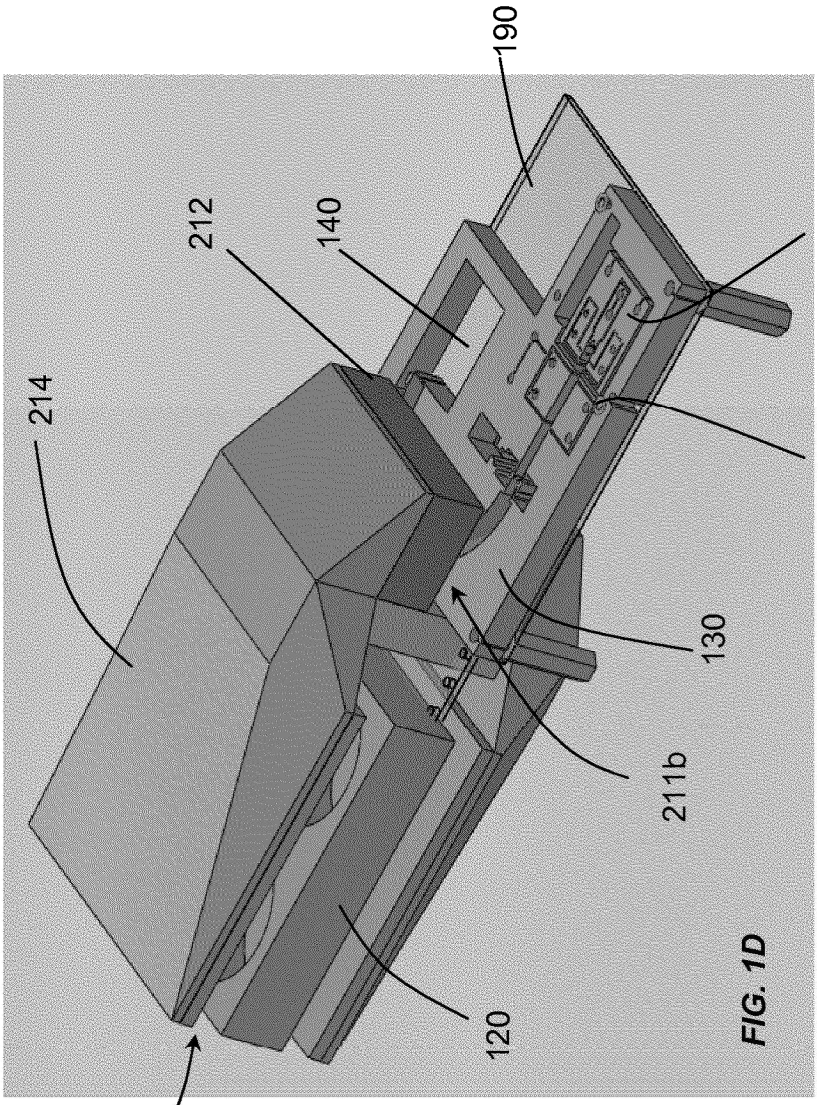

190
212
140
214
Ion Source 104
Ion Optics 300
130
211b
120
211a

FIG. 1D

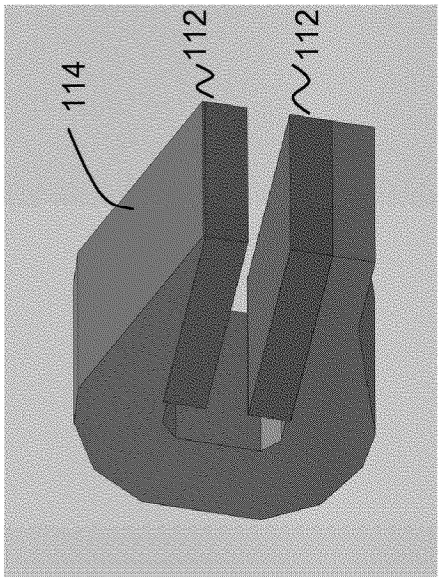

114
112
112

FIG. 1C

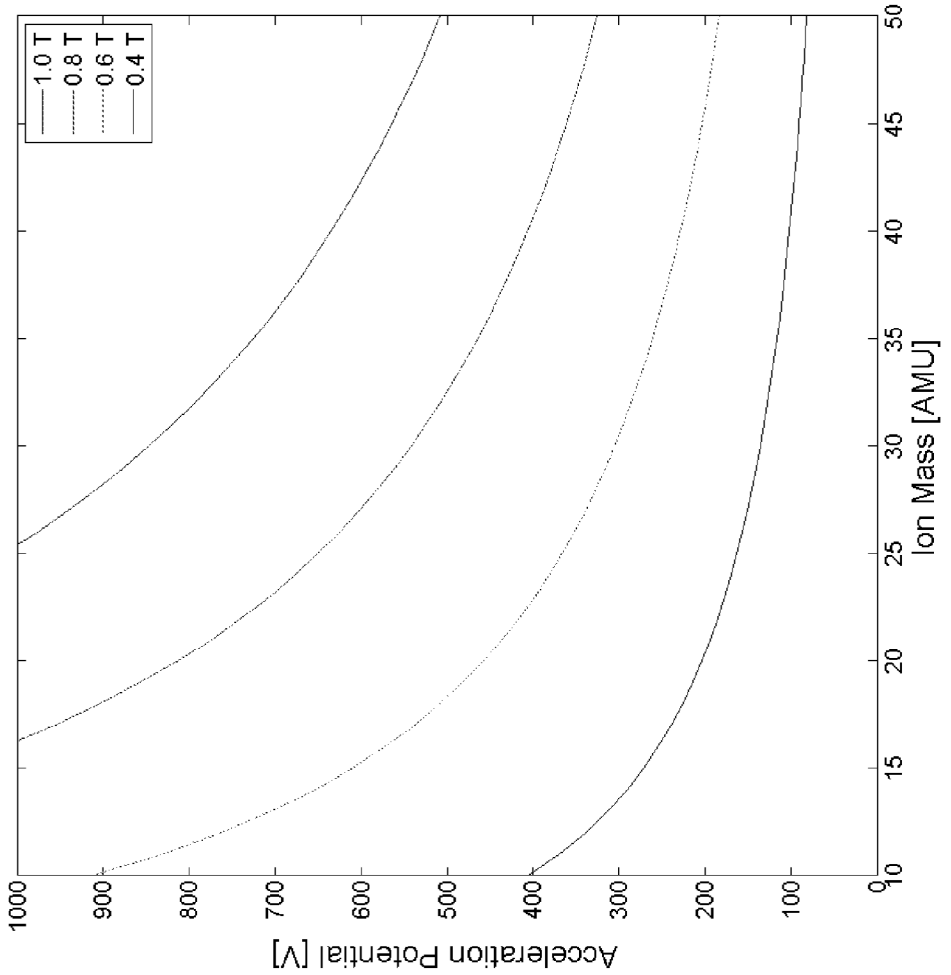

1.0 T
0.8 T
0.6 T
0.4 T
Acceleration Potential [V]
Ion Mass [AMU]
1000
900
800
700
600
500
400
300
200
100
0
10
15
20
25
30
35
40
45
50

FIG. 2

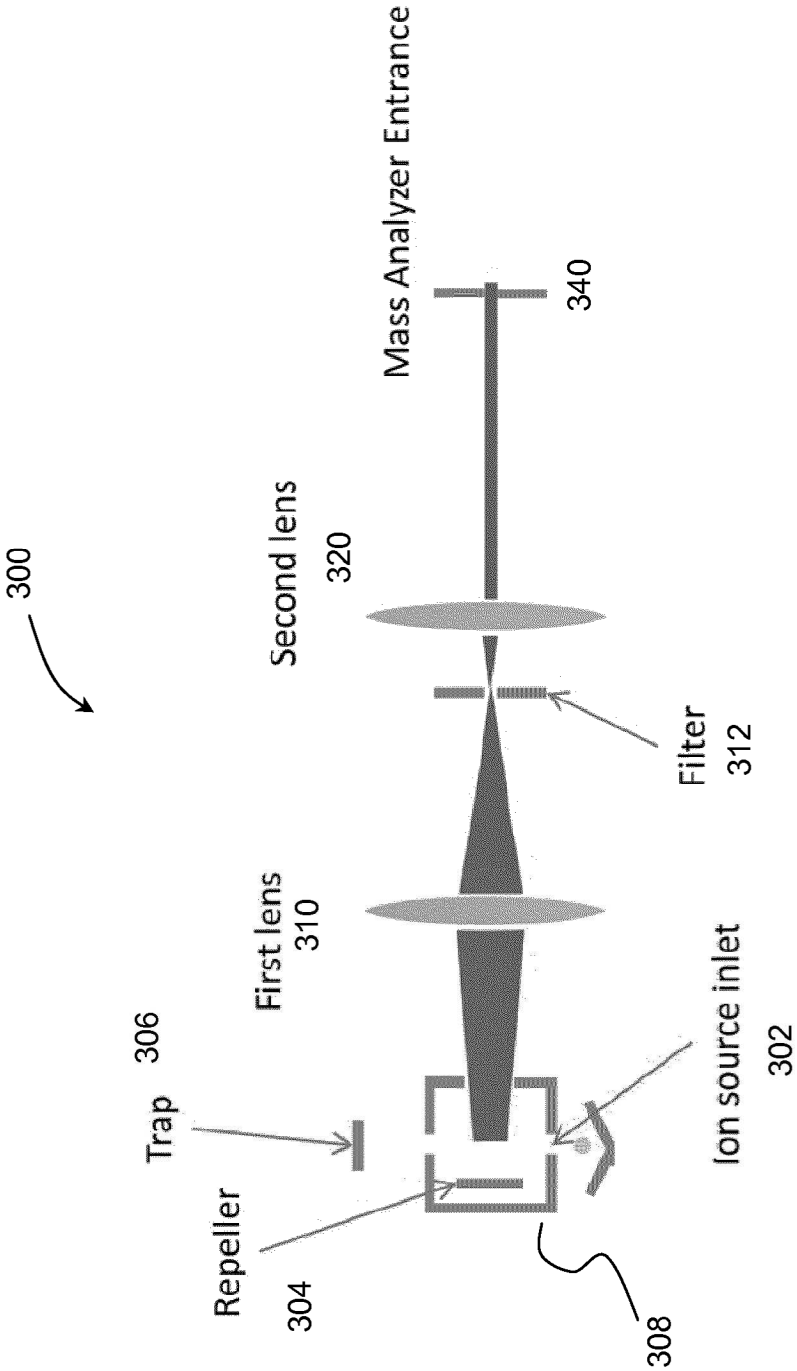

300
Mass Analyzer Entrance
340
Second lens
320
Filter
312
First lens
310
306
Trap
Repeller
304
308
Ion source inlet
302

FIG. 3

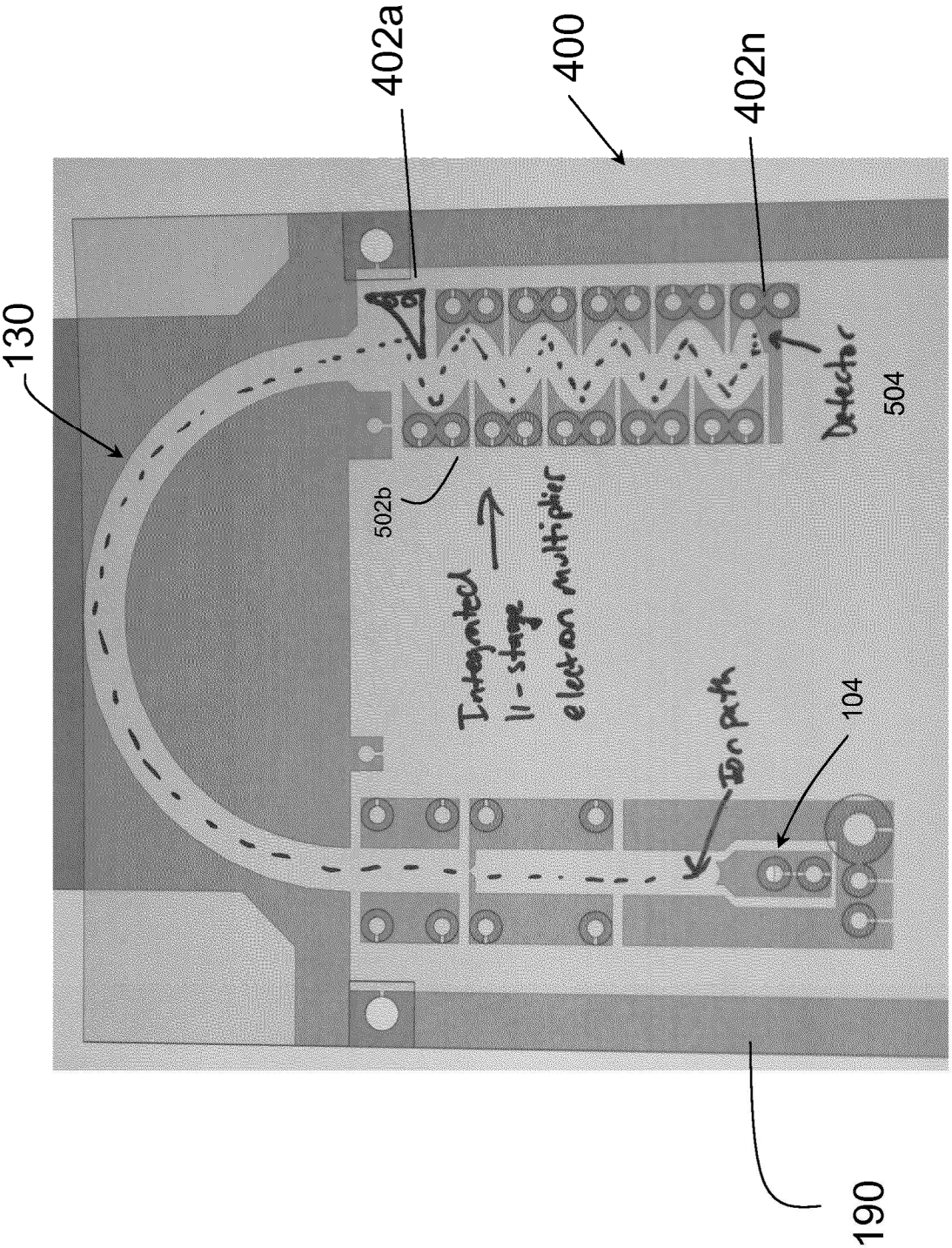

130
402a
400
402n
190
502b
504
104
Integrated
11-stage
electron multiplier
Detector
Ion path

FIG. 4

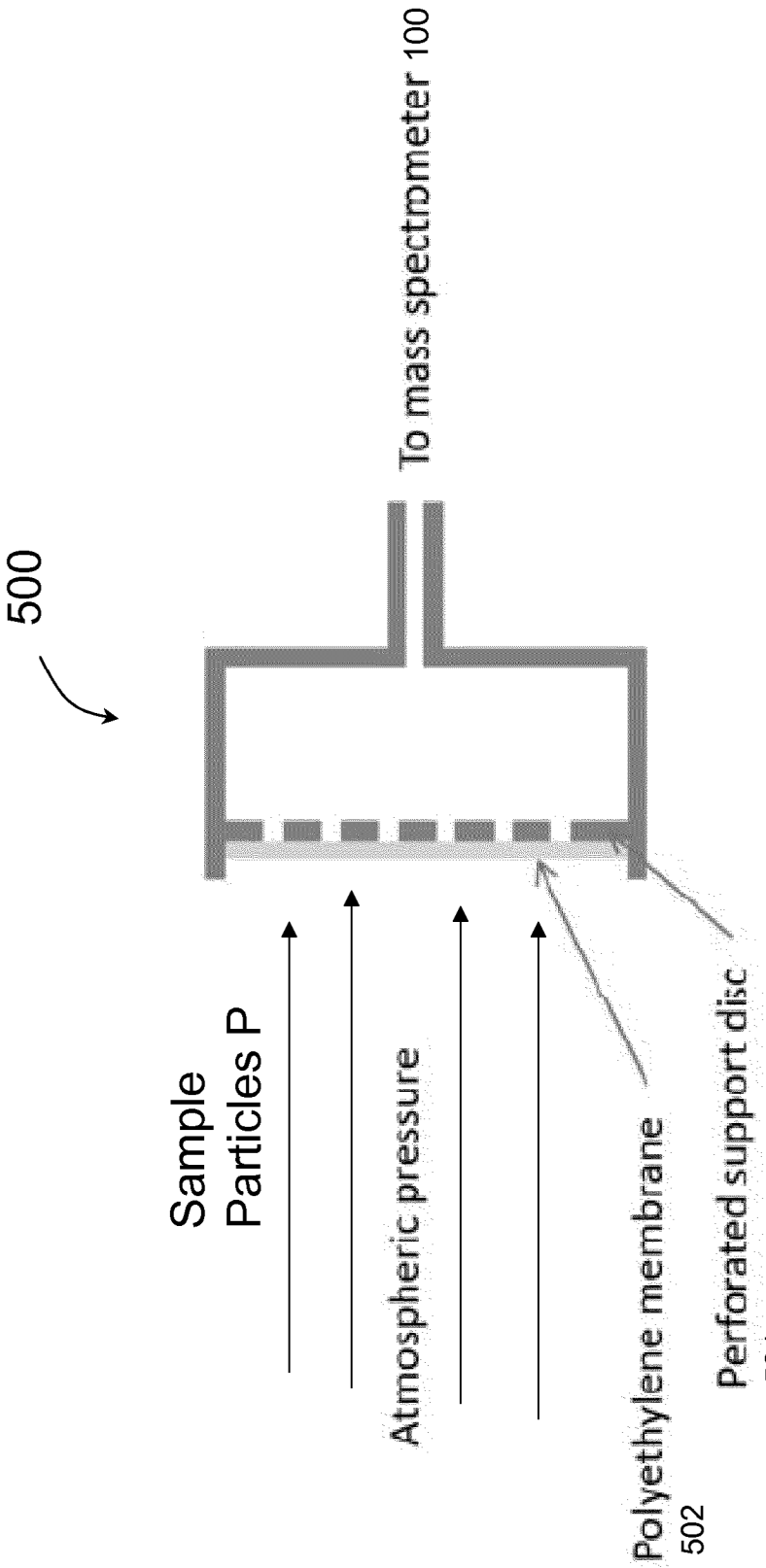

500
To mass spectrometer 100
Sample Particles P
Atmospheric pressure
Polyethylene membrane 502
Perforated support disc 504

FIG. 5

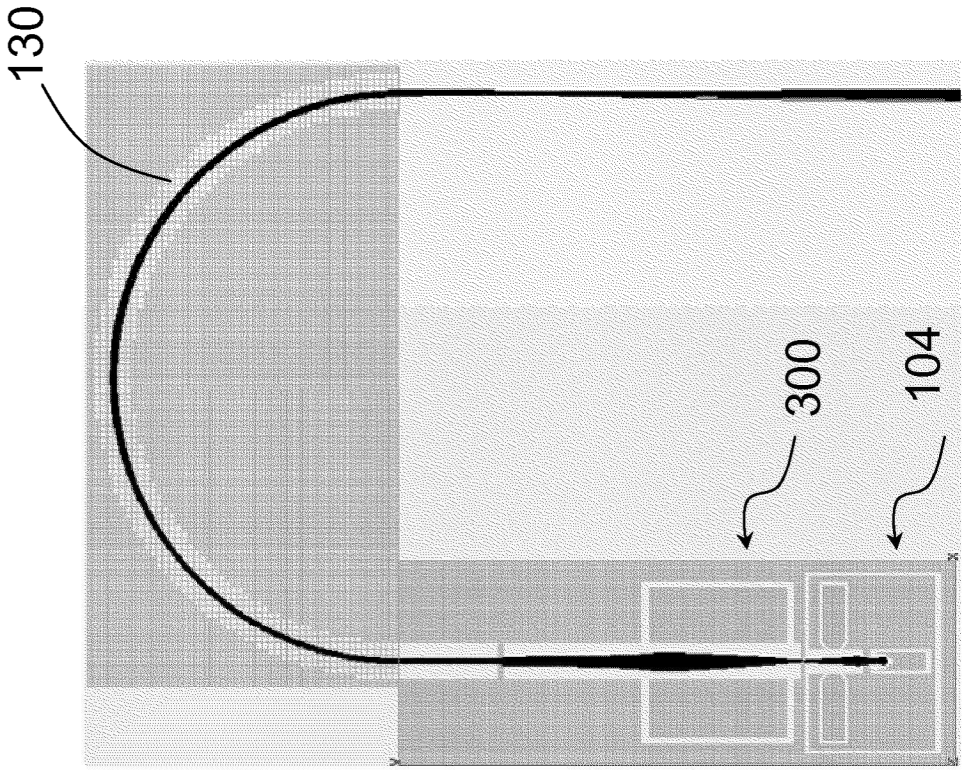

130
300
104

FIG. 6B

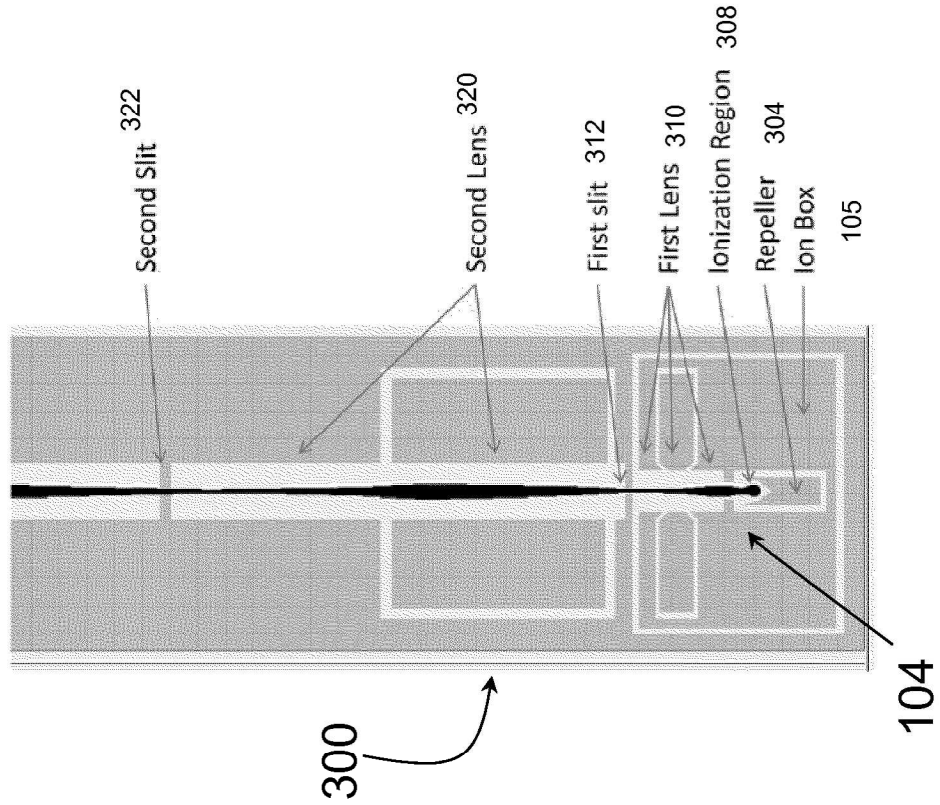

Second Slit 322
Second Lens 320
First slit 312
First Lens 310
Ionization Region 308
Repeller 304
Ion Box 105
300
104

FIG. 6A

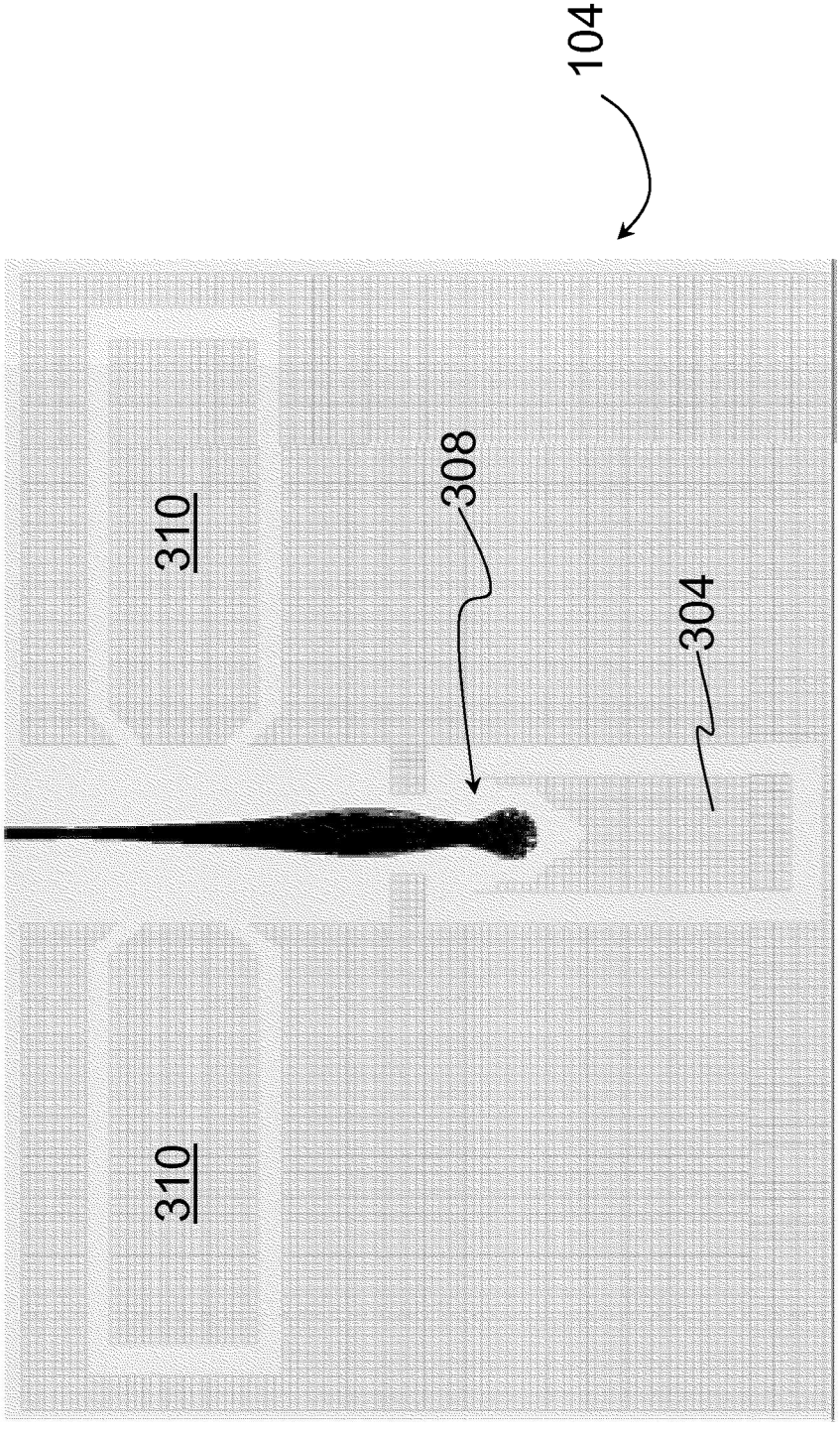


FIG. 6C

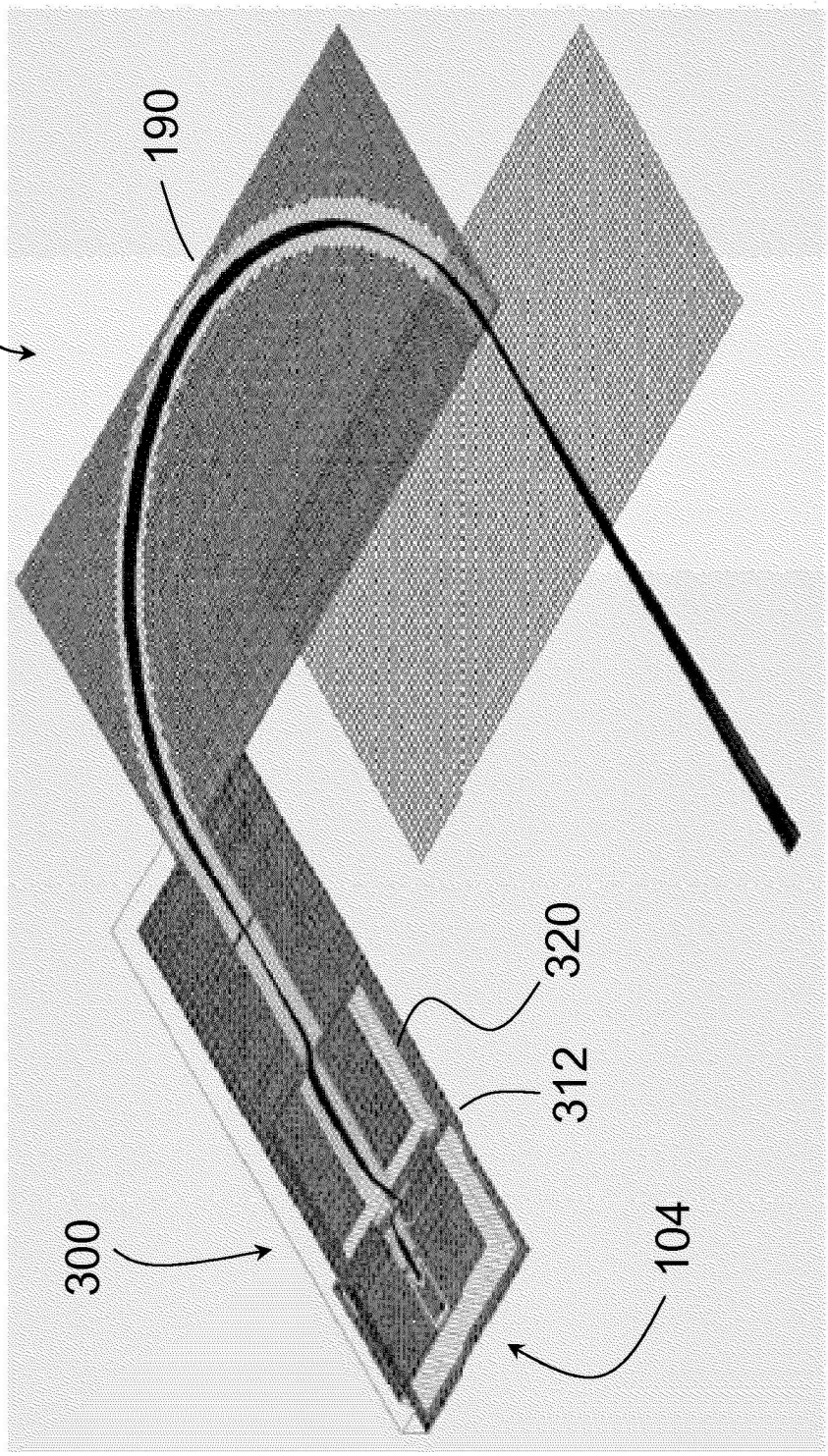


FIG. 7

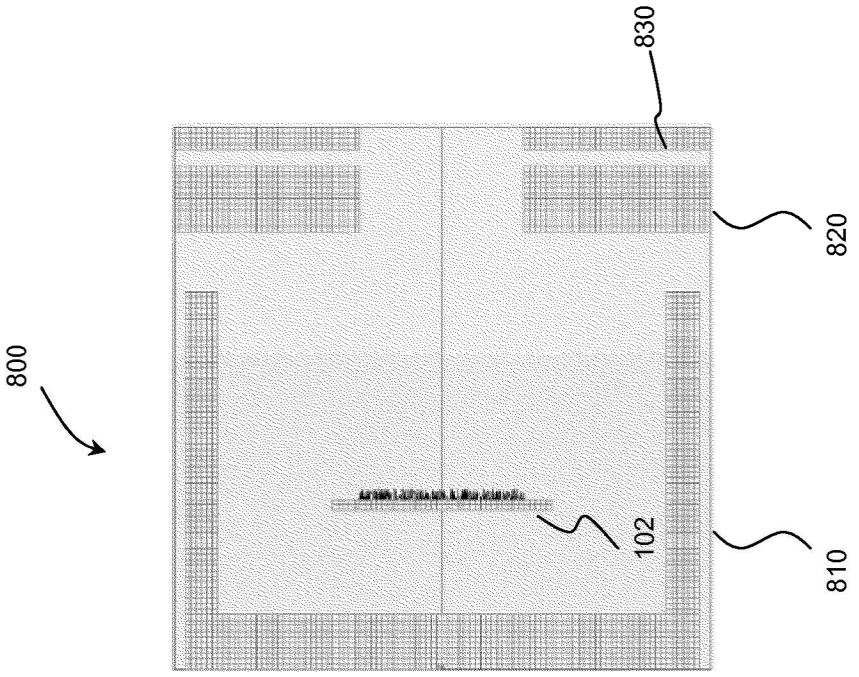


FIG. 9

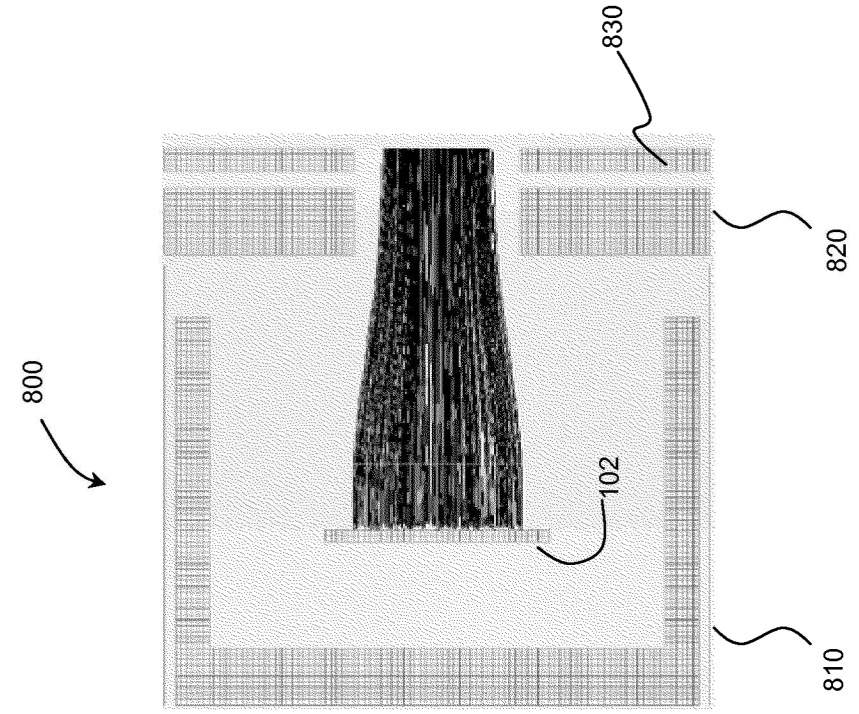


FIG. 8

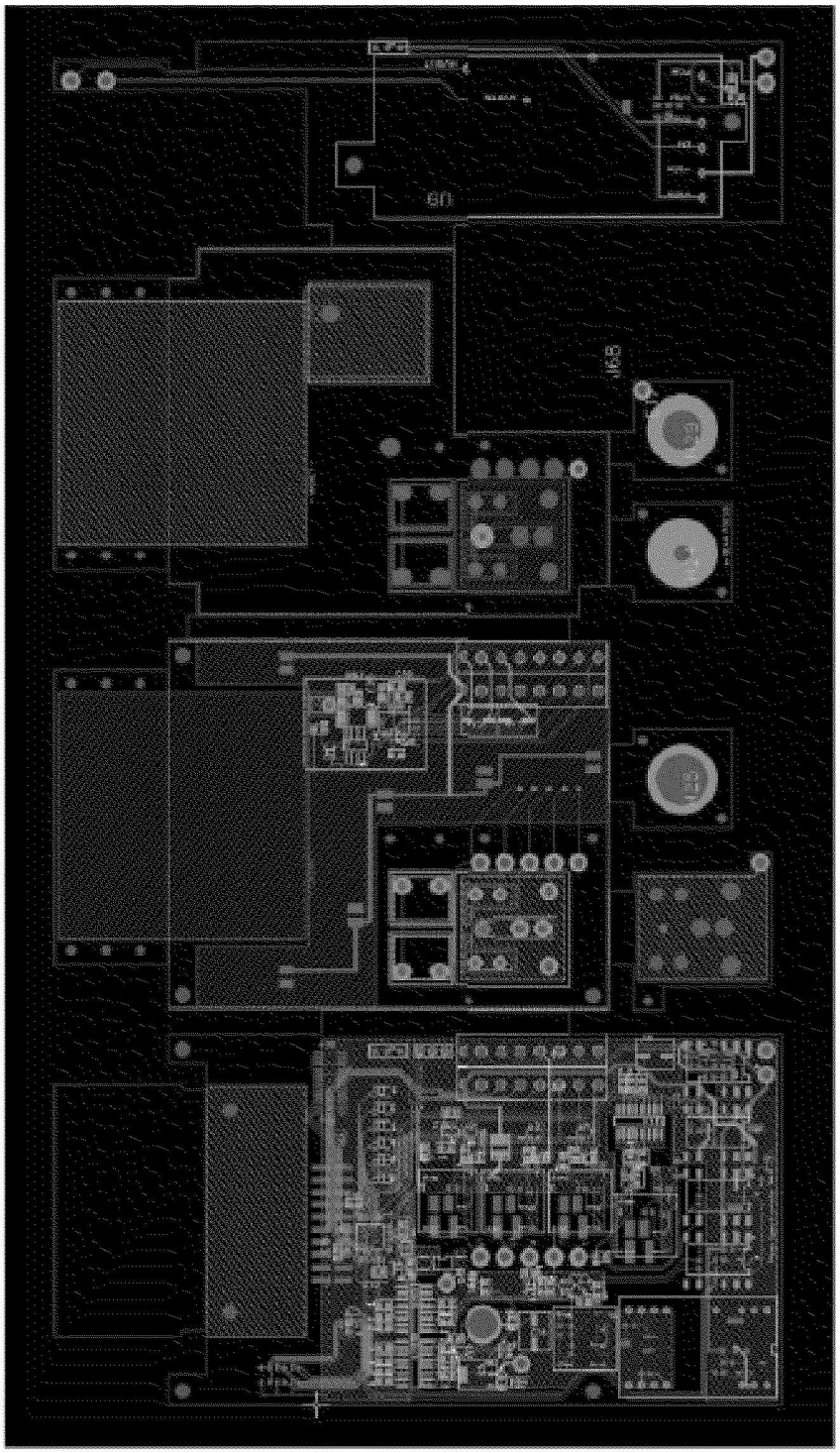


FIG. 10

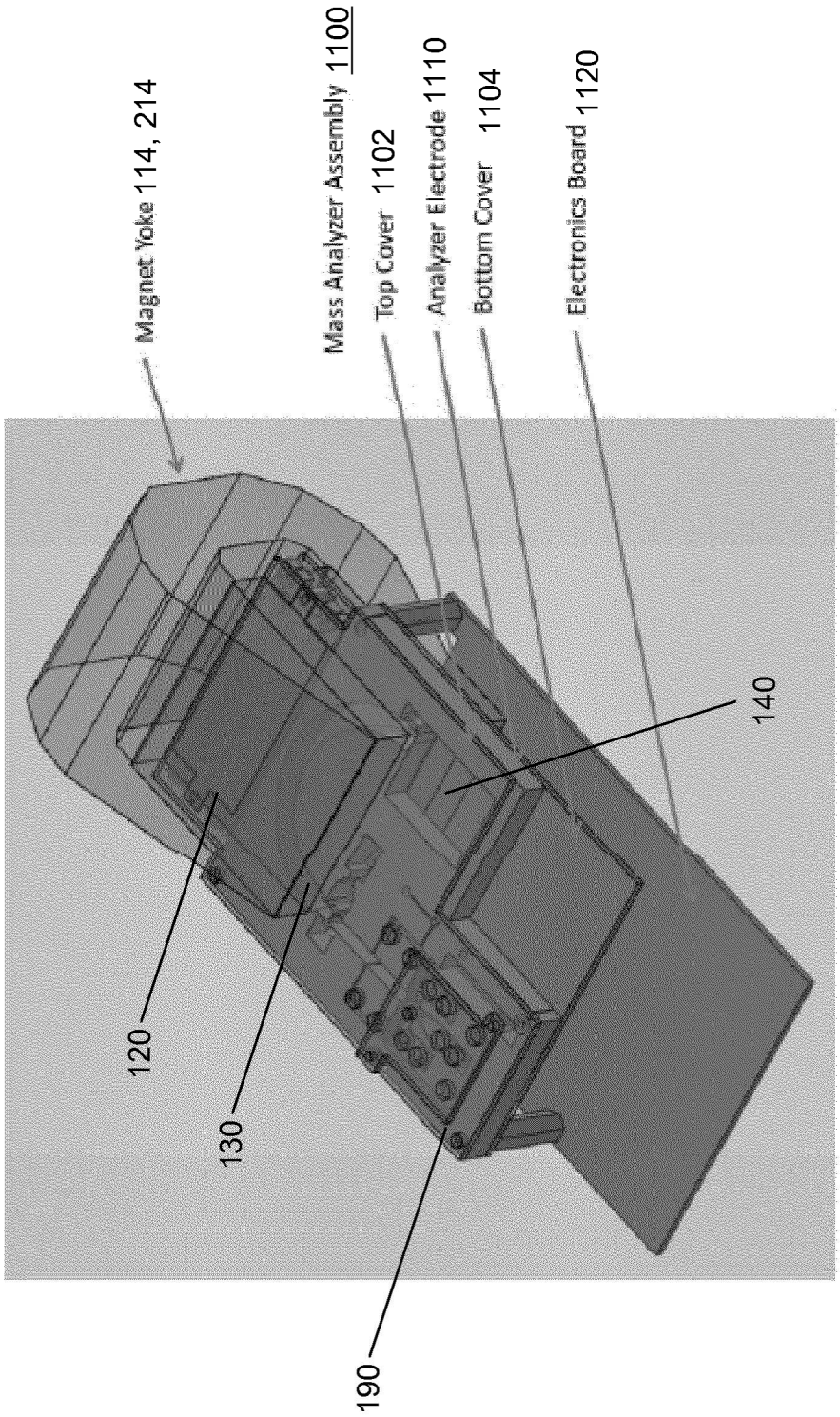

Magnet Yoke 114, 214
Mass Analyzer Assembly 1100
Top Cover 1102
Analyzer Electrode 1110
Bottom Cover 1104
Electronics Board 1120
120
130
140
190

FIG. 11

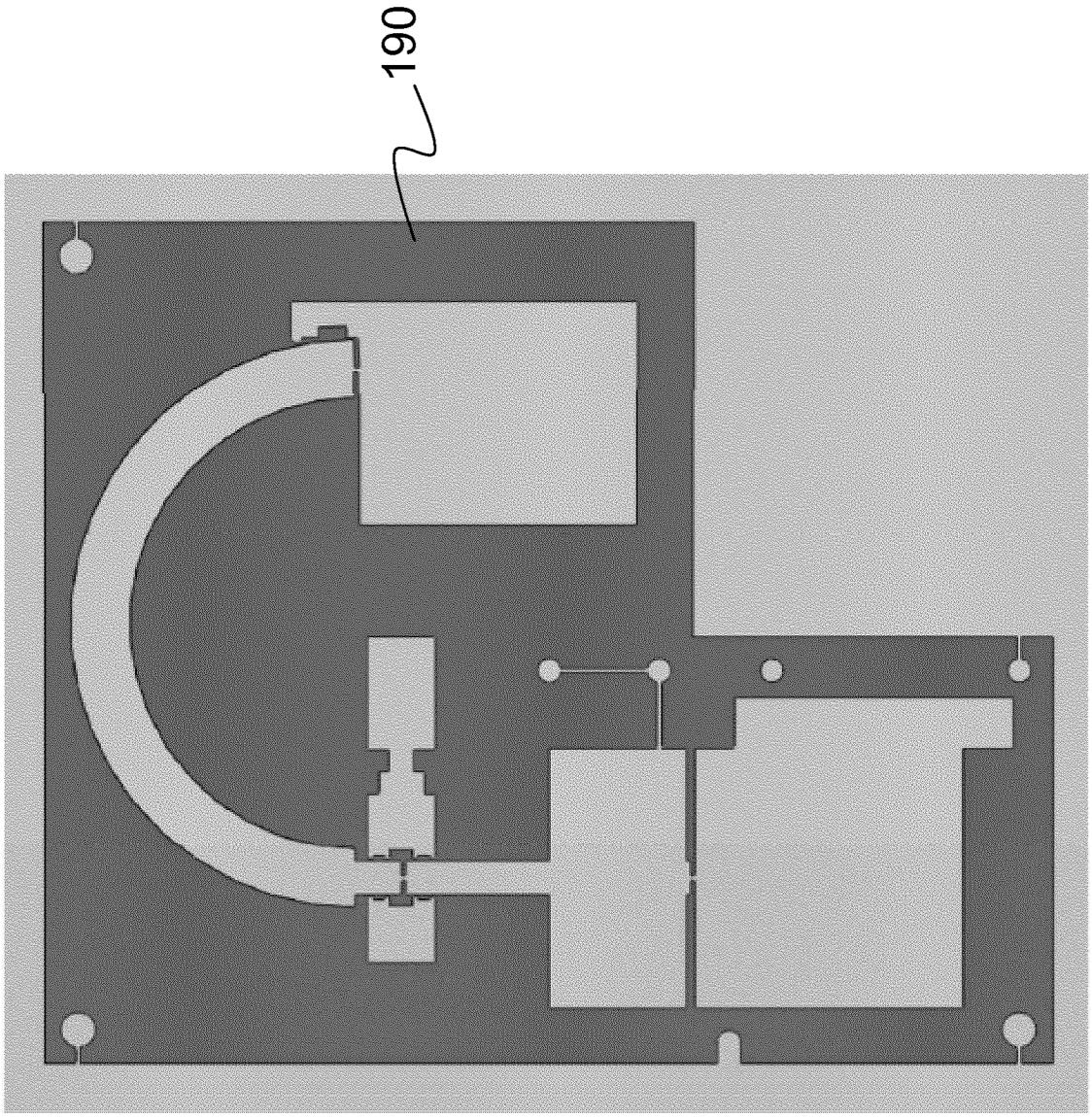


FIG. 12

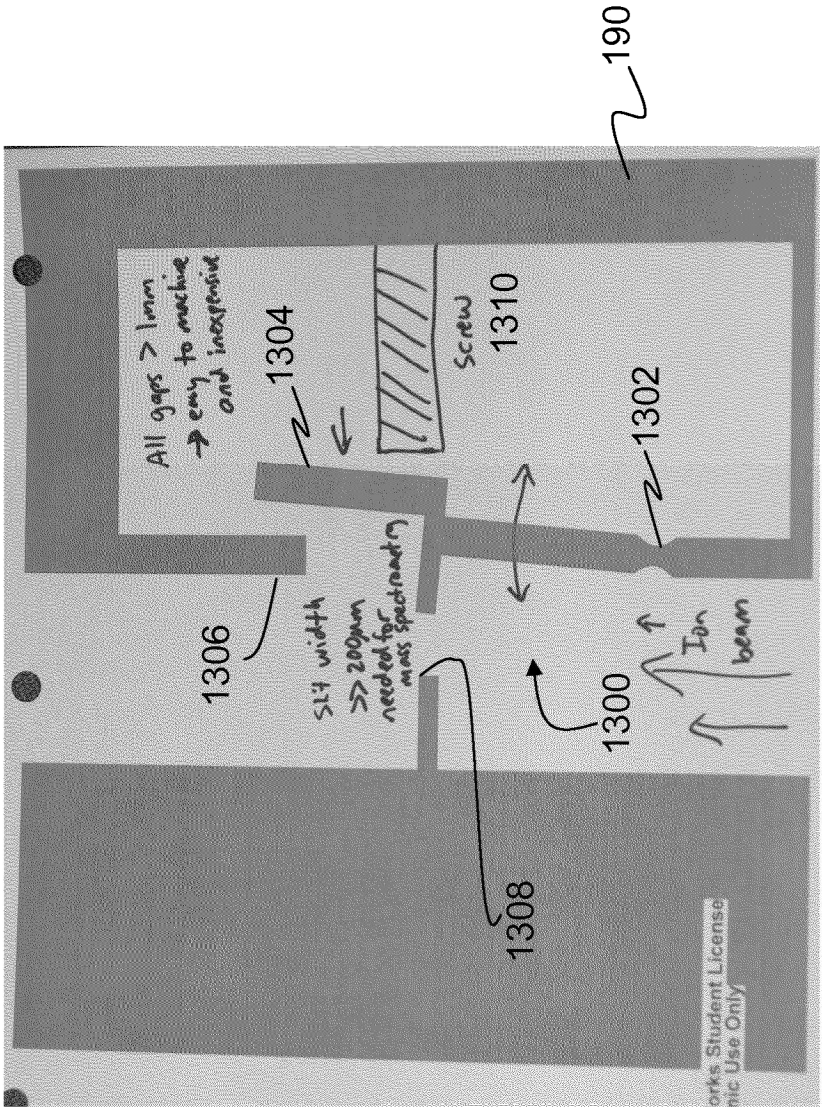

All gaps > 1mm
→ easy to machine
and inexpensive
1304
Screw
1310
190
1306
Slit width
>= 200μm
needed for
mass spectrometry
1302
1308
1300
Ion
beam

FIG. 13

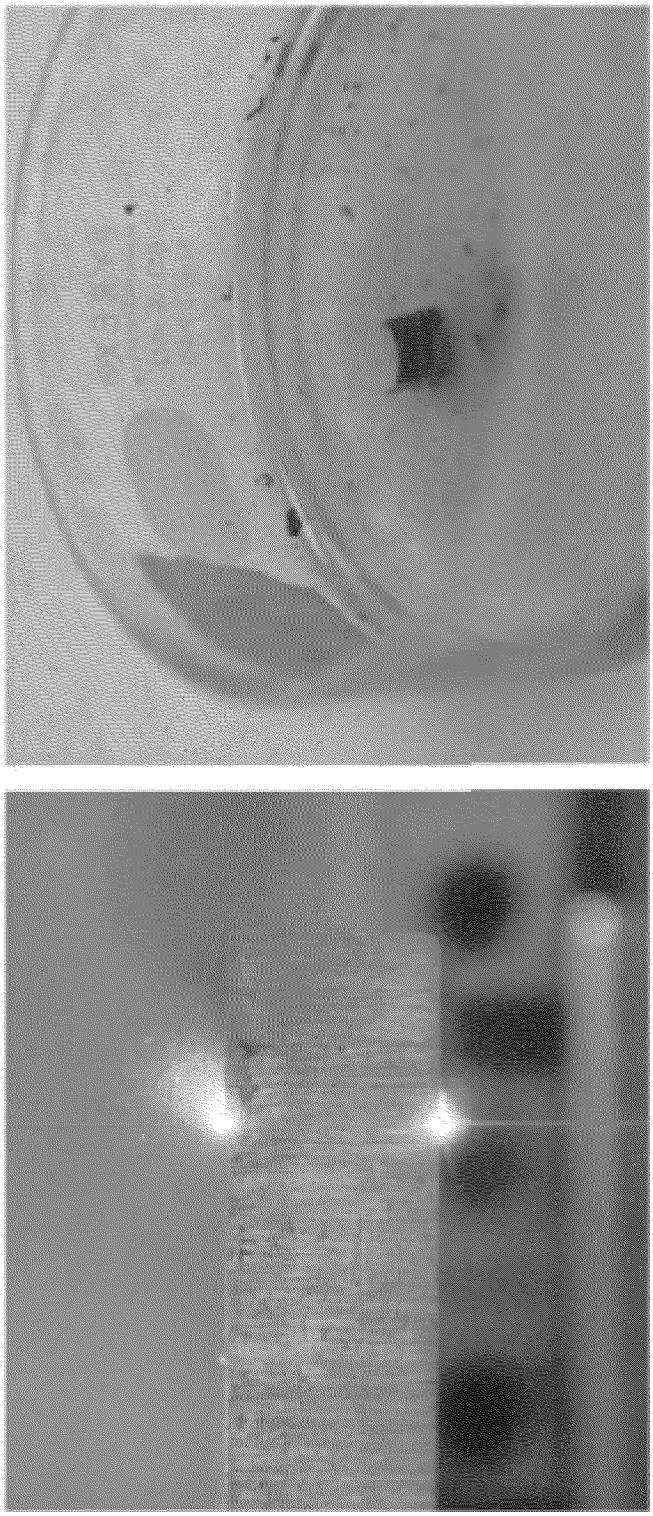


FIG. 14

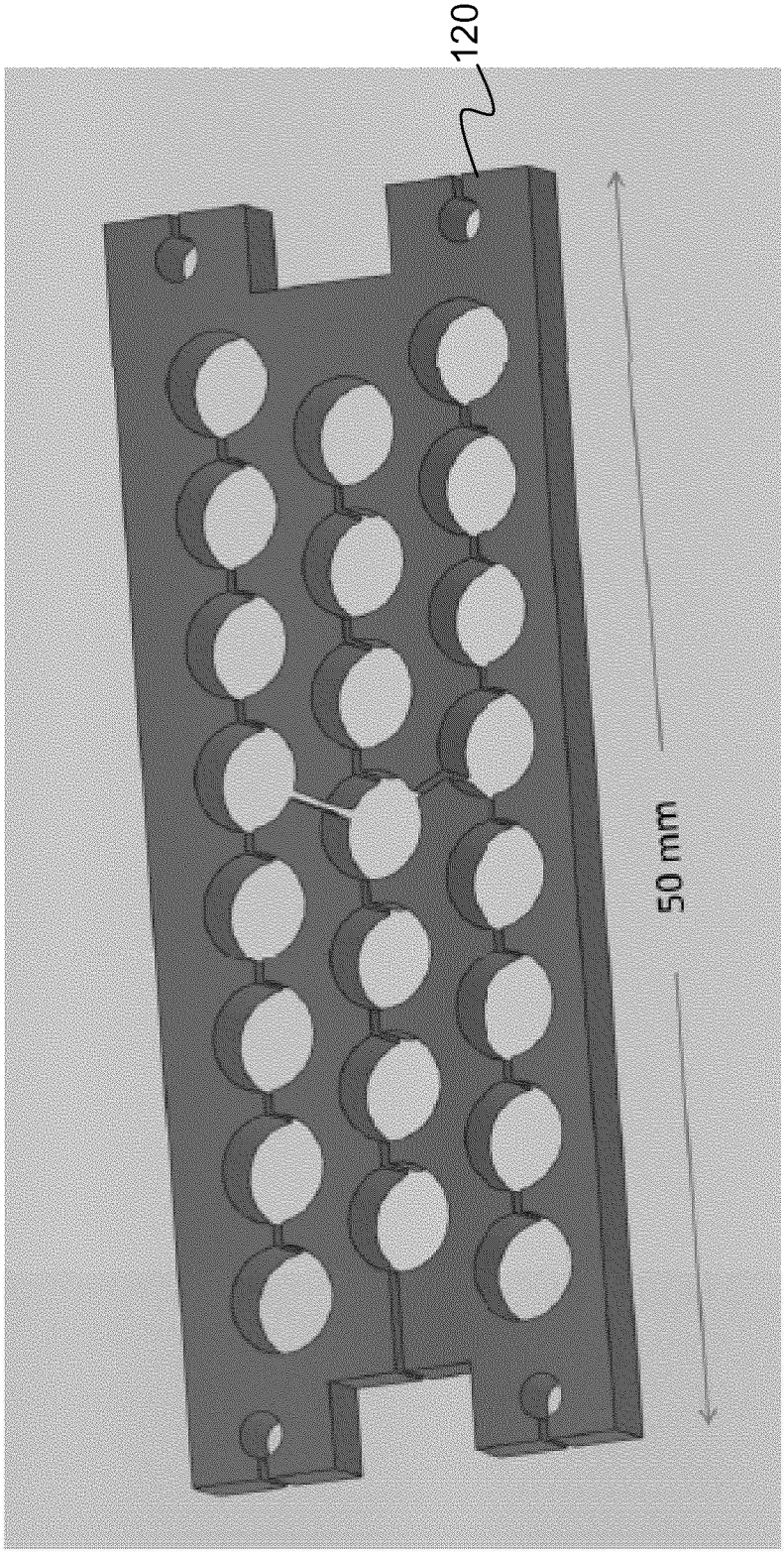
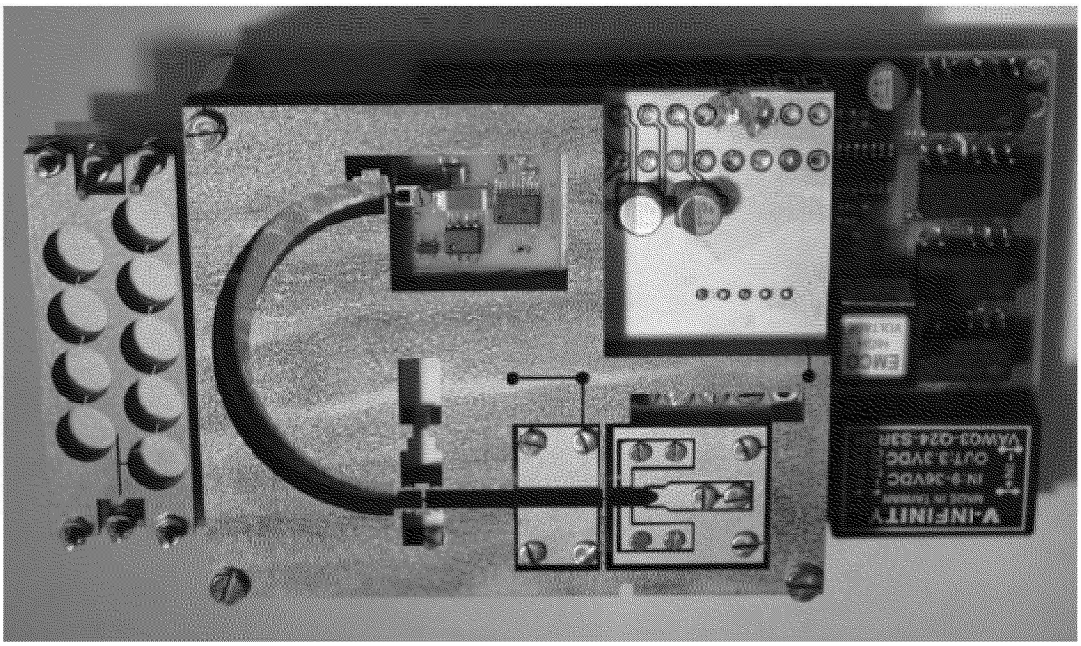


FIG. 15

FIG. 16



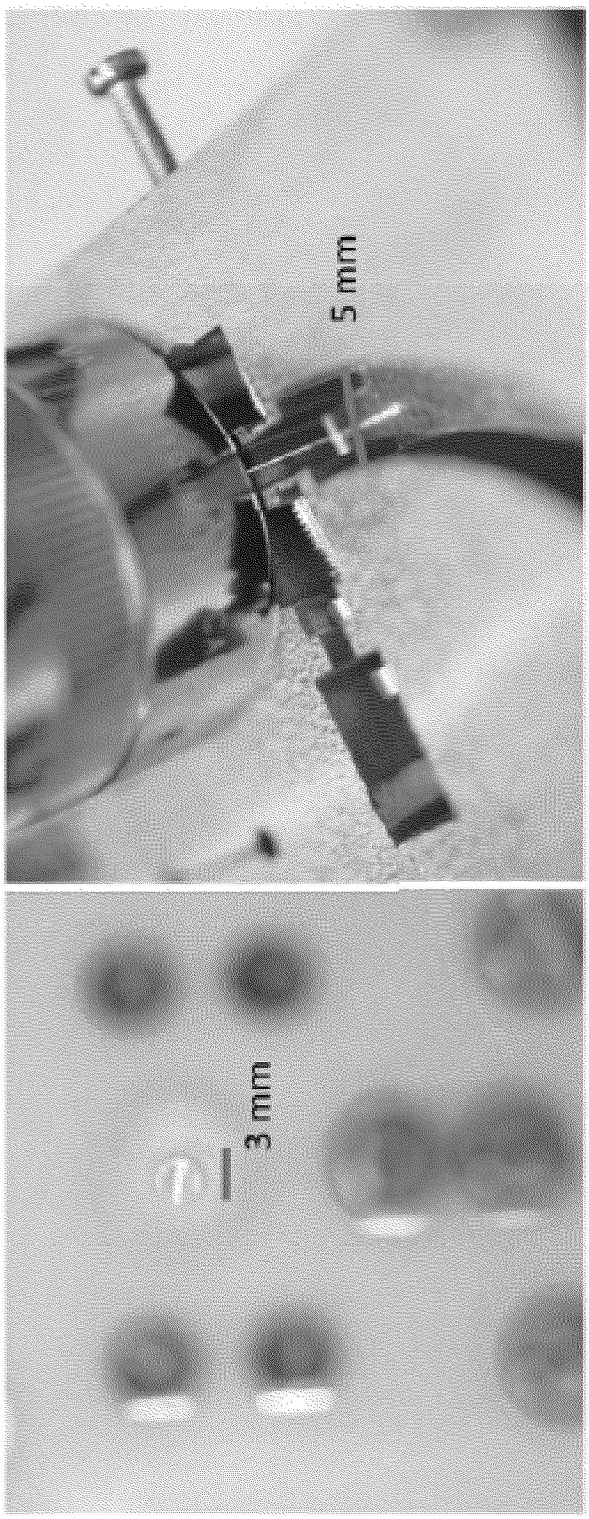


FIG. 17

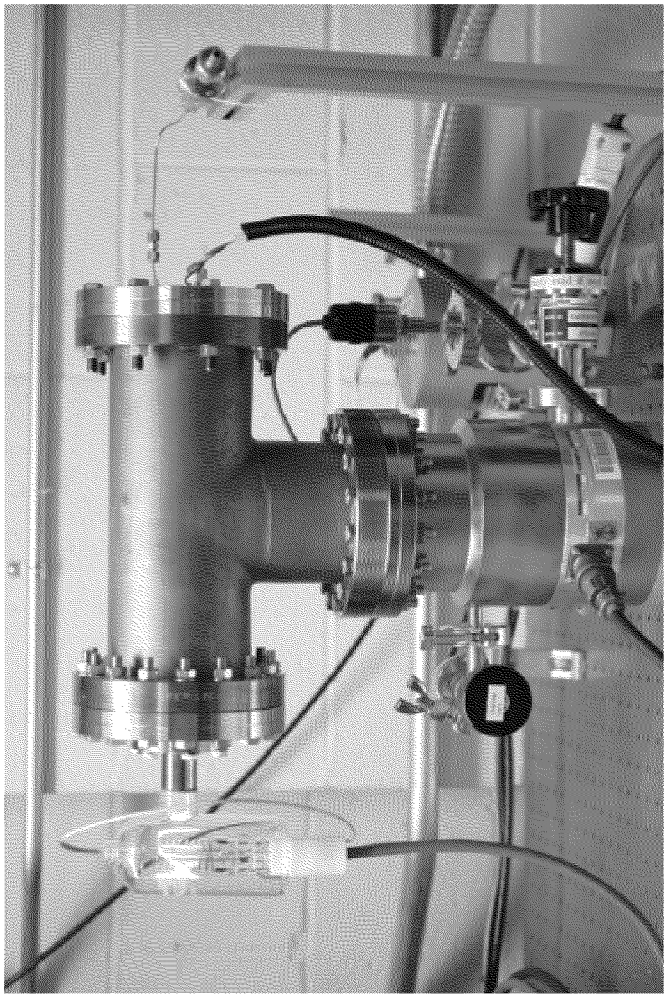


FIG. 18B

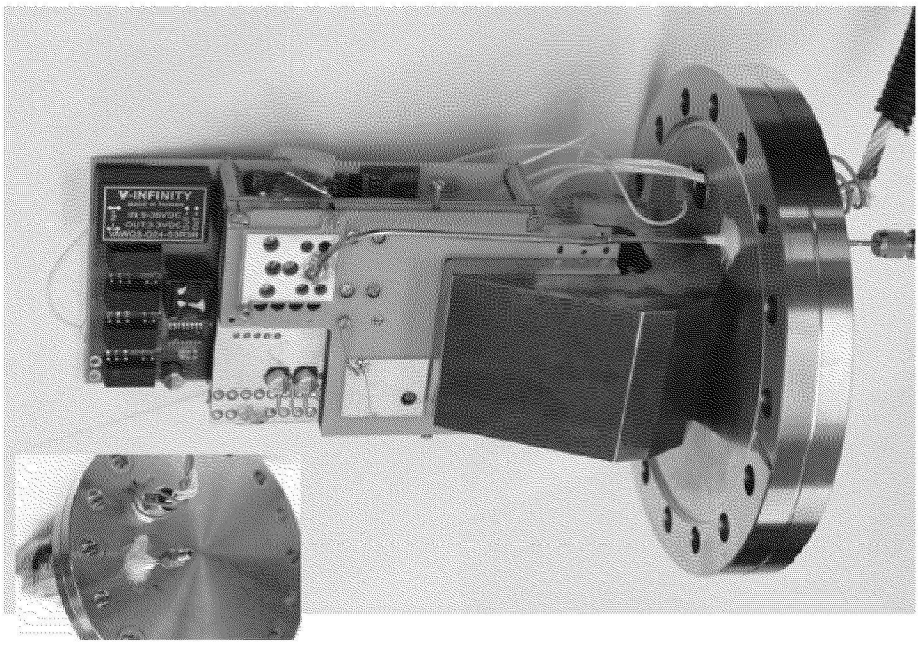


FIG. 18A

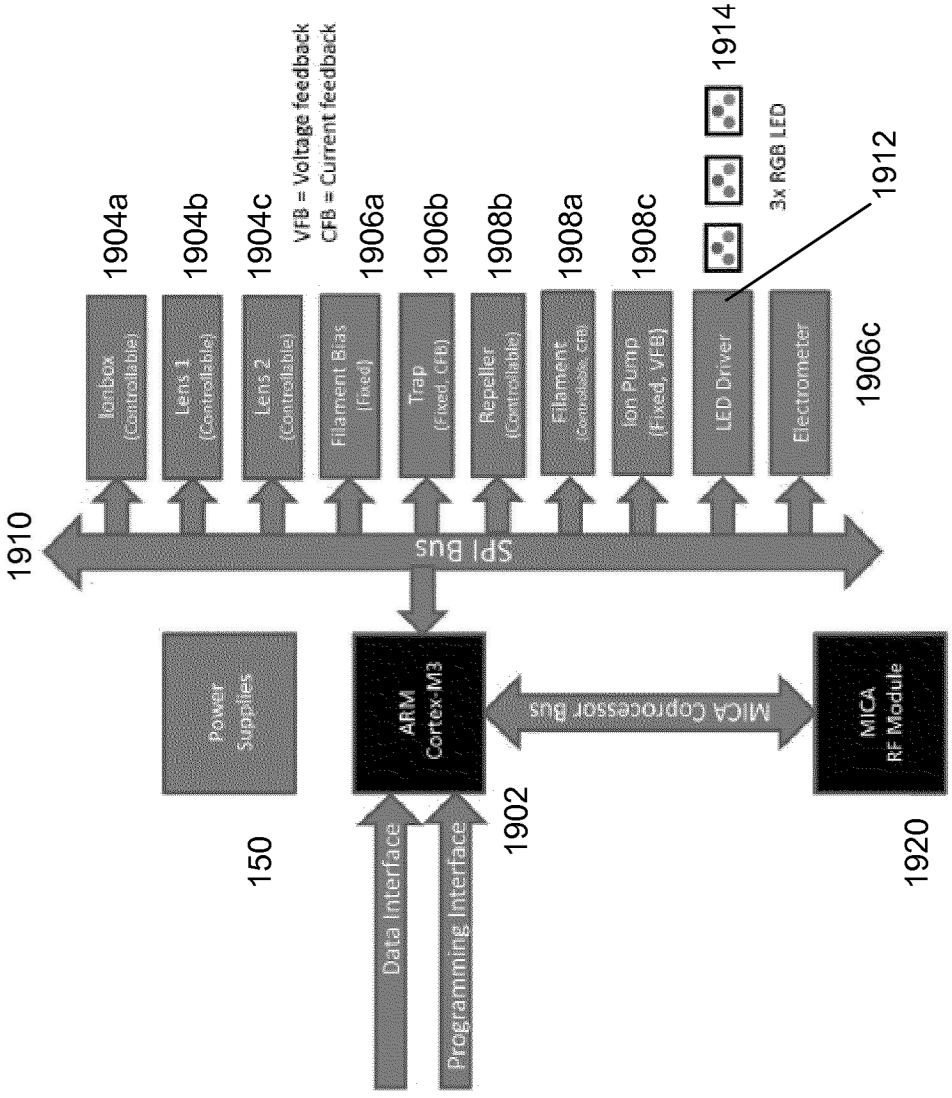

1910
SPI Bus
Ionbox (Controllable)
Lens 1 (Controllable)
Lens 2 (Controllable)
Filament Bias (Fixed)
Trap (Fixed, CFB)
Repeller (Controllable)
Filament (Controllable, CFB)
Ion Pump (Fixed, VFB)
LED Driver
Electrometer
1904a
1904b
1904c
1906a
1906b
1908b
1908a
1908c
1906c
1912
1914
3x RGB LED
VFB = Voltage feedback
CFB = Current feedback
Power Supplies
150
ARM Cortex-M3
1902
MICA Coprocessor Bus
MICA RF Module
1920
Data Interface
Programming Interface

FIG. 19

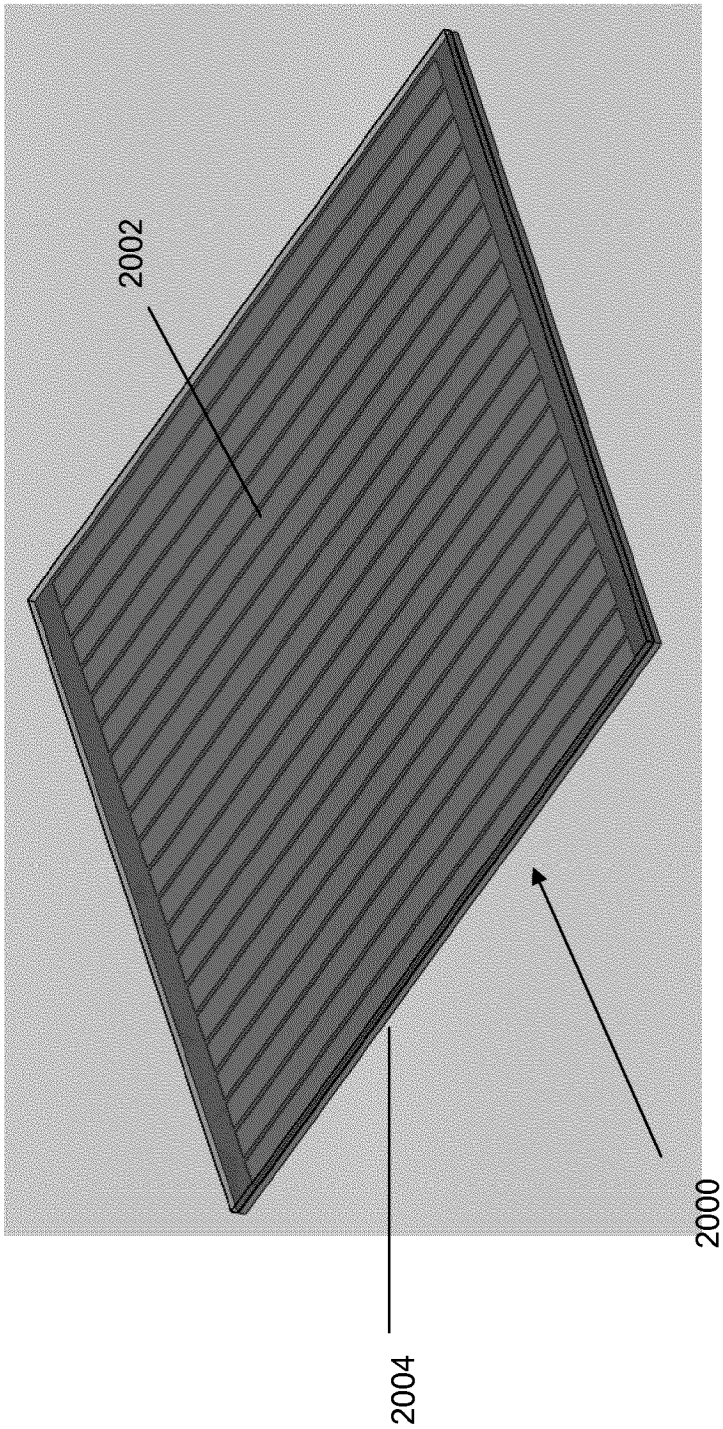


FIG. 20

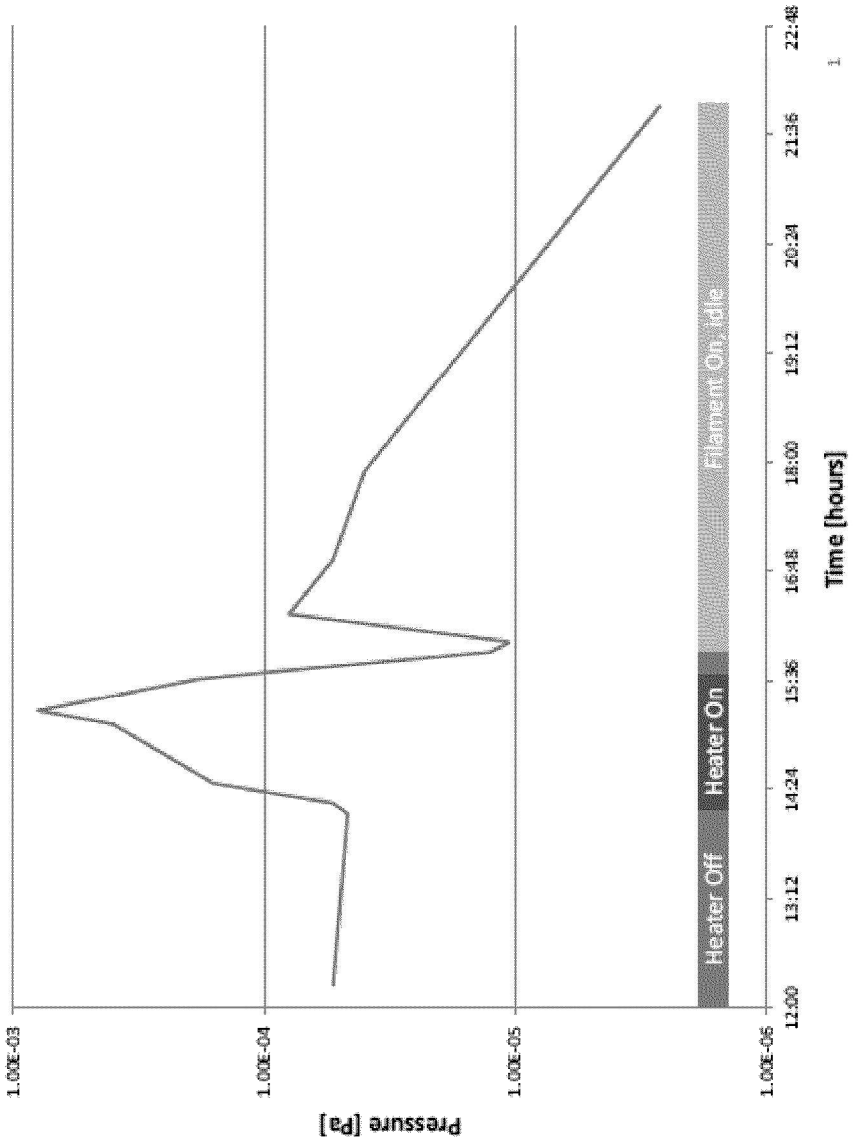

1.00E-03
1.00E-04
1.00E-05
1.00E-06
Pressure [Pa]
12:00
13:12
14:24
15:36
16:48
18:00
19:12
20:24
21:36
22:48
Time [hours]
Heater Off
Heater On
Filament On, Idle

FIG. 21

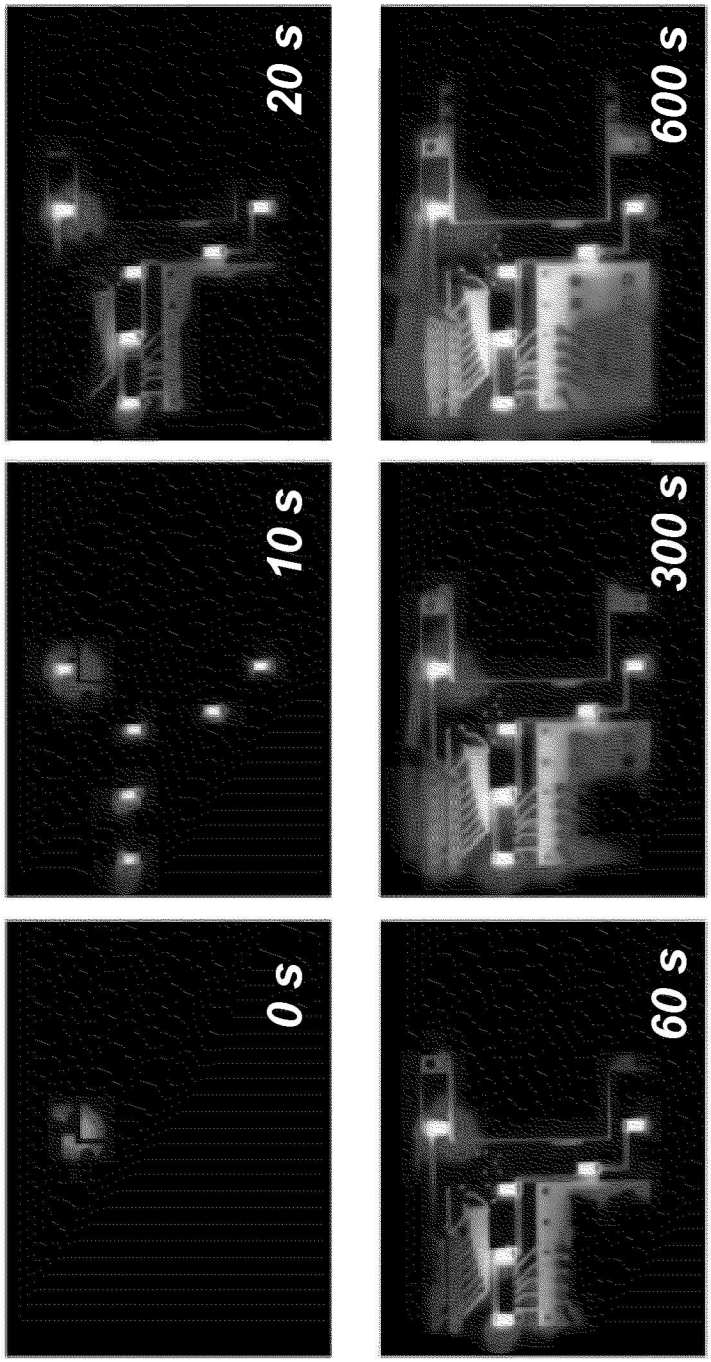


FIG. 22

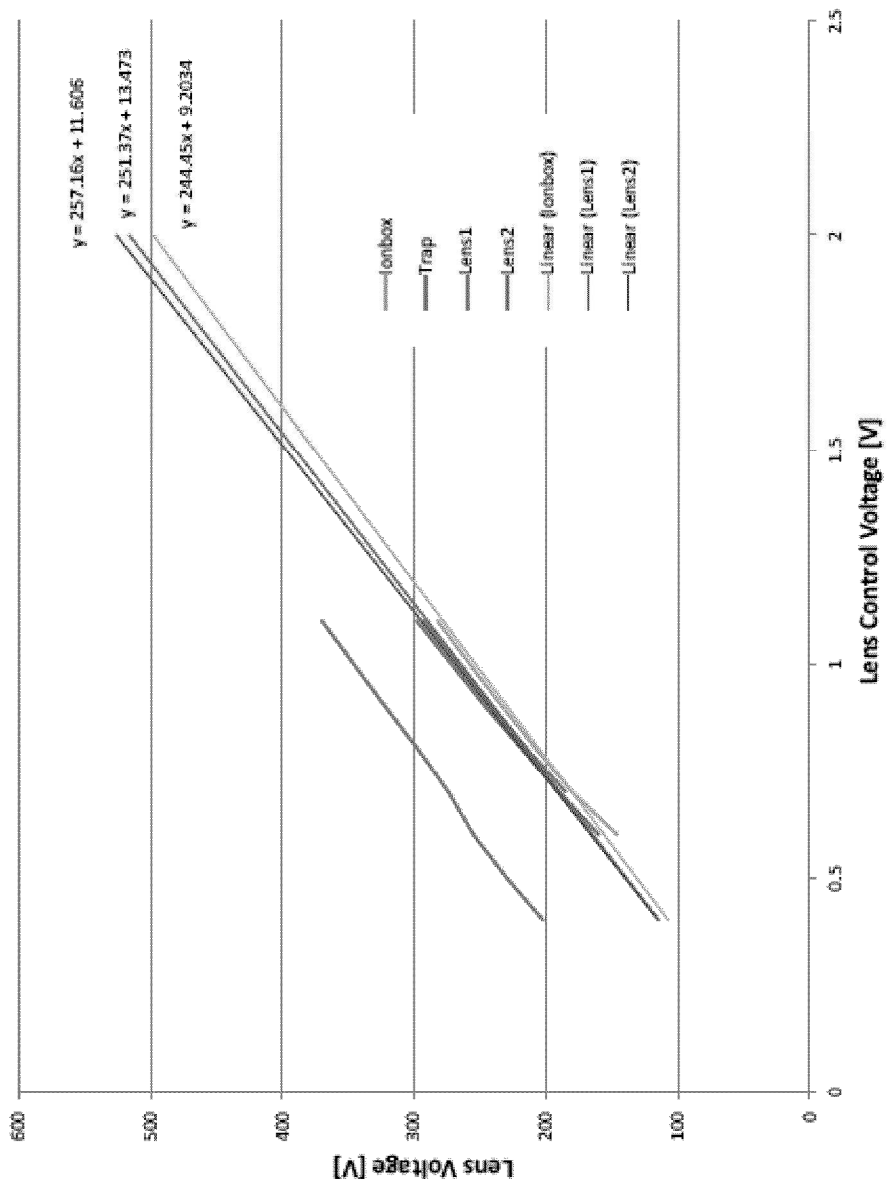

y = 257.16x + 11.606
y = 251.37x + 13.473
y = 244.45x + 9.2034
Ionbox
Trap
Lens1
Lens2
Linear (Ionbox)
Linear (Lens1)
Linear (Lens2)
Lens Voltage [V]
Lens Control Voltage [V]
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5

FIG. 23

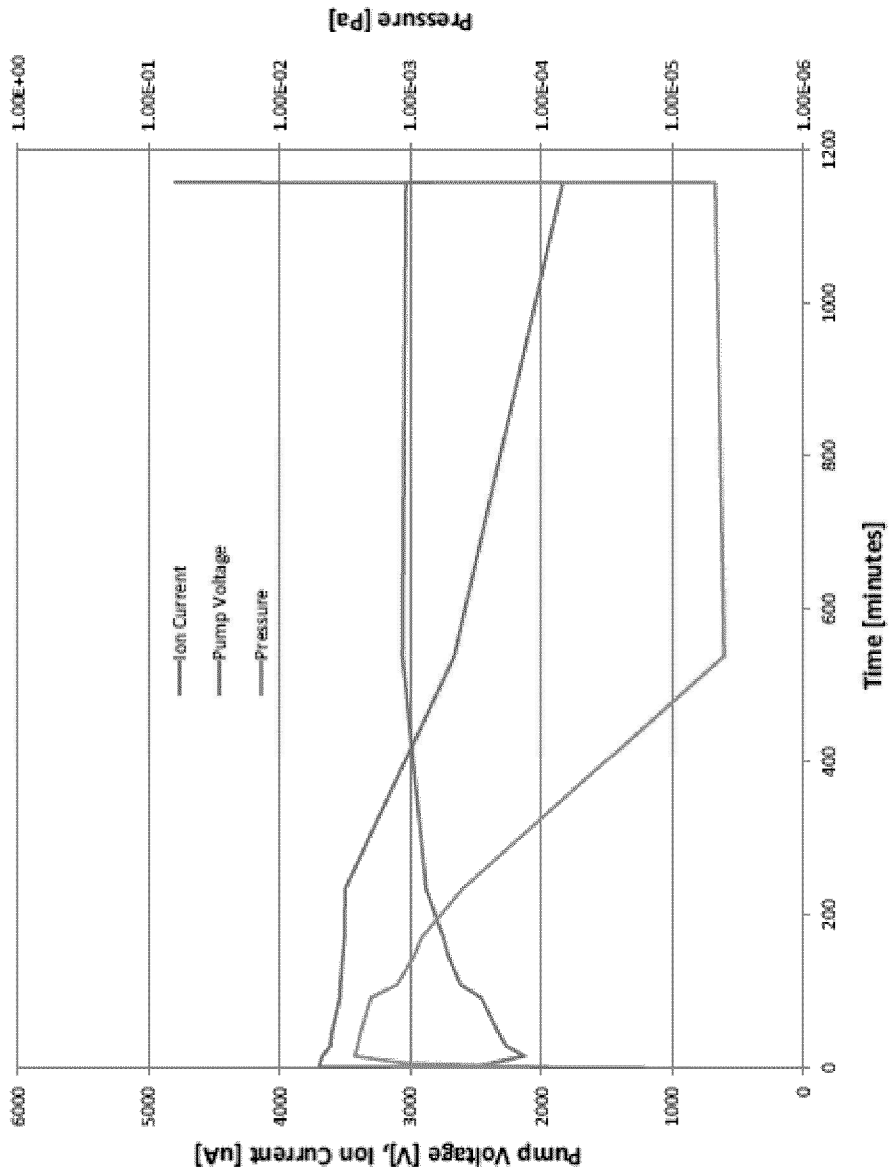

Pressure [Pa]
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
Ion Current
Pump Voltage
Pressure
Time [minutes]
0
200
400
600
800
1000
1200
Pump Voltage [V], Ion Current [uA]
6000
5000
4000
3000
2000
1000
0

FIG. 24

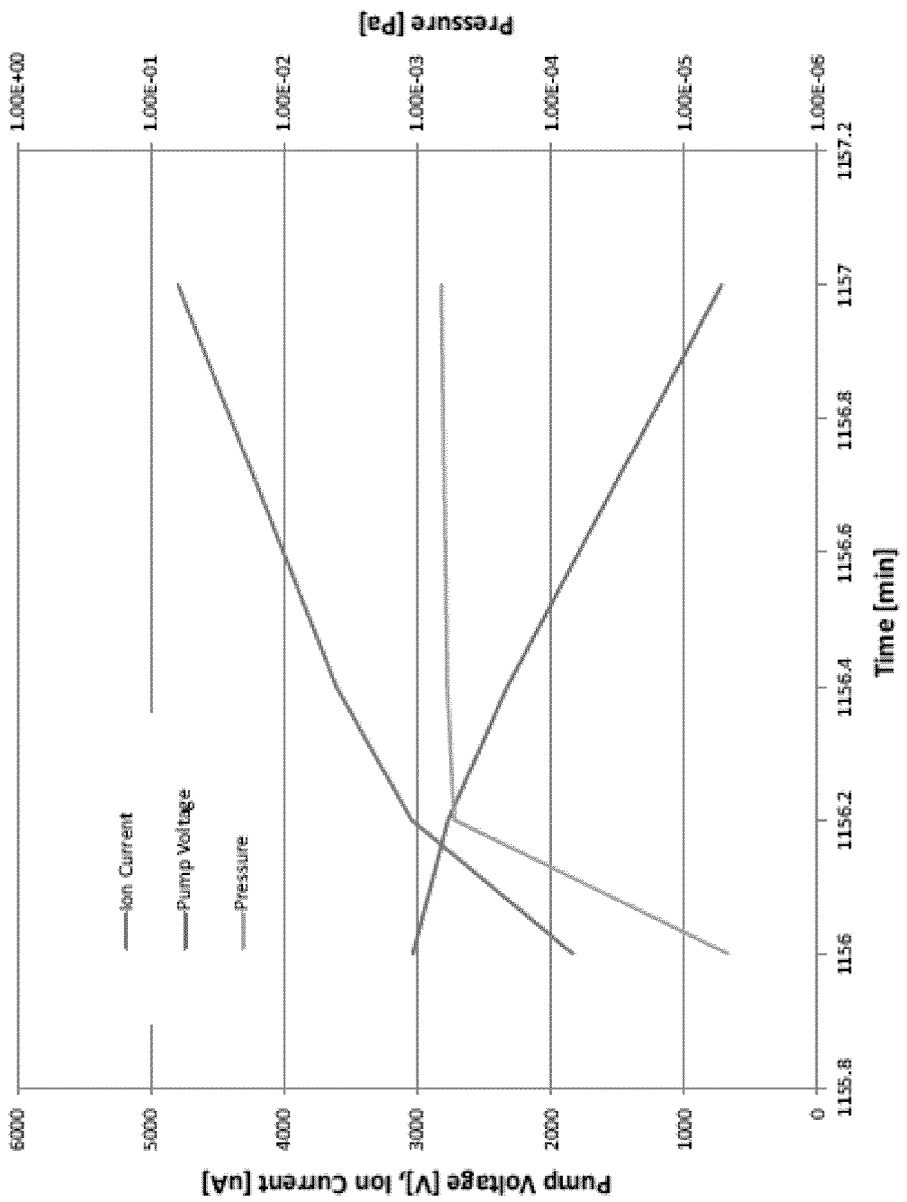

Pressure [Pa]
1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
Pump Voltage [V], Ion Current [uA]
6000
5000
4000
3000
2000
1000
0
Ion Current
Pump Voltage
Pressure
1155.8
1156
1156.2
1156.4
1156.6
1156.8
1157
1157.2
Time [min]

FIG. 25

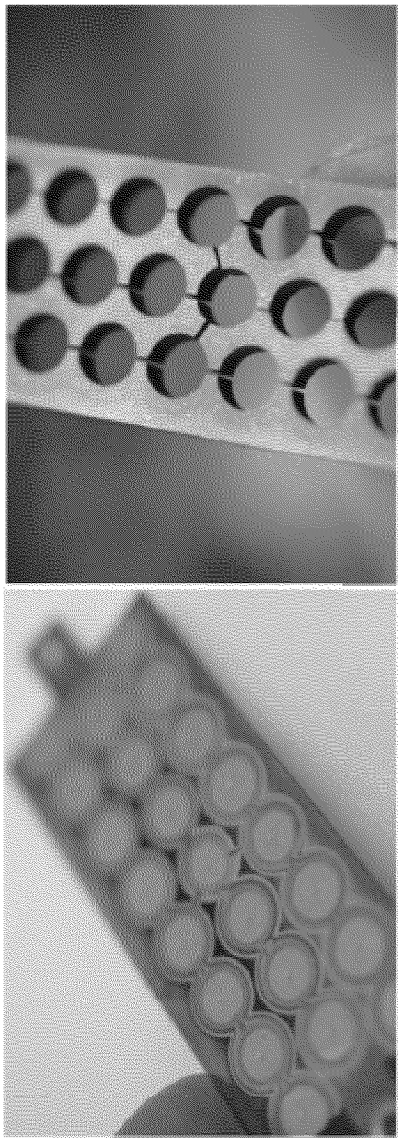


FIG. 26

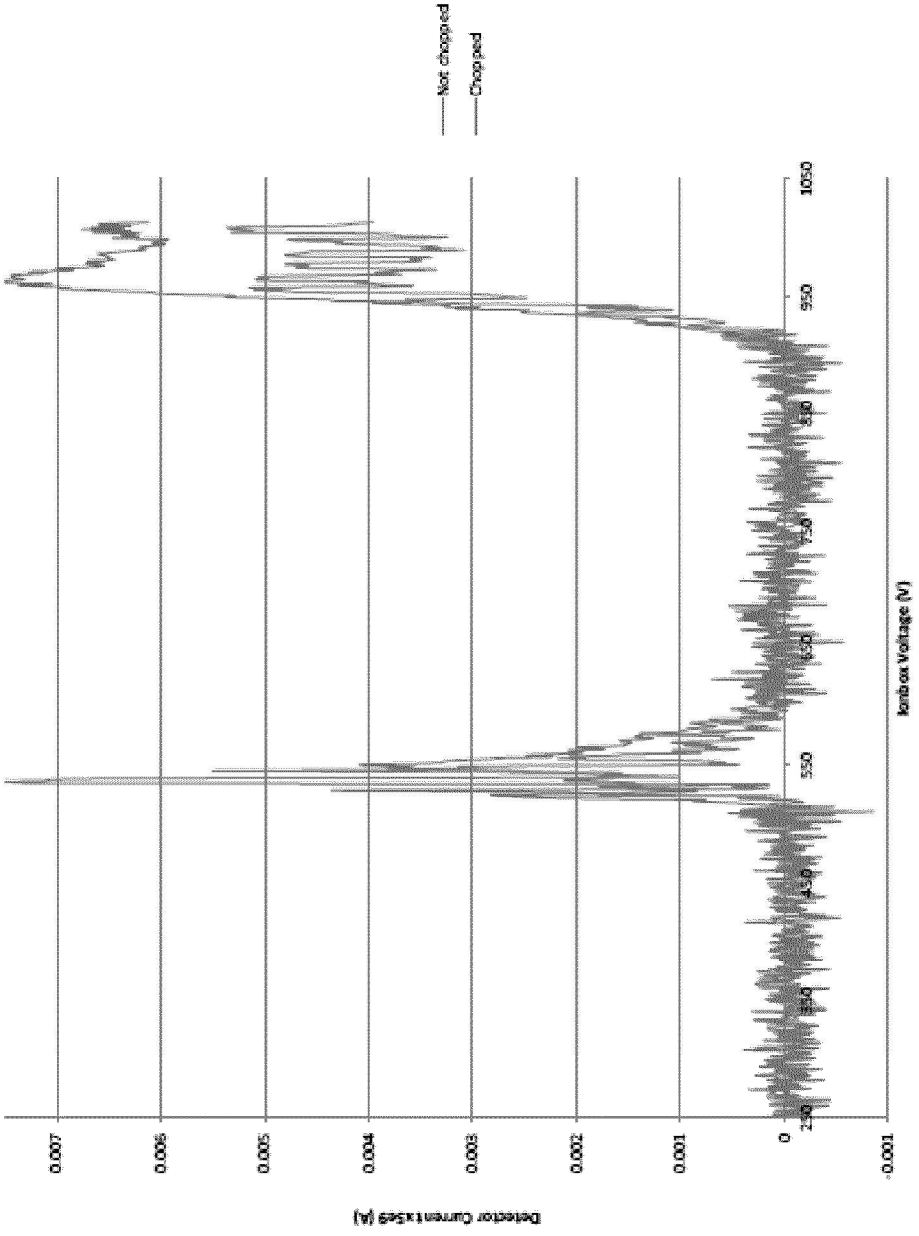

Not chopped
Chopped
Detector Current x5e9 (A)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
-0.001
250
350
450
550
650
750
850
950
1050
Ionbox Voltage (V)

FIG. 27

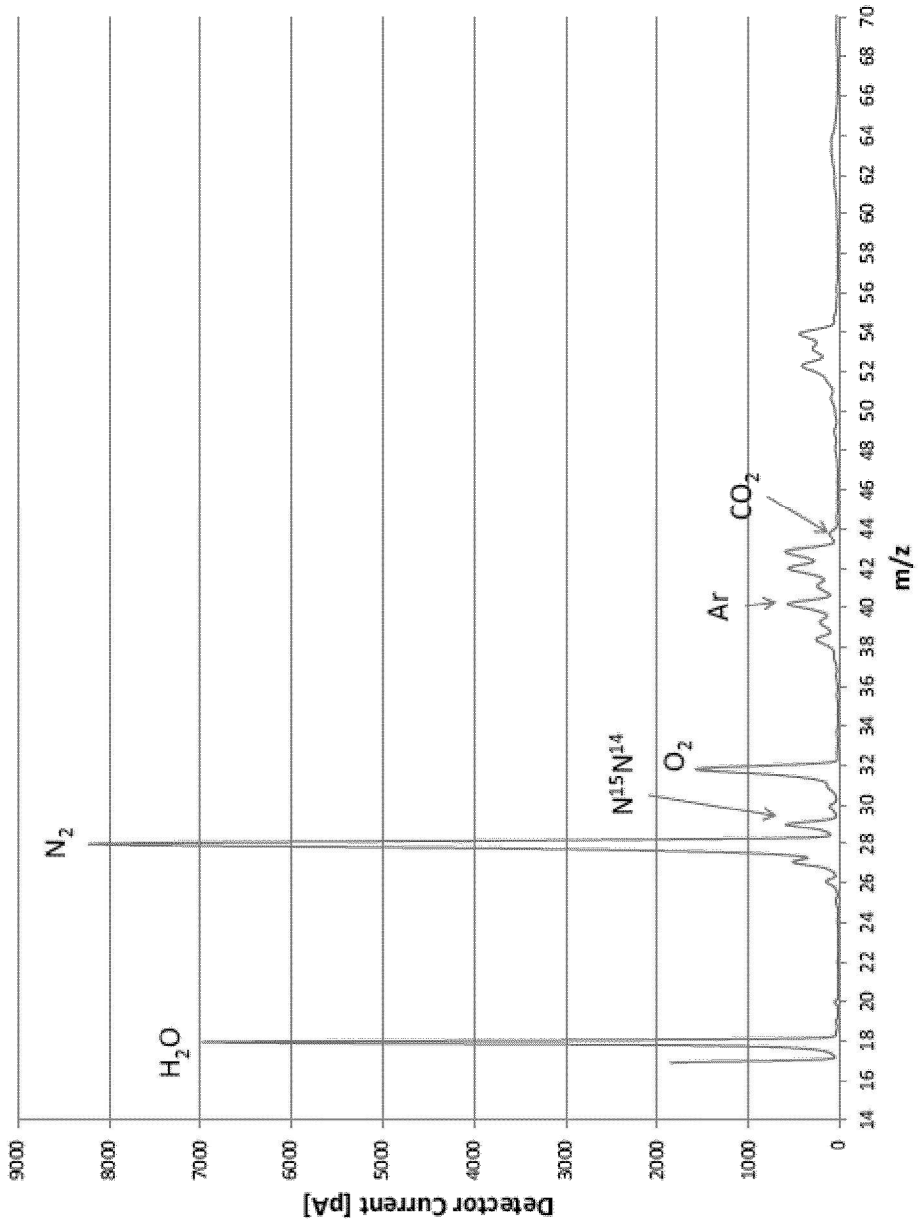

Detector Current [pA]
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70
m/z
H_2O
N_2
$N^{15}N^{14}$
O_2
Ar
CO_2

FIG. 28

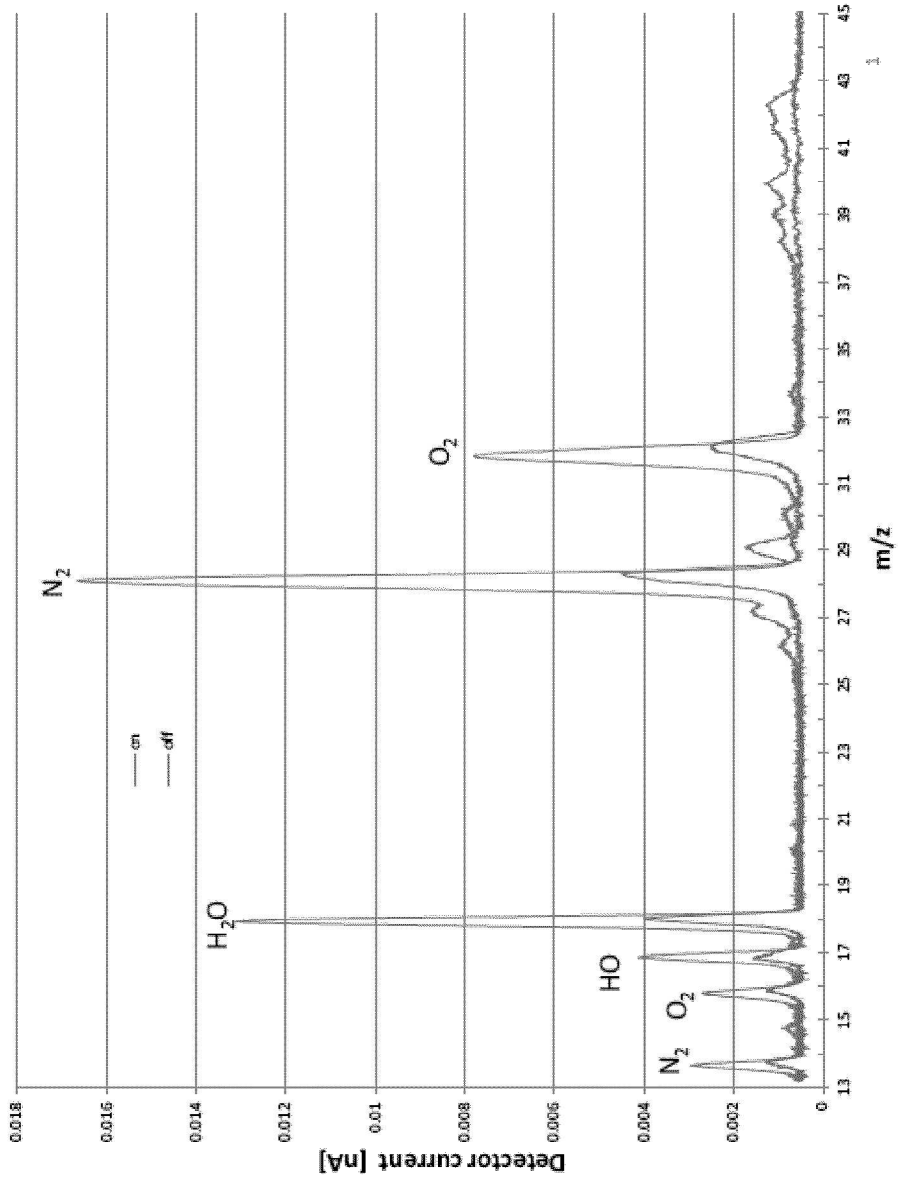


FIG. 29

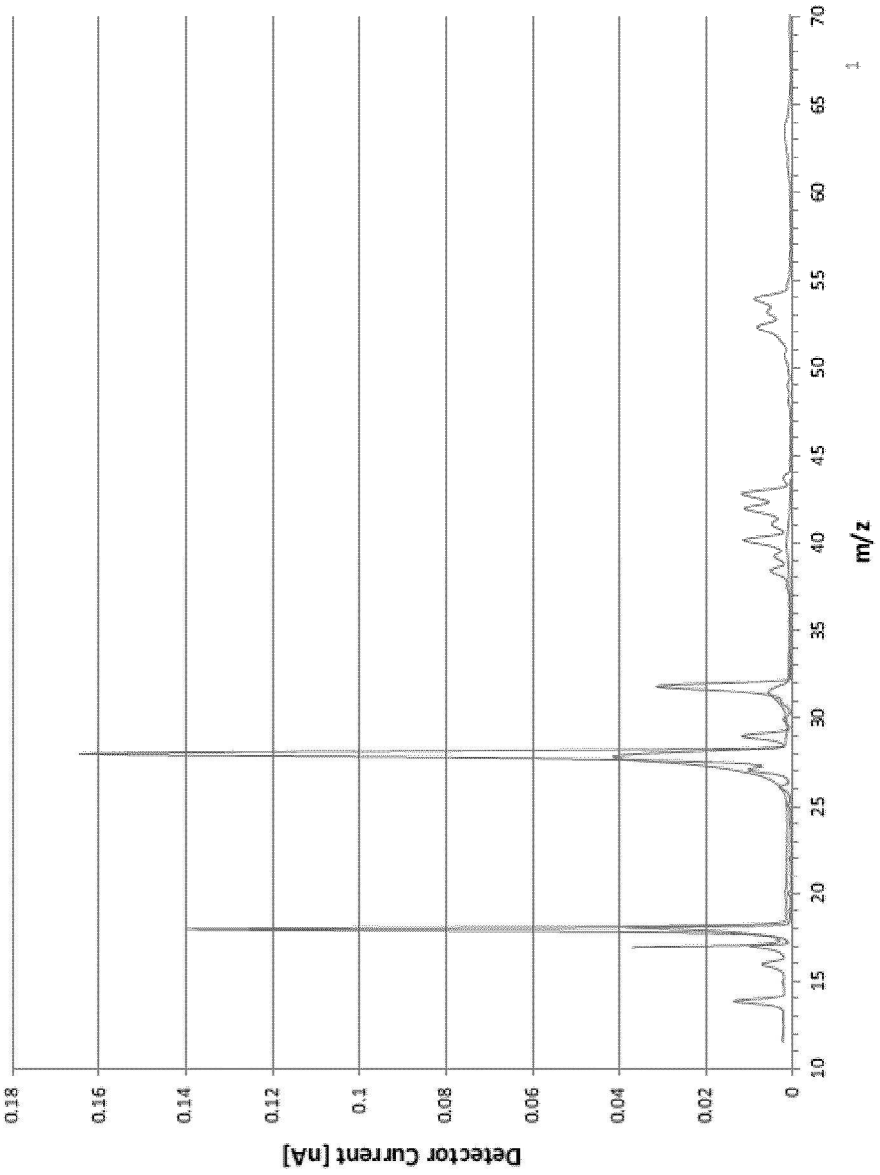

Detector Current [nA]
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
10
15
20
25
30
35
40
45
50
55
60
65
70
m/z
1

FIG. 30

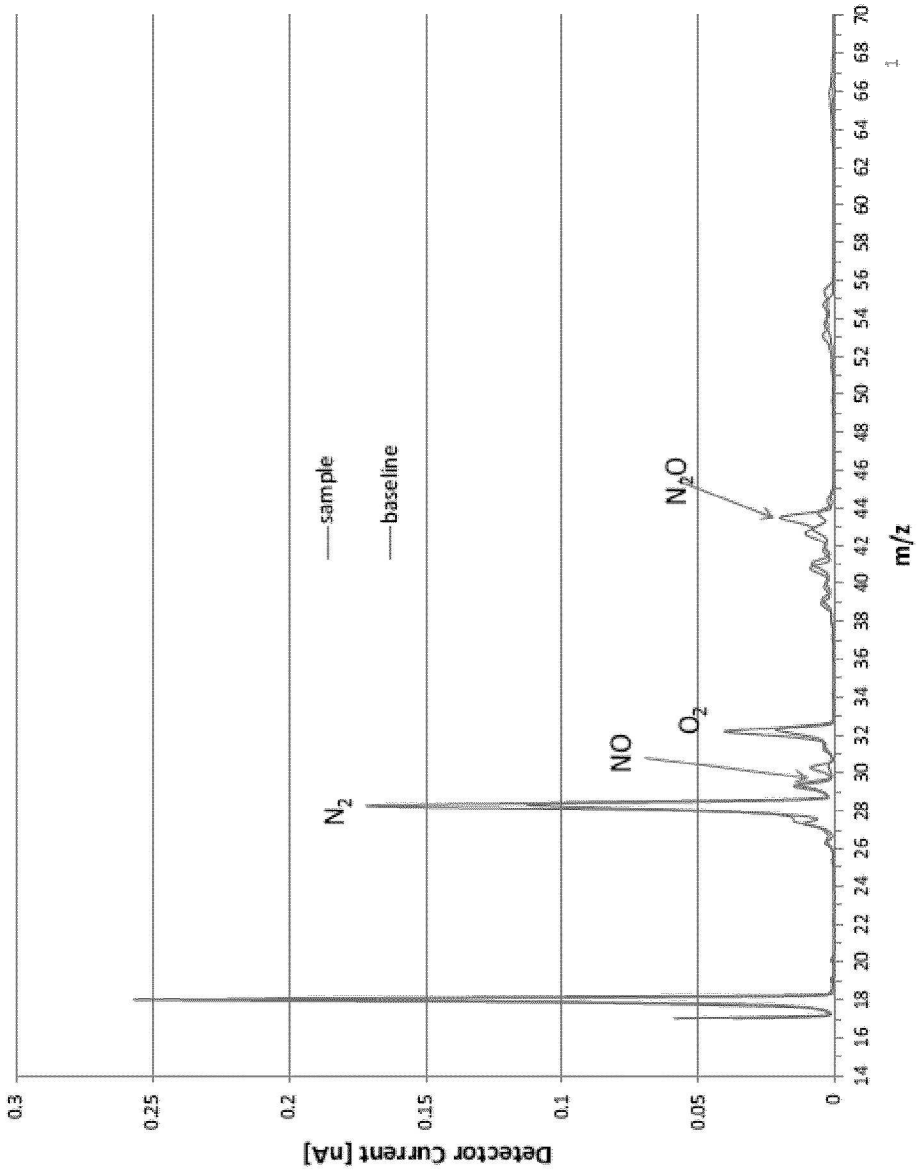

Detector Current [nA]
0.3
0.25
0.2
0.15
0.1
0.05
0
14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70
m/z
sample
baseline
N_2
NO
O_2
N_2O

FIG. 31

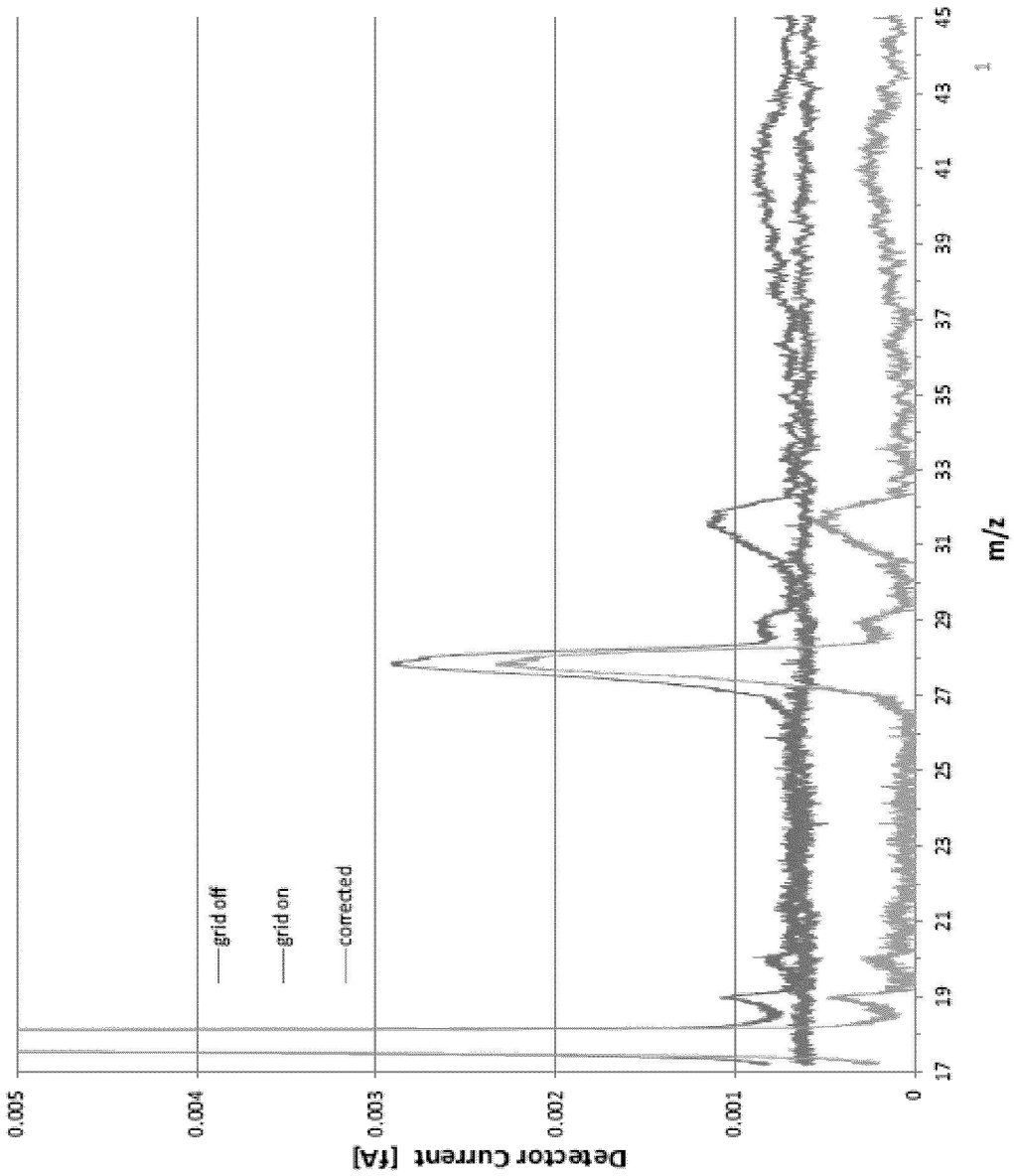

Detector Current [fA]
0.005
0.004
0.003
0.002
0.001
0
grid off
grid on
corrected
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
m/z

FIG. 32