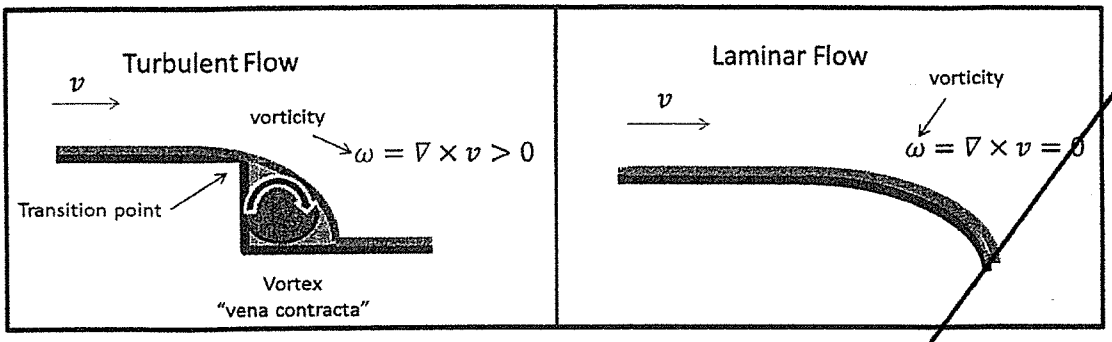


Figure 1

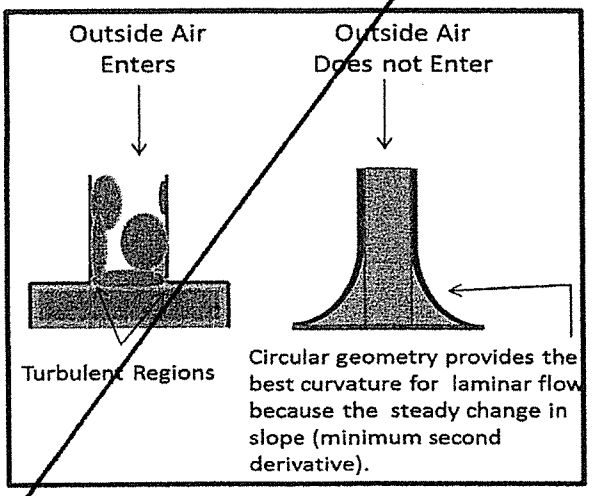


Figure 2

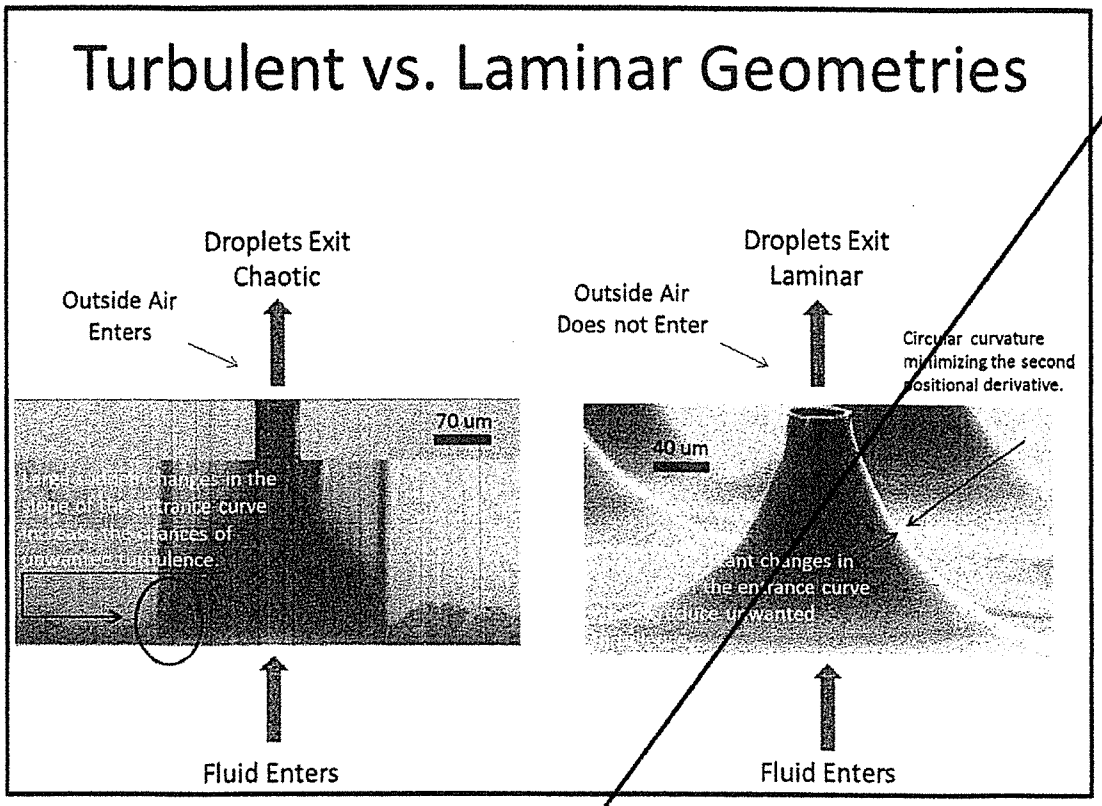

Turbulent vs. Laminar Geometries
Droplets Exit
Chaotic
Outside Air
Enters
70 um
Fluid Enters
Droplets Exit
Laminar
Outside Air
Does not Enter
Circular curvature
minimizing the second
positional derivative.
40 um
Fluid Enters

Figure 3

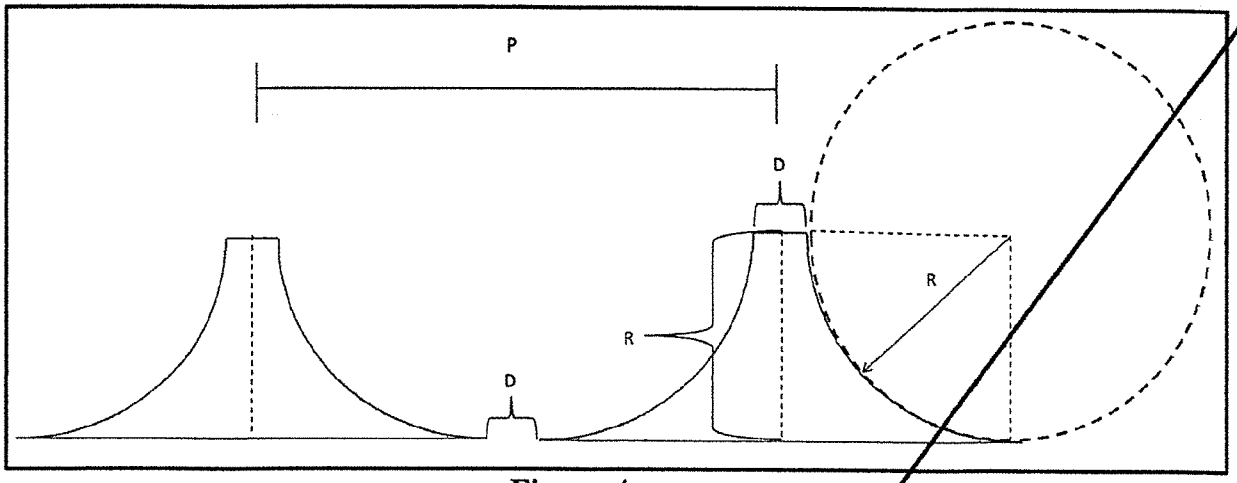


Figure 4

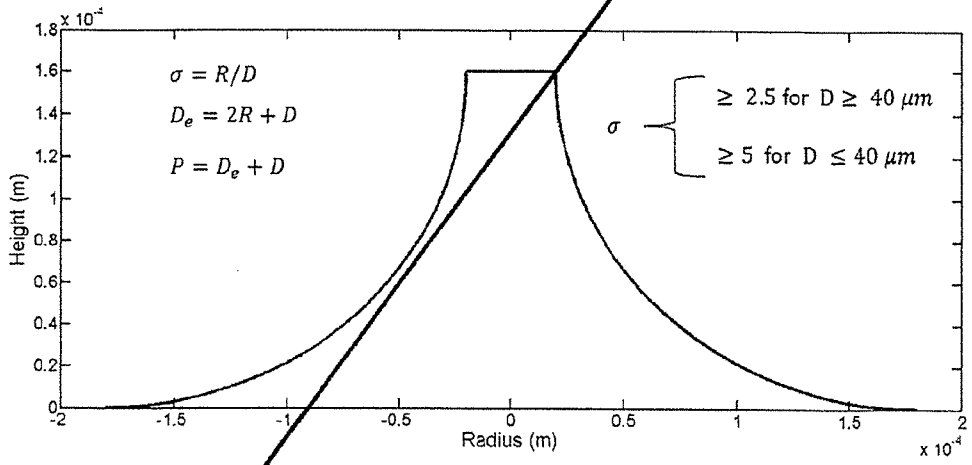


Figure 5

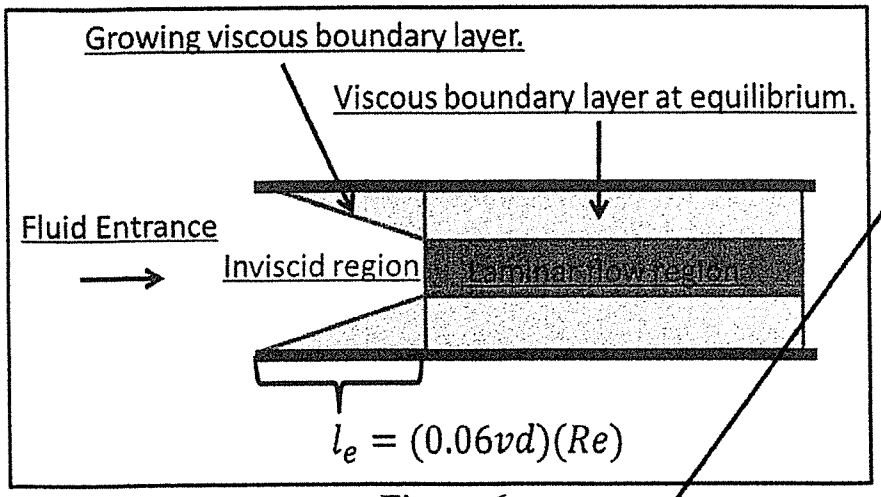


Figure 6

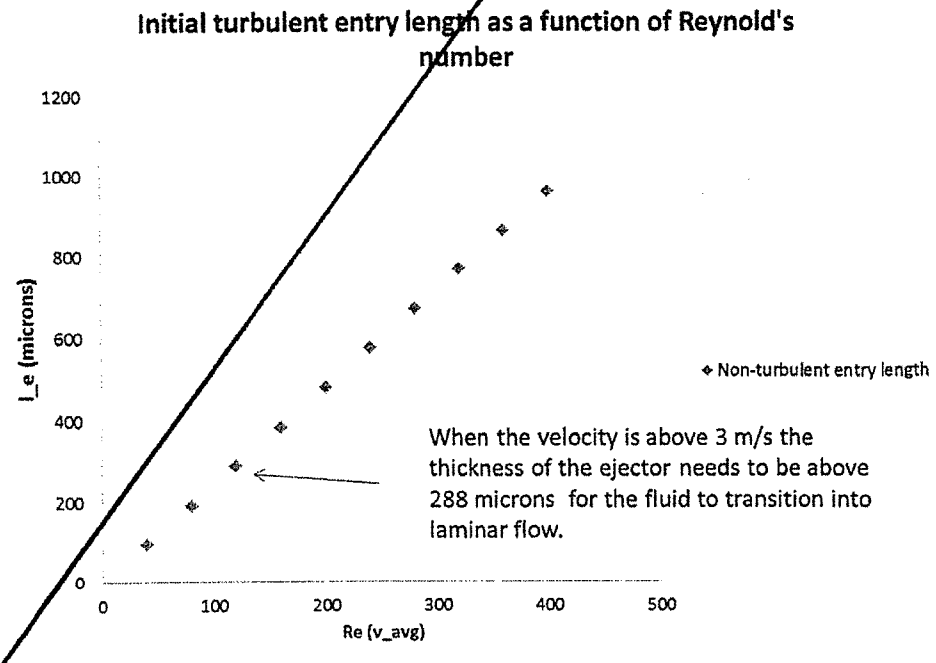


Figure 7

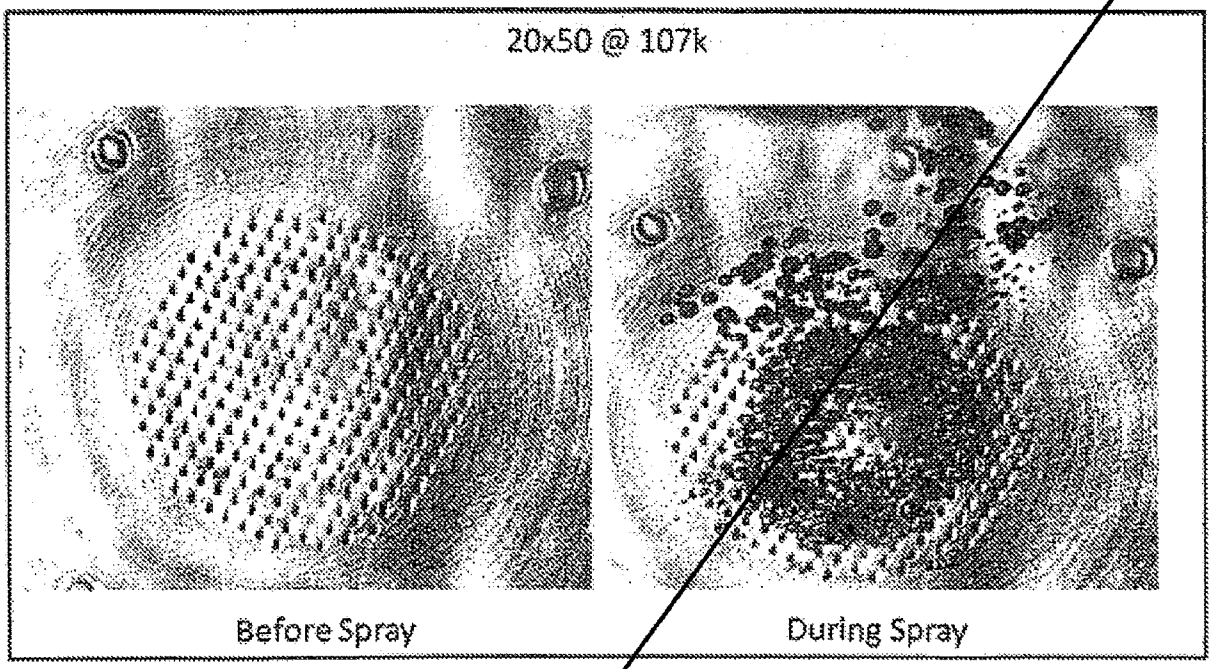


Figure 8

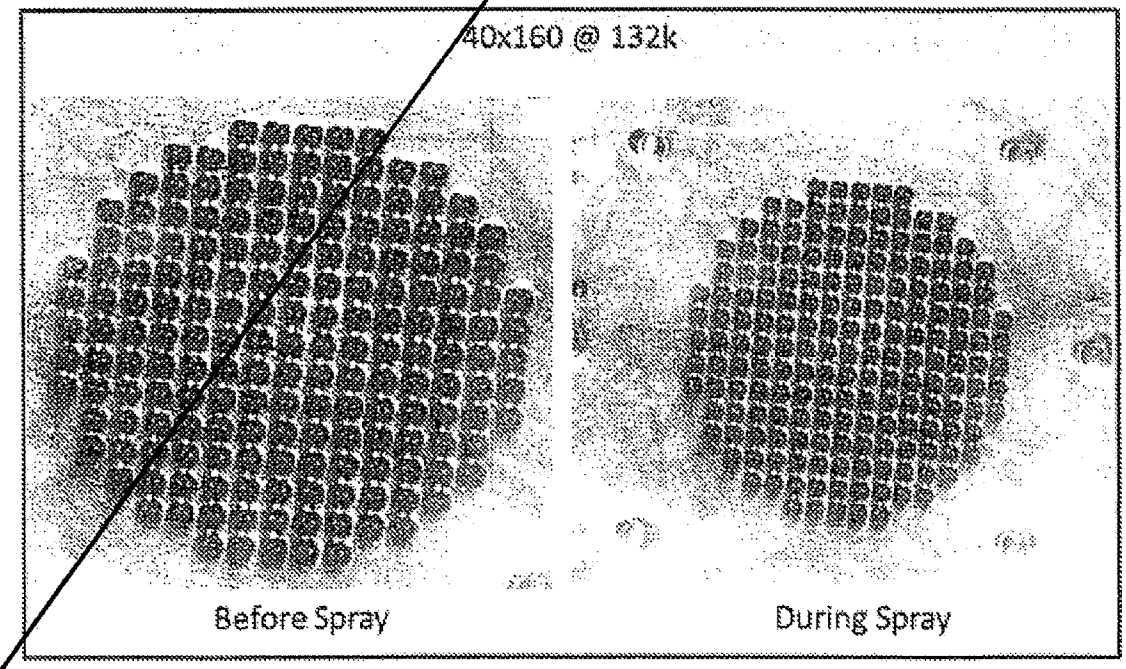


Figure 9

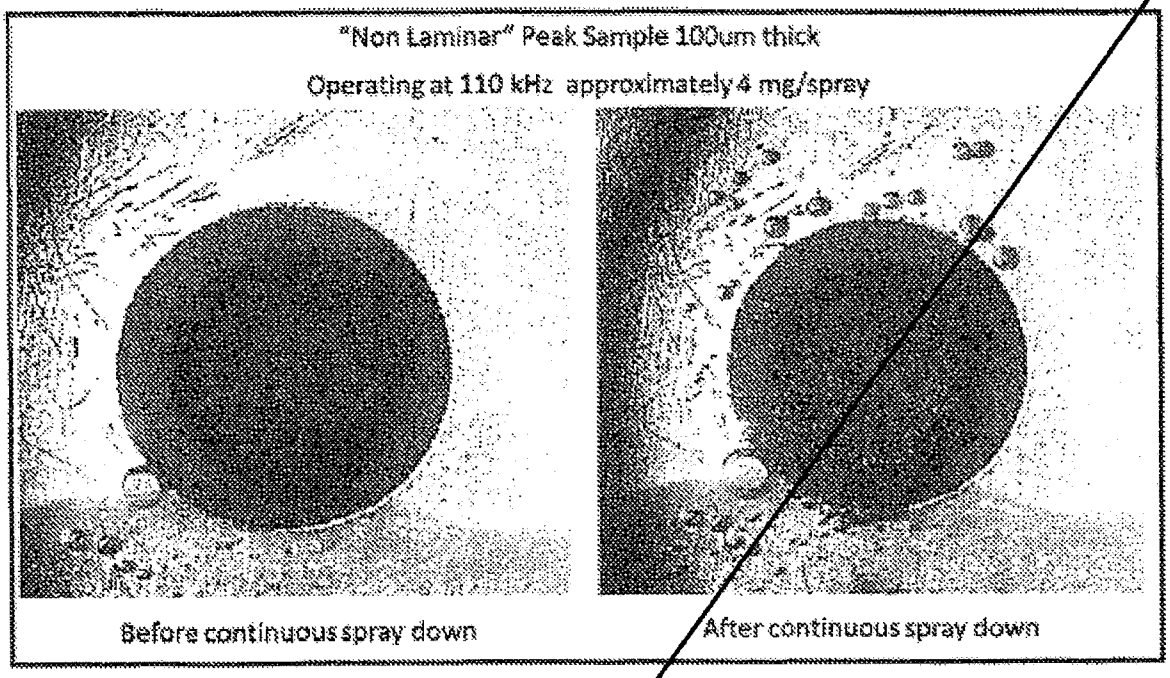


Figure 10

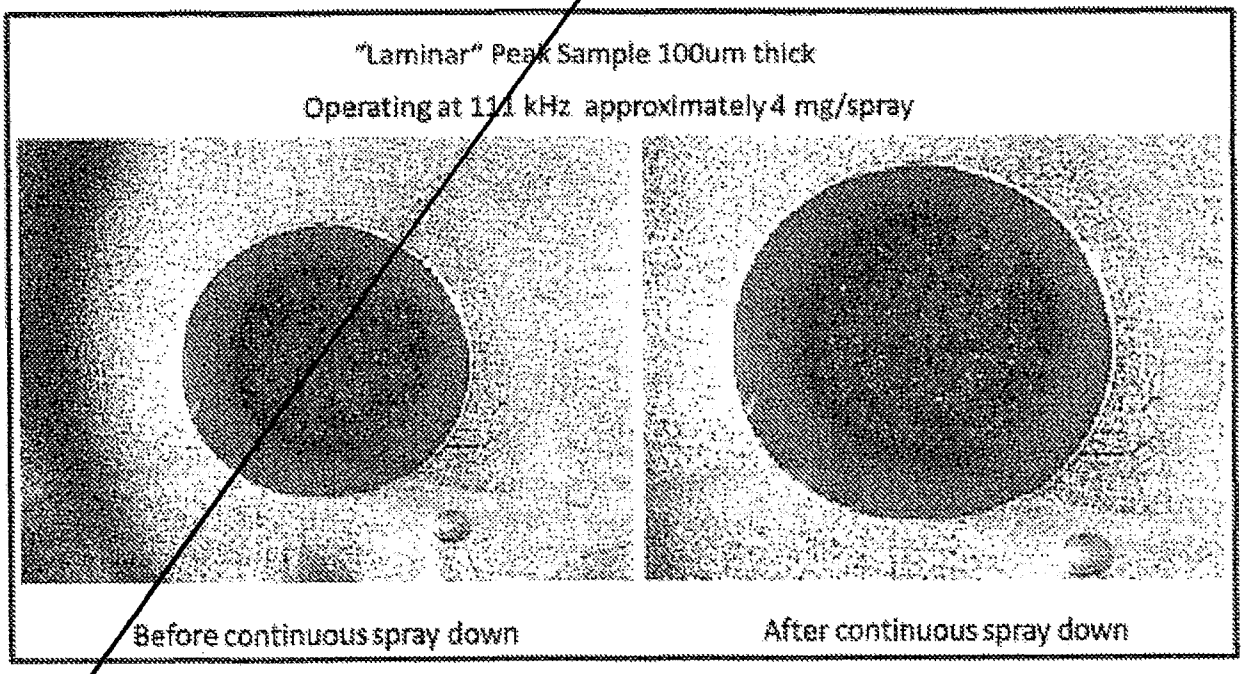
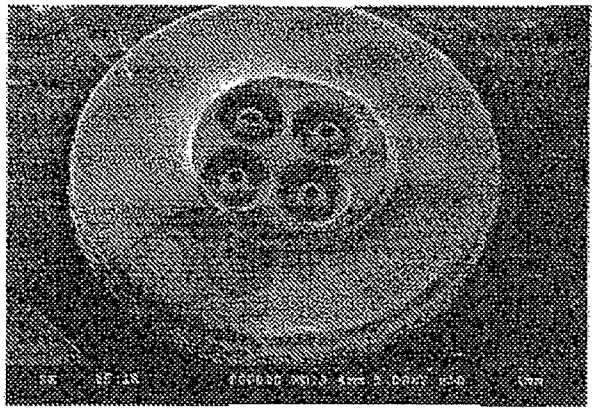
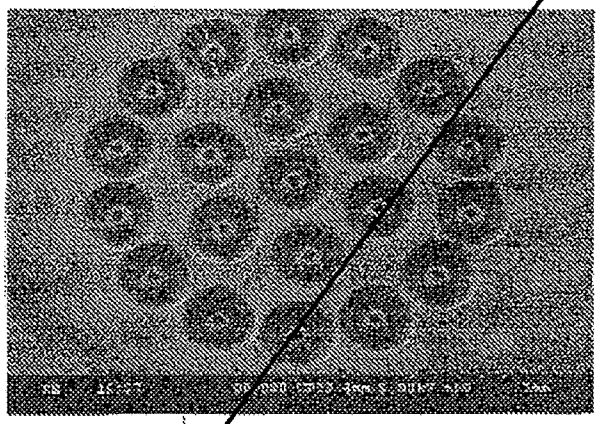


Figure 11



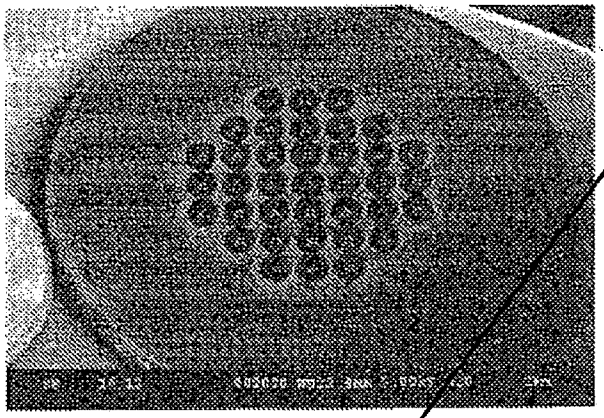
4-hole with mesa

Figure 12



21-hole

Figure 13



37-hole

Figure 14

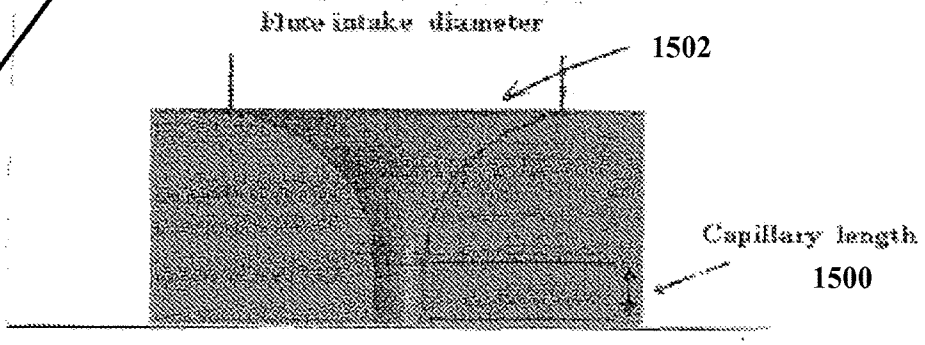


Figure 15

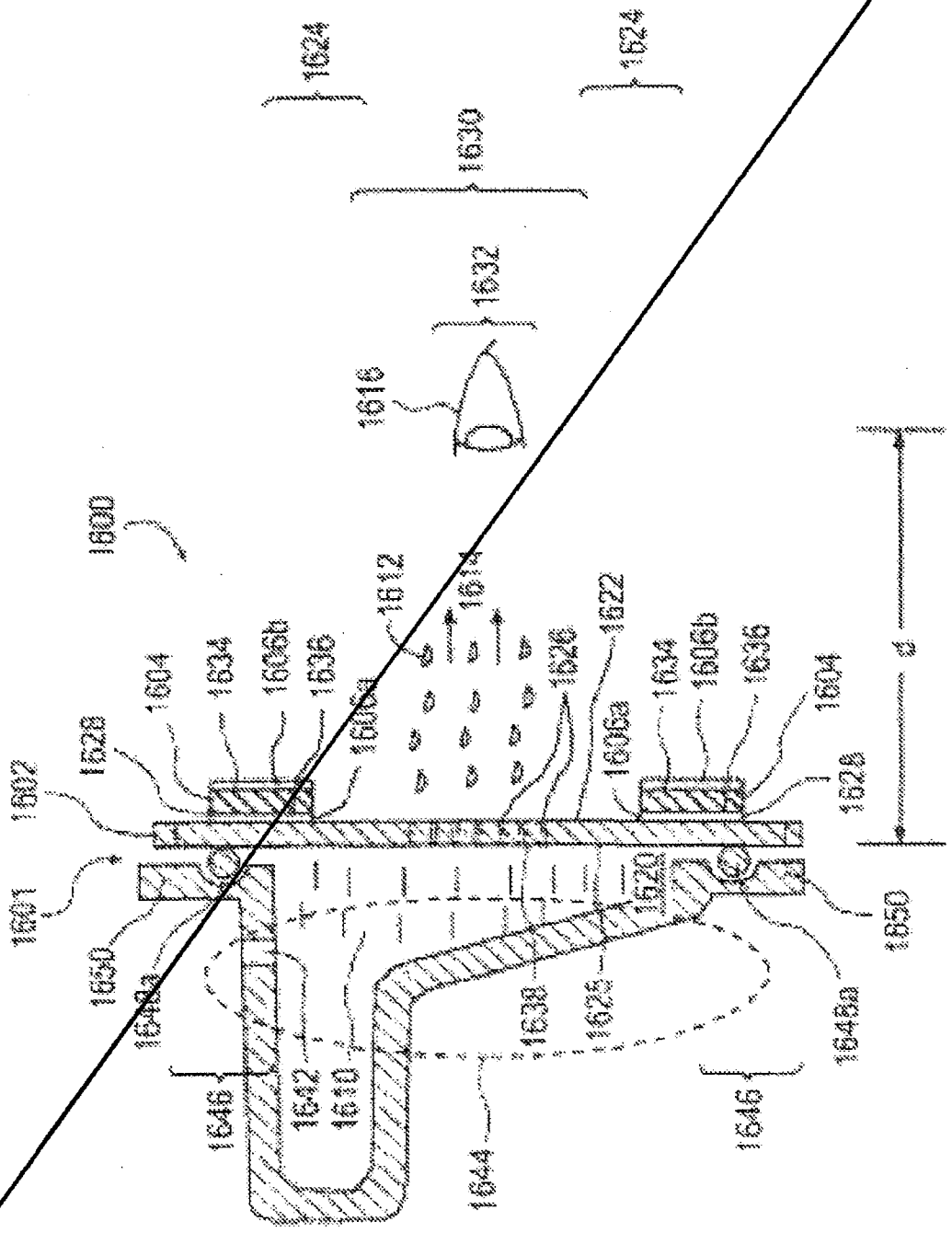

1624
1630
1624
1632
1616
1600
1612
1614
1622
1602
1628
1604
1634
1606b
1636
1606a
1626
1601
1650
1620
1646a
1638
1625
1642
1610
1646
1644

Figure 16

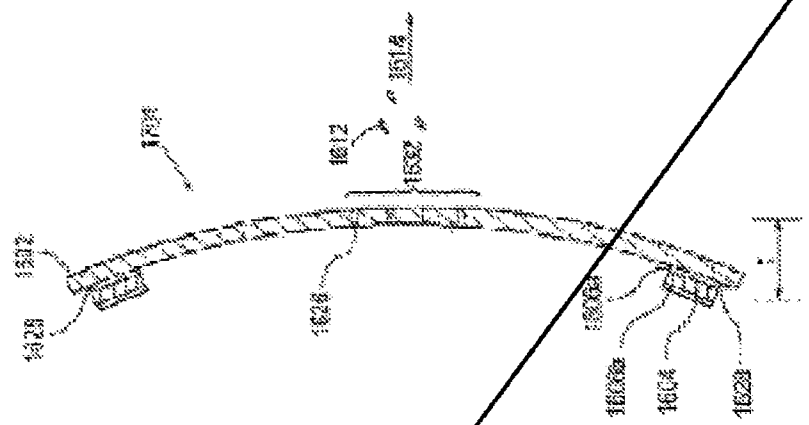


Figure 17B

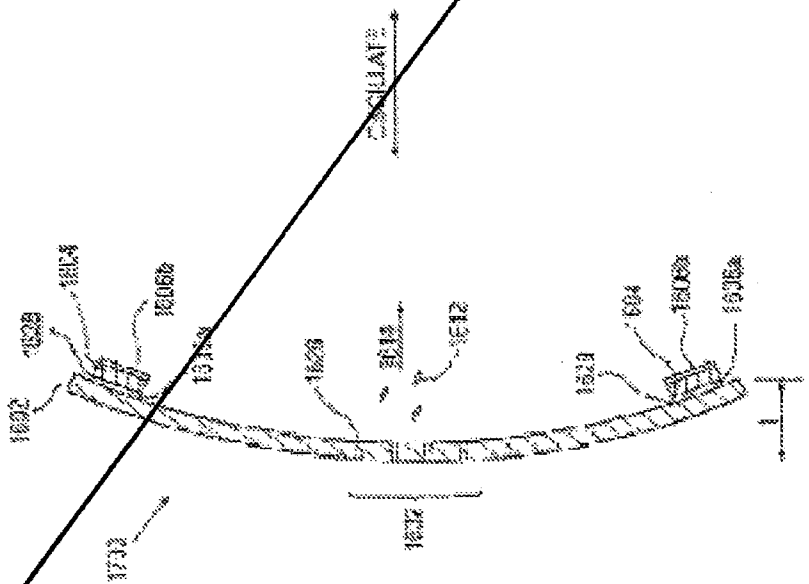


Figure 17A

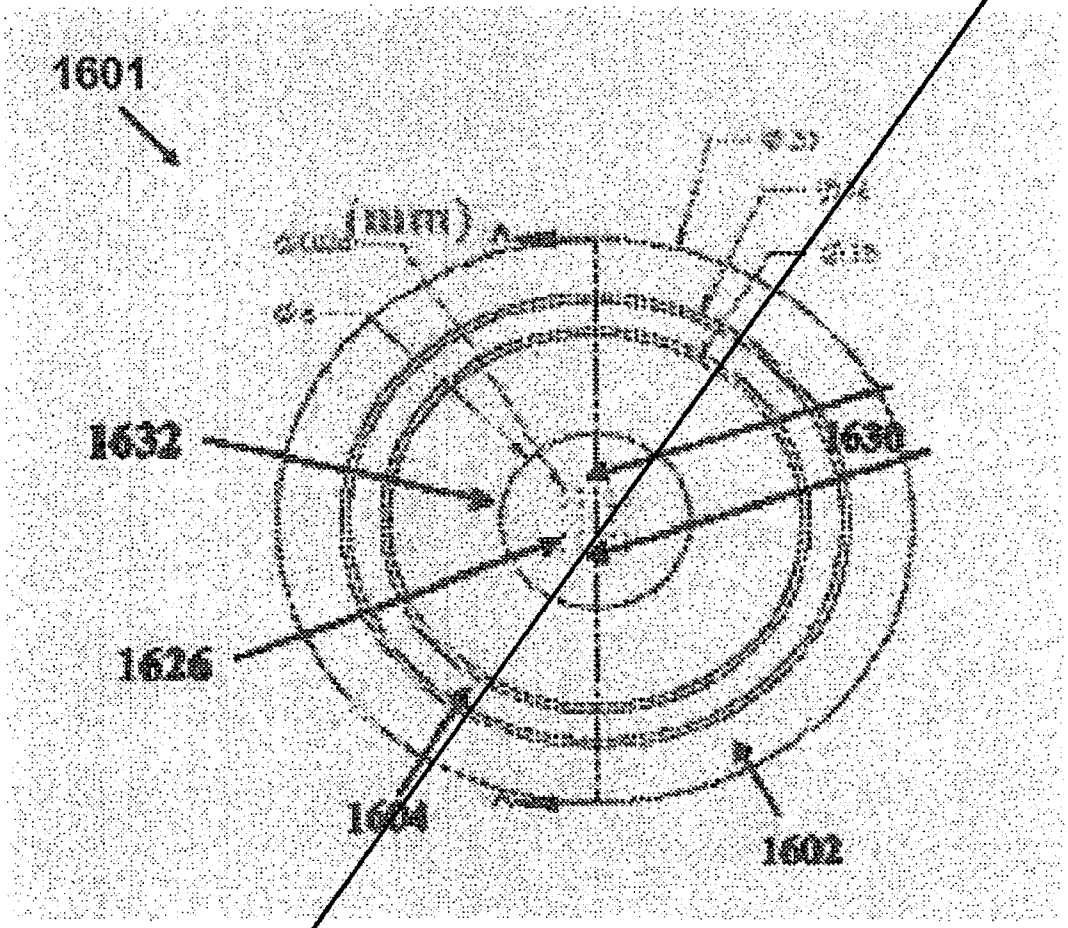


Figure 18

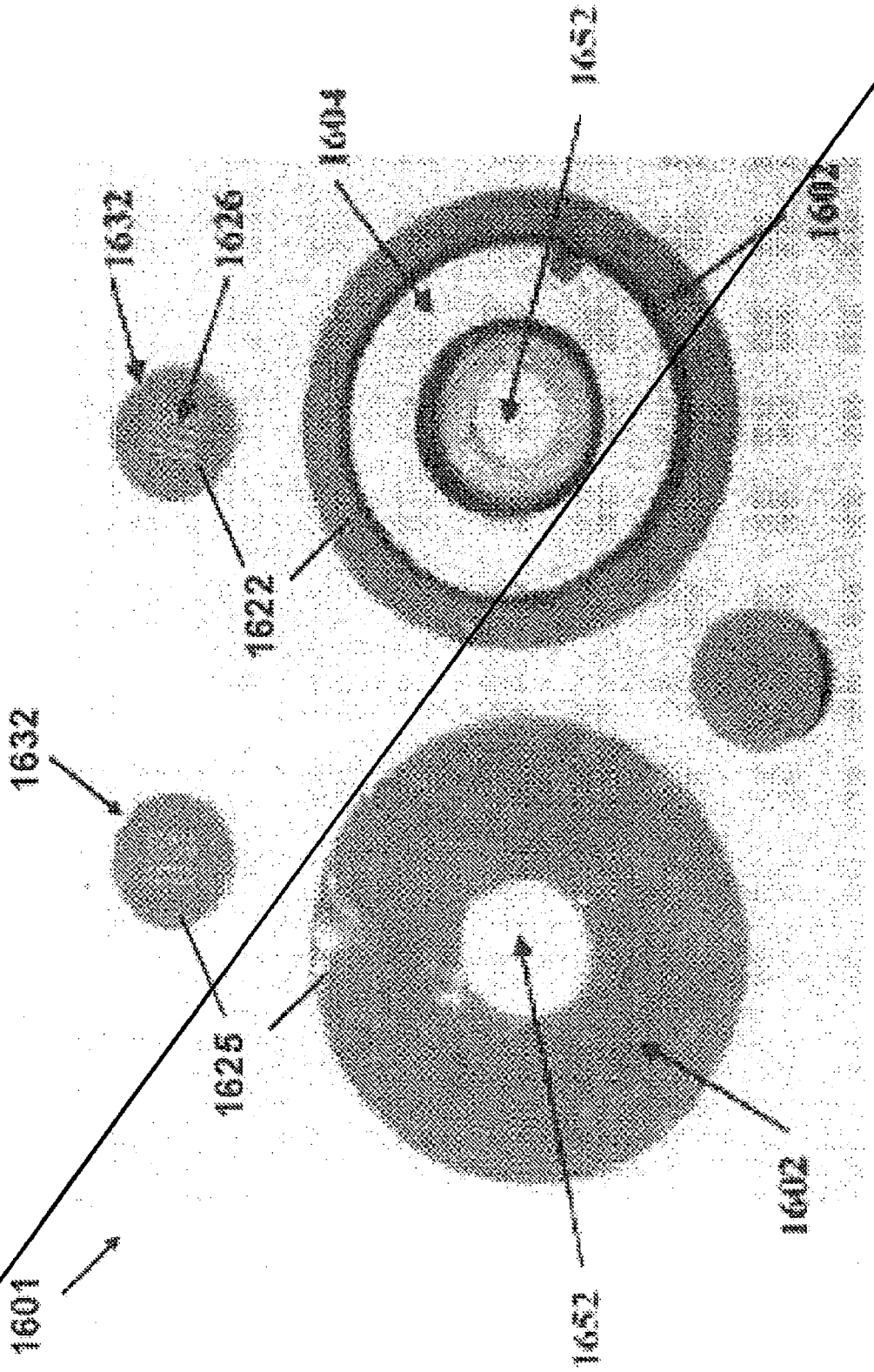


Figure 19

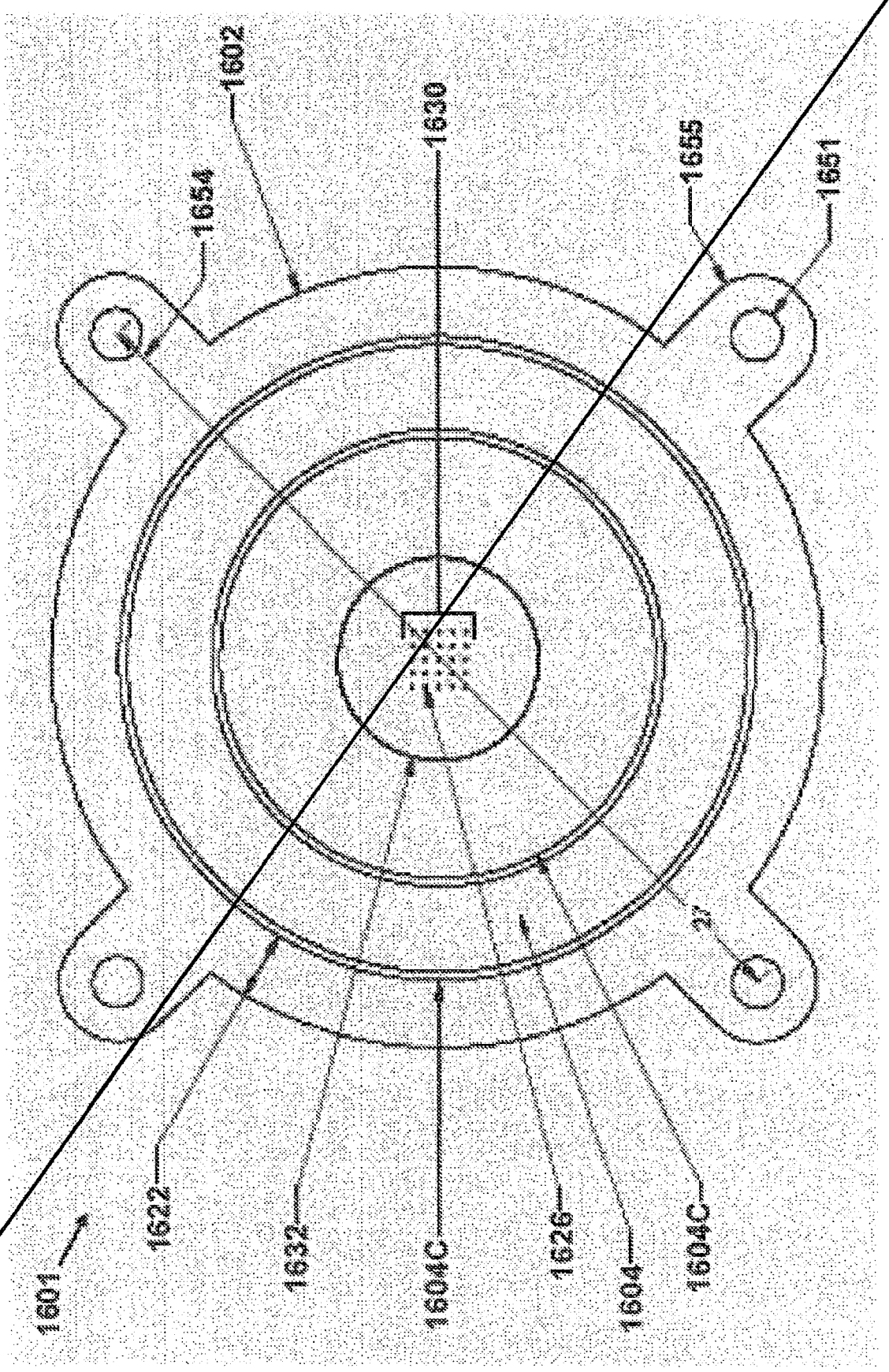

1602
1630
1654
1655
1651
1601
1622
1632
1604C
1626
1604
1604C
27

Figure 20

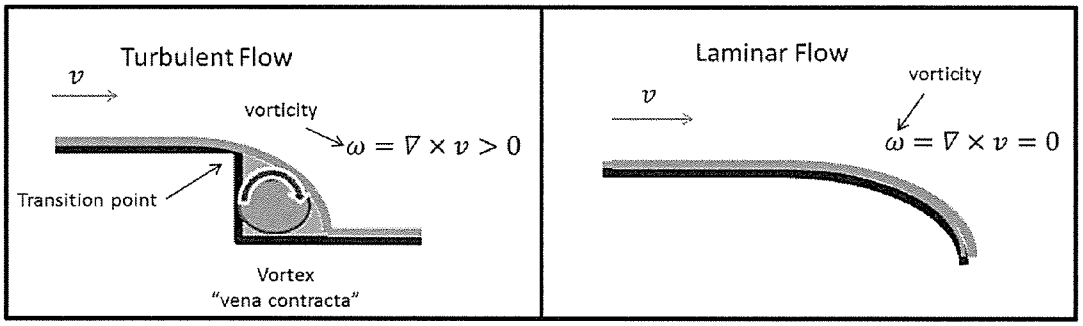

Turbulent Flow
v
vorticity
$\omega = \nabla \times v > 0$
Transition point
Vortex
"vena contracta"
Laminar Flow
vorticity
v
$\omega = \nabla \times v = 0$

FIG. 1

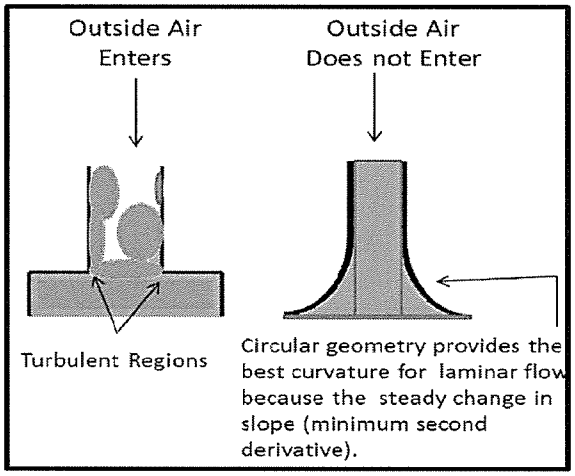

Outside Air
Enters
Outside Air
Does not Enter
Turbulent Regions
Circular geometry provides the best curvature for laminar flow because the steady change in slope (minimum second derivative).

FIG. 2

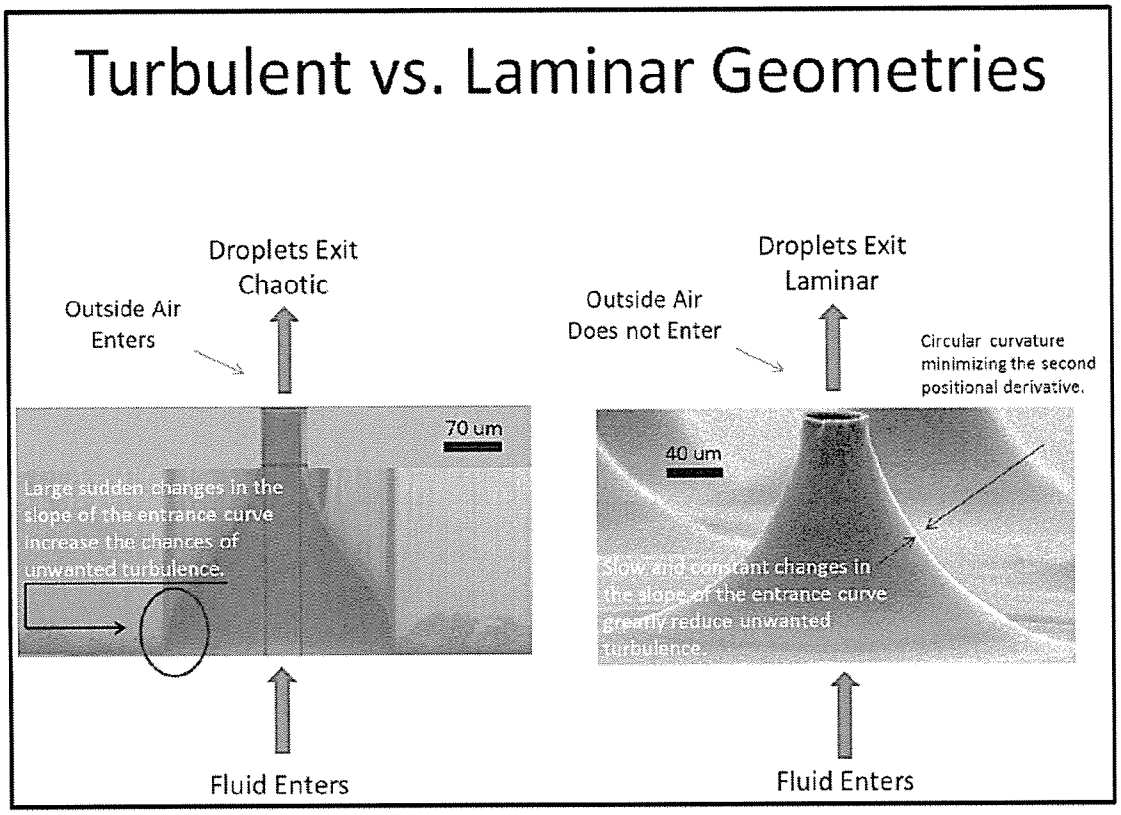

Turbulent vs. Laminar Geometries
Droplets Exit
Chaotic
Outside Air
Enters
70 um
Large sudden changes in the slope of the entrance curve increase the chances of unwanted turbulence.
Fluid Enters
Droplets Exit
Laminar
Outside Air
Does not Enter
Circular curvature minimizing the second positional derivative.
40 um
Slow and constant changes in the slope of the entrance curve greatly reduce unwanted turbulence.
Fluid Enters

FIG. 3

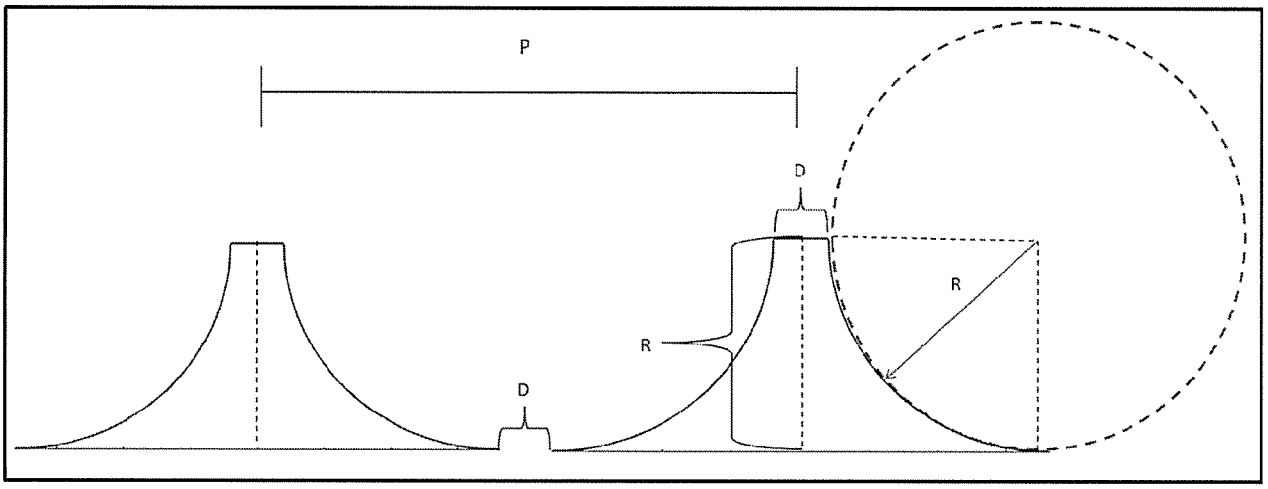

P
D
R
D
R

FIG. 4

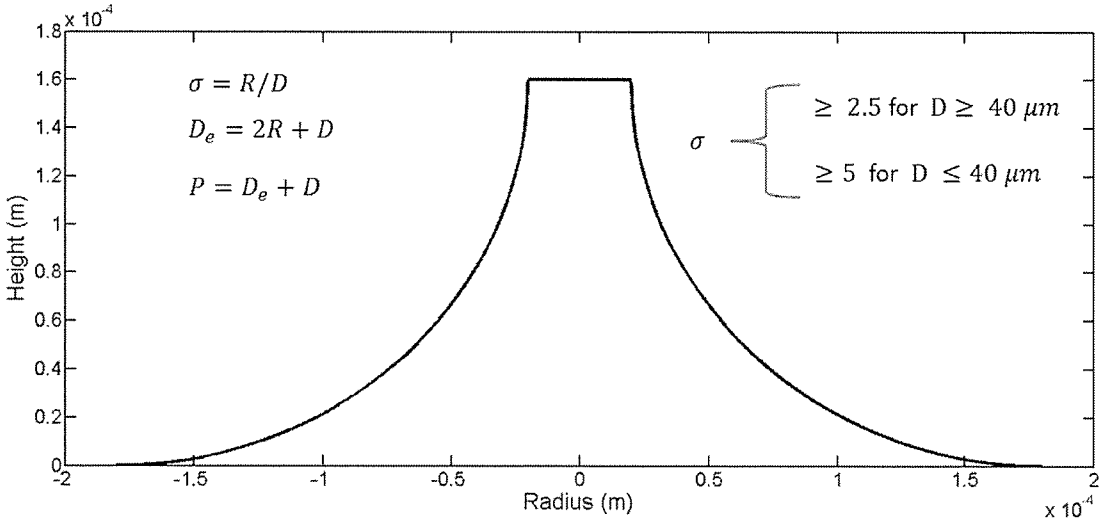

x 10^-4
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Height (m)
$\sigma = R/D$
$D_e = 2R + D$
$P = D_e + D$
σ
$\geq$ 2.5 for D $\geq$ 40 μm
$\geq$ 5 for D $\leq$ 40 μm
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Radius (m)
x 10^-4

FIG. 5

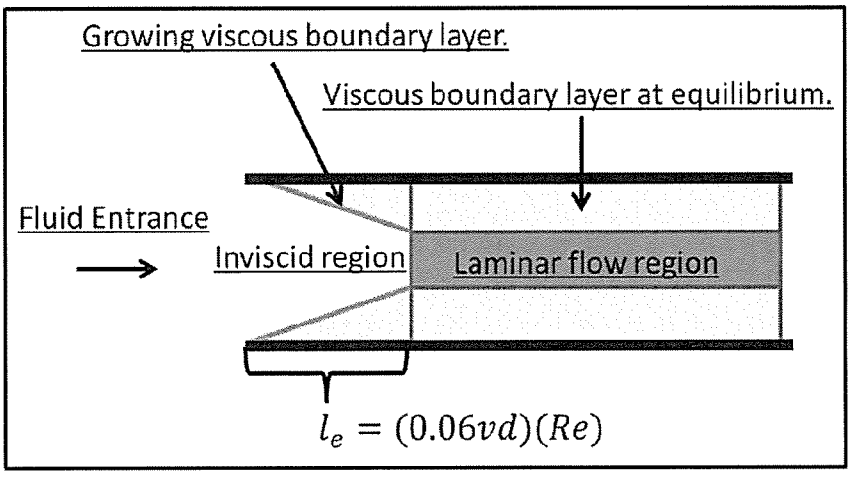

Growing viscous boundary layer.
Viscous boundary layer at equilibrium.
Fluid Entrance
Inviscid region
Laminar flow region
$l_e = (0.06vd)(Re)$

FIG. 6

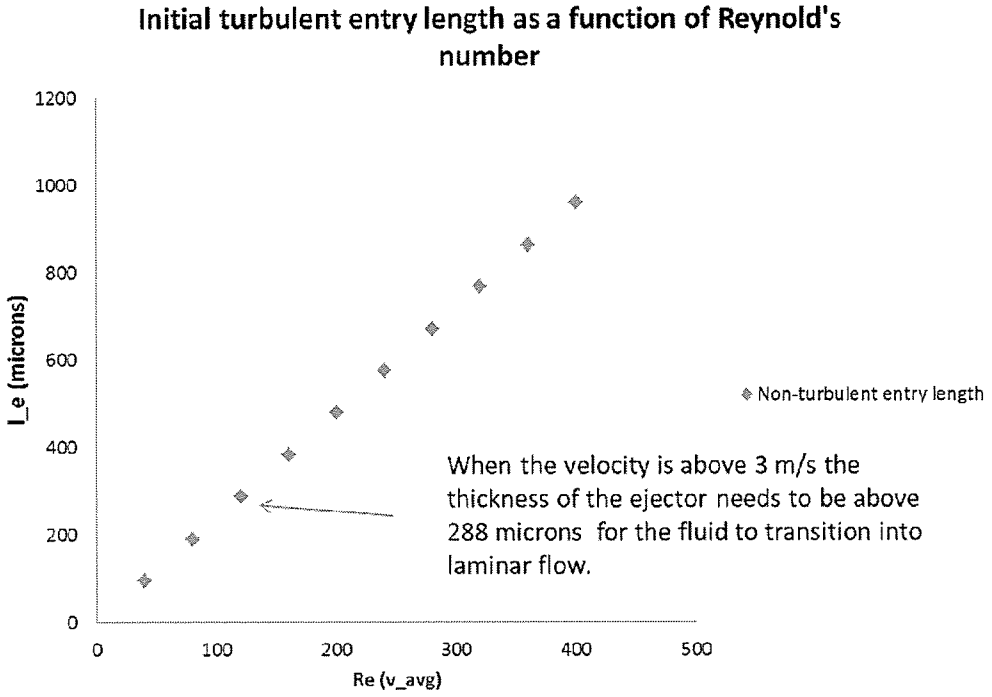

Initial turbulent entry length as a function of Reynold's number
l_e (microns)
Re (v_avg)
0
200
400
600
800
1000
1200
0
100
200
300
400
500
Non-turbulent entry length
When the velocity is above 3 m/s the thickness of the ejector needs to be above 288 microns for the fluid to transition into laminar flow.

FIG. 7

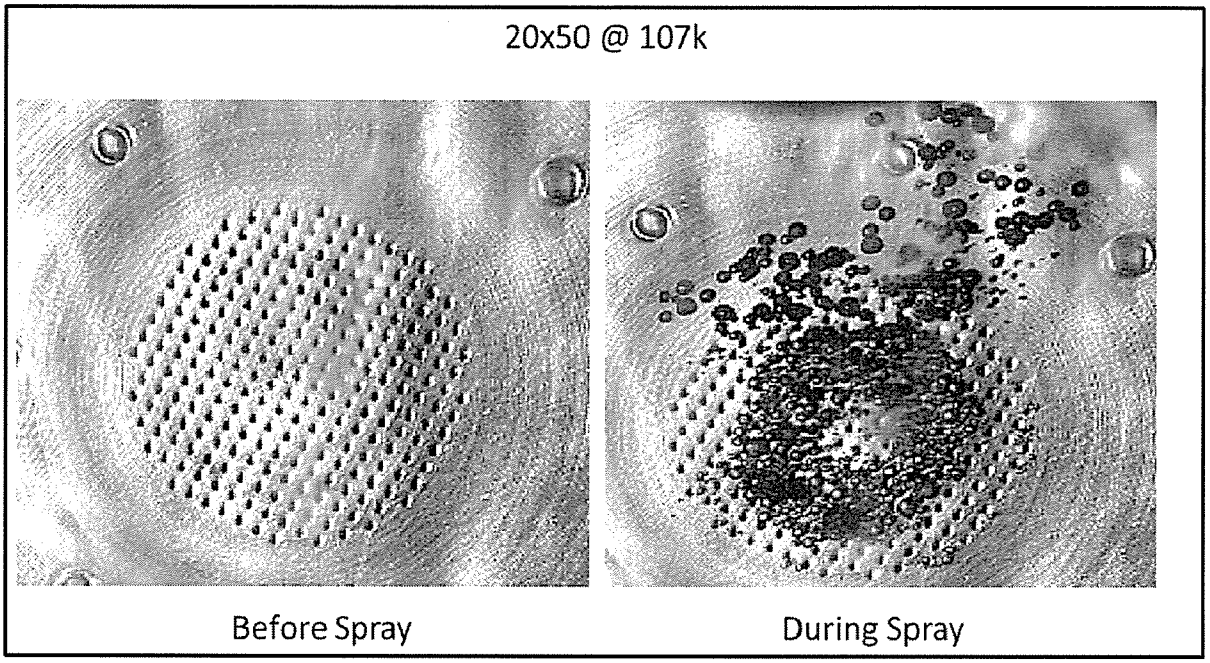

20x50 @ 107k
Before Spray
During Spray

FIG. 8

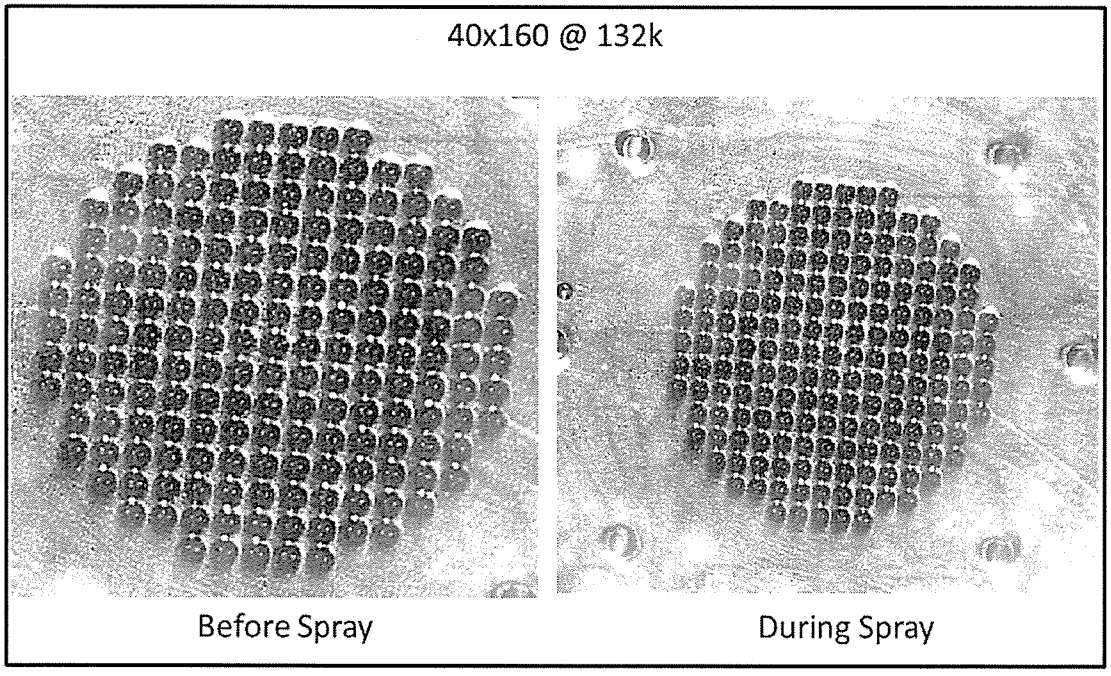

40x160 @ 132k
Before Spray
During Spray

FIG. 9

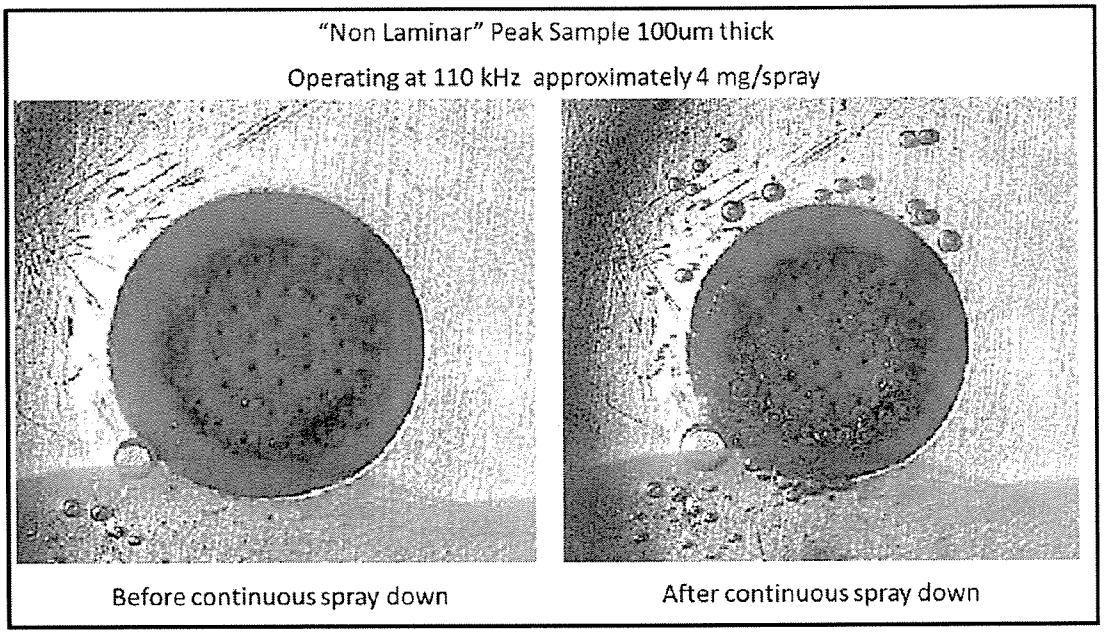

"Non Laminar" Peak Sample 100um thick
Operating at 110 kHz approximately 4 mg/spray
Before continuous spray down
After continuous spray down

FIG. 10

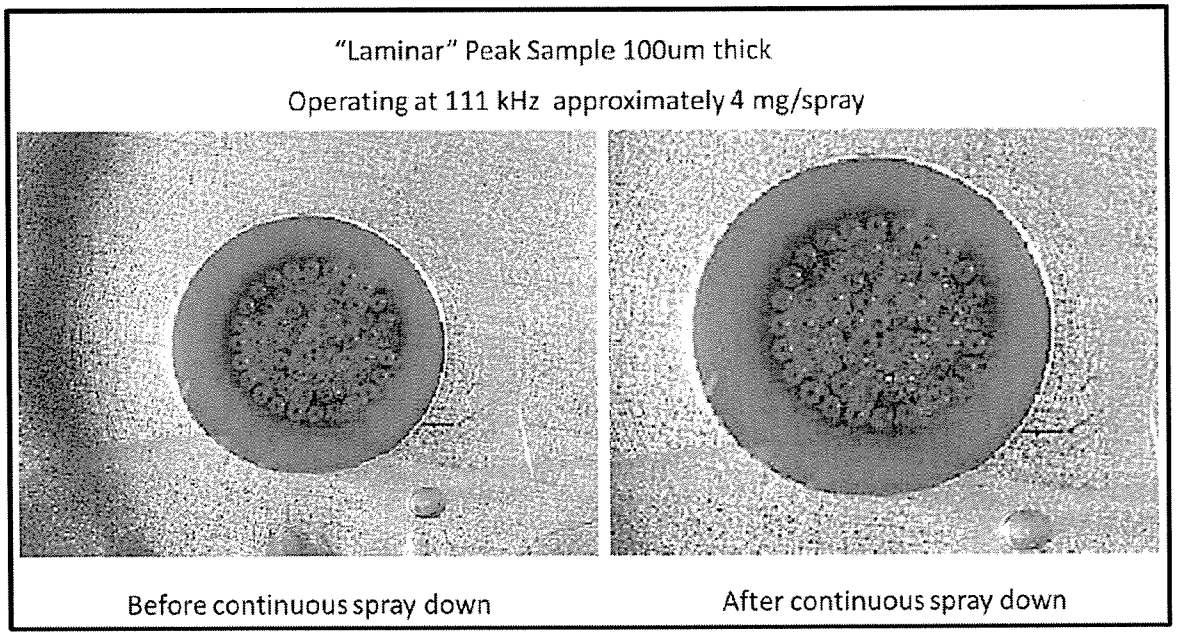
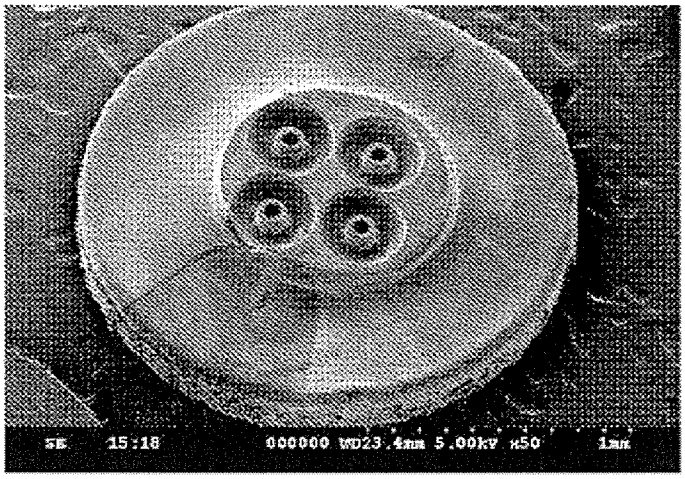
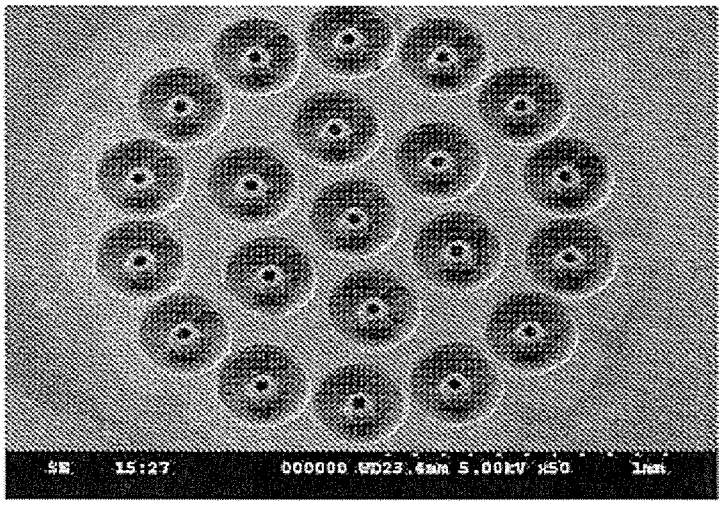

"Laminar" Peak Sample 100um thick
Operating at 111 kHz approximately 4 mg/spray
Before continuous spray down
After continuous spray down

FIG. 11



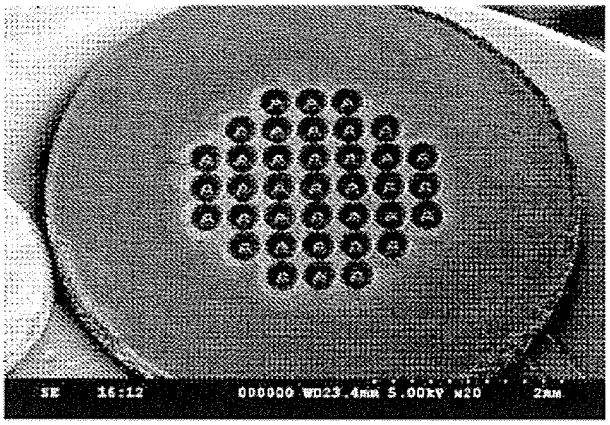
4-hole with mesa

FIG. 12



21-hole

FIG. 13



37-hole

FIG. 14

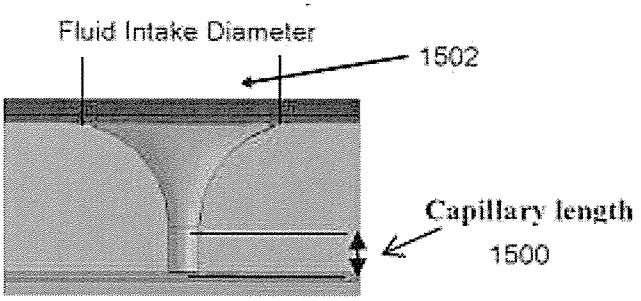


FIG. 15

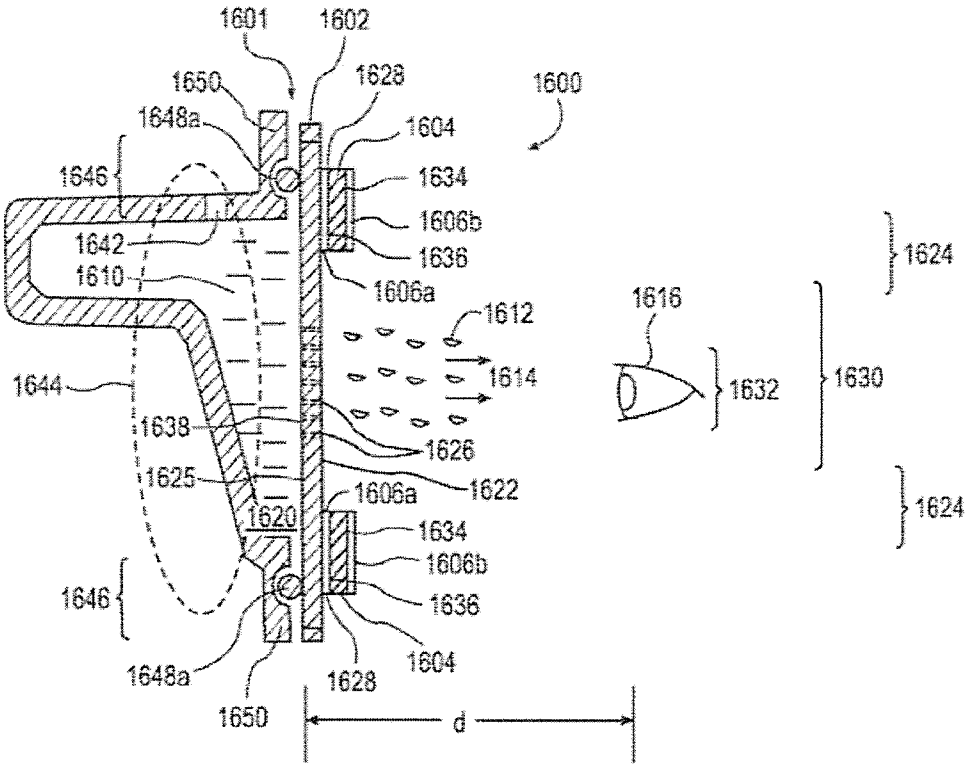

1601
1602
1650
1628
1600
1648a
1604
1646
1634
1606b
1642
1636
1610
1606a
1612
1616
1624
1644
1614
1632
1630
1638
1626
1625
1622
1606a
1620
1624
1634
1606b
1646
1636
1604
1648a
1628
1650
d

FIG. 16

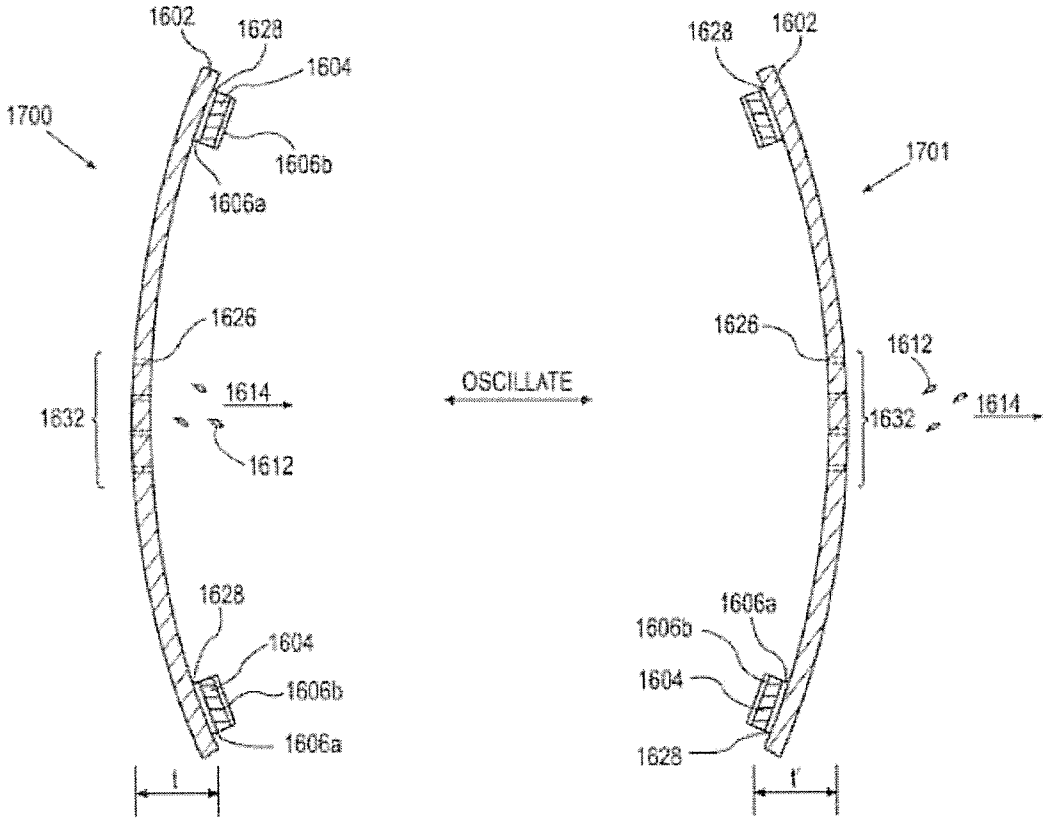


FIG. 17A and 17B

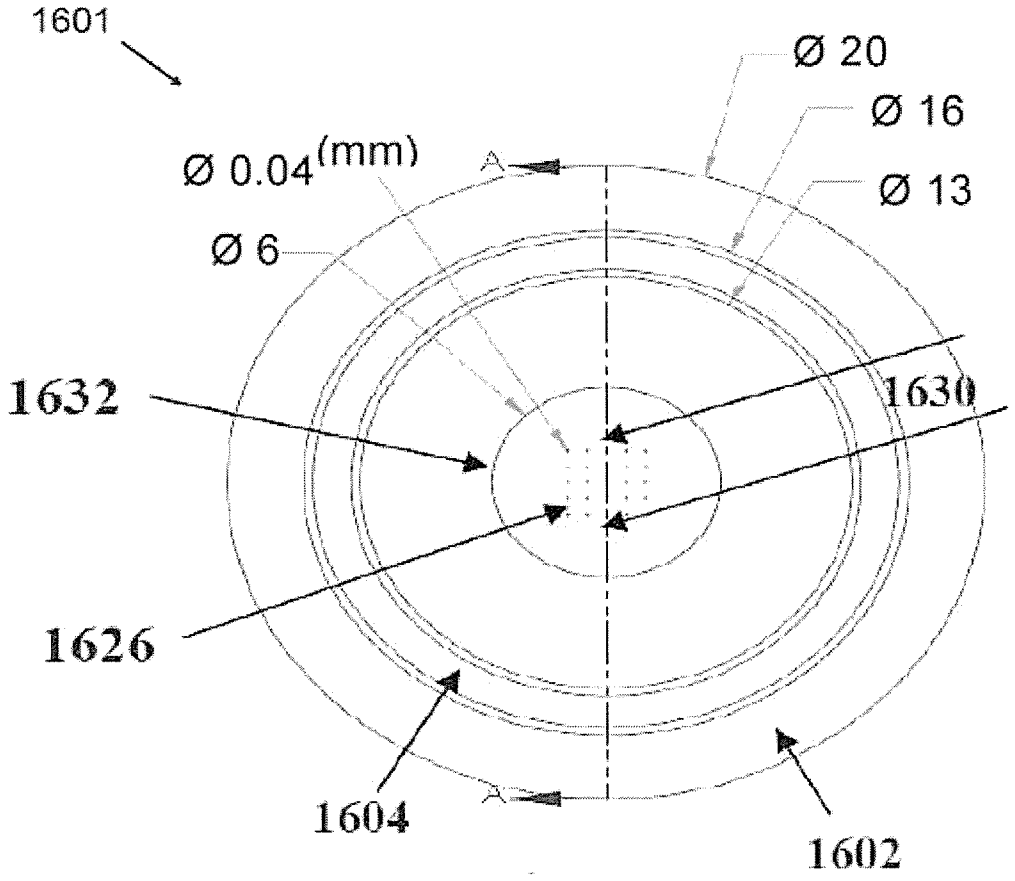


FIG. 18

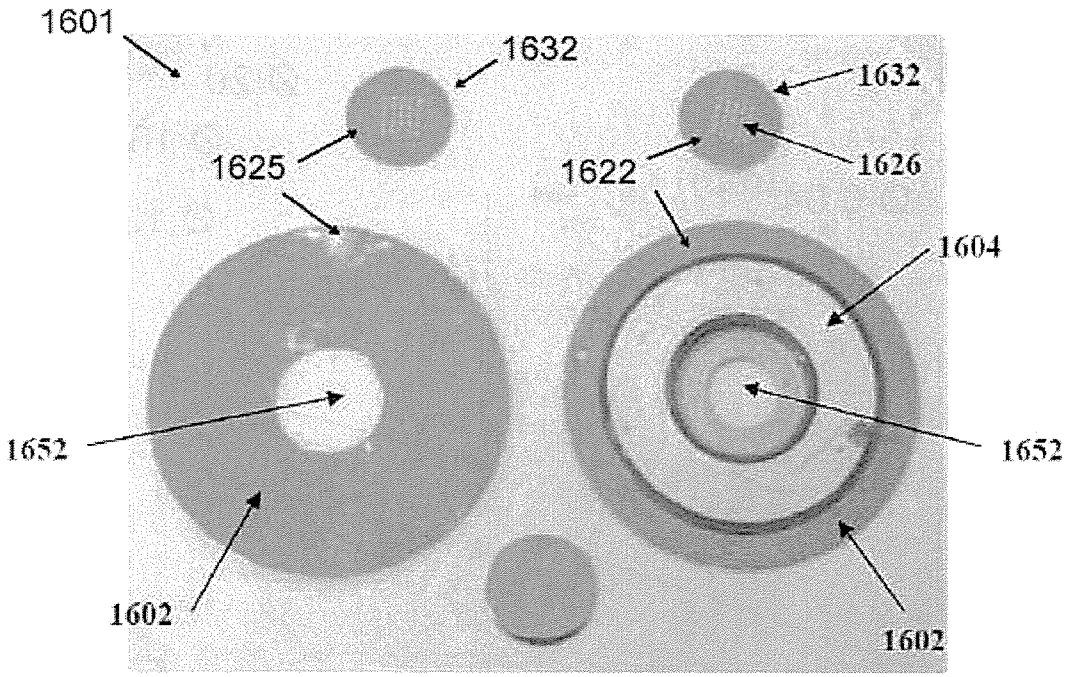


FIG. 19

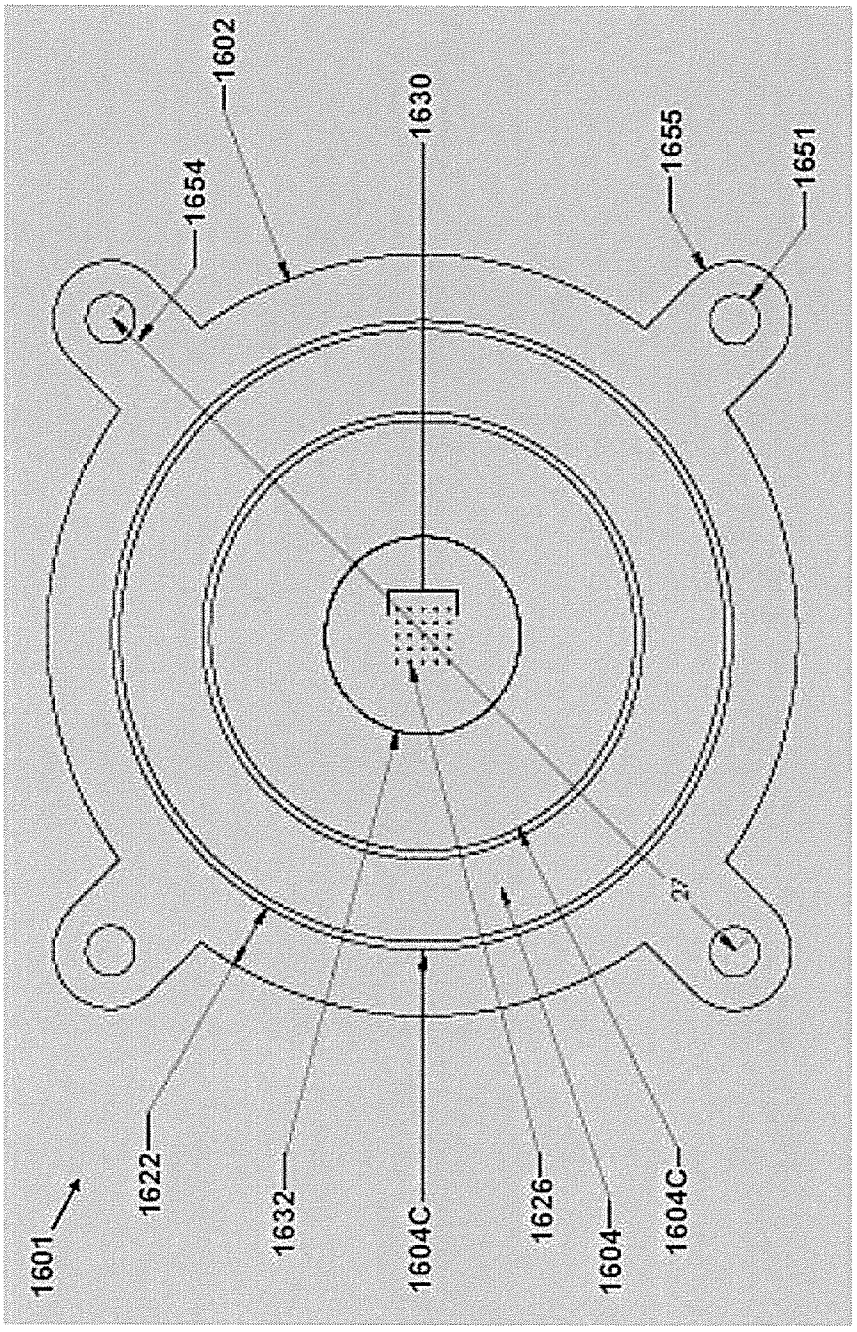

1602
1630
1654
1655
1651
1622
1632
1604C
1626
1604
1604C
1601
2'

FIG. 20