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(54) VAPORIZER INCLUDING POSITIVE TEMPERATURE COEFFICIENT OF RESISTIVITY HEATER

(71) Applicant: **JUUL Labs, Inc.**, Washington, DC (US)

(72) Inventors: **William W. Alston**, Lincoln, CA (US); **Adam Bowen**, San Mateo, CA (US); **Ian Garcia-Doty**, Oakland, CA (US); **Joshua A. Kurzman**, San Francisco, CA (US); **James Monsees**, San Francisco, CA (US); **Paul R. Vieira**, Oakland, CA (US)

(21) Appl. No.: **19/058,435**

(22) Filed: **Feb. 20, 2025**

**Related U.S. Application Data**

(63) Continuation of application No. 17/372,357, filed on Jul. 9, 2021, now Pat. No. 12,232,529, which is a continuation of application No. PCT/US2020/013224, filed on Jan. 10, 2020.

(60) Provisional application No. 62/959,737, filed on Jan. 10, 2020, provisional application No. 62/898,522, filed on Sep. 10, 2019, provisional application No. 62/816,452, filed on Mar. 11, 2019, provisional application No. 62/791,709, filed on Jan. 11, 2019.

**Publication Classification**

(51) **Int. Cl.**

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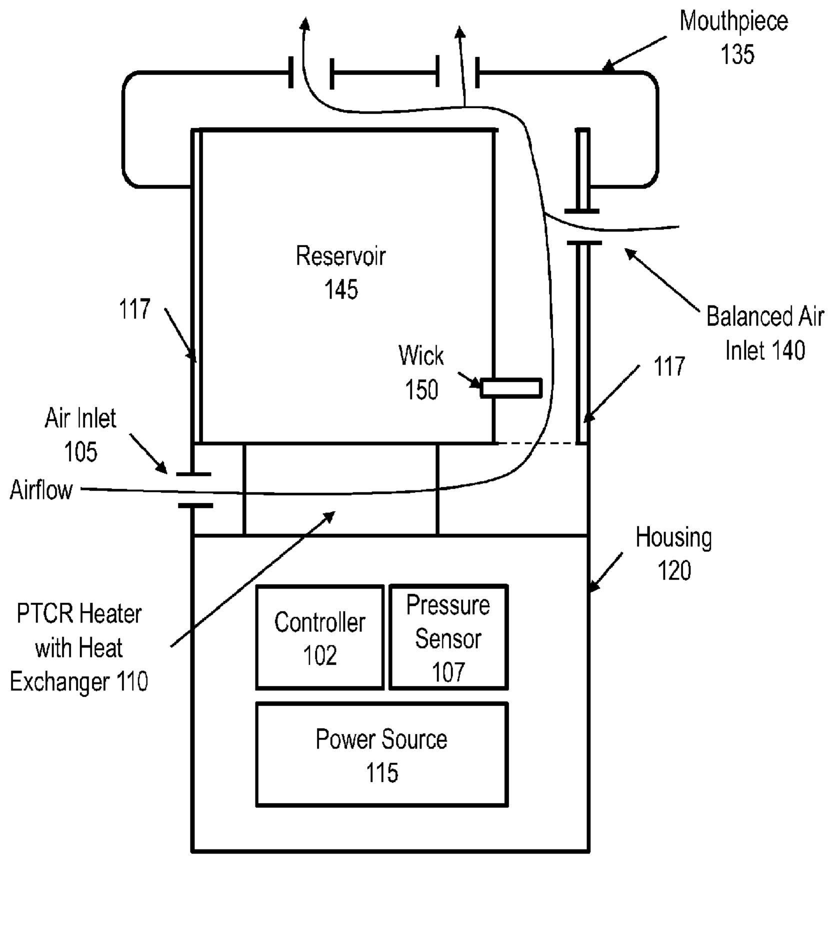
| ***H05B 1/02*** | (2006.01) |
| ***H05B 3/06*** | (2006.01) |

(52) **U.S. Cl.**

CPC .............. ***A24F 40/46*** (2020.01); ***A24F 40/10*** (2020.01); ***A24F 40/42*** (2020.01); ***A24F 40/44*** (2020.01); ***A24F 40/485*** (2020.01); ***H05B 1/0244*** (2013.01); ***H05B 3/06*** (2013.01); *H05B 2203/02* (2013.01); *H05B 2203/022* (2013.01)

(57) **ABSTRACT**

A vaporizer device includes a housing including an air inlet, a heating element within the housing and a heat exchanger. The heating element includes a nonlinear positive temperature coefficient of resistance material. The heat exchanger is thermally coupled to the heating element and arranged to receive airflow from the air inlet. The heat exchanger is configured to transfer heat between the heating element and the airflow to produce a heated airflow. The heated airflow exiting the heat exchanger is configured to vaporize a vaporizable material. Related apparatus, systems, techniques and articles are also described.



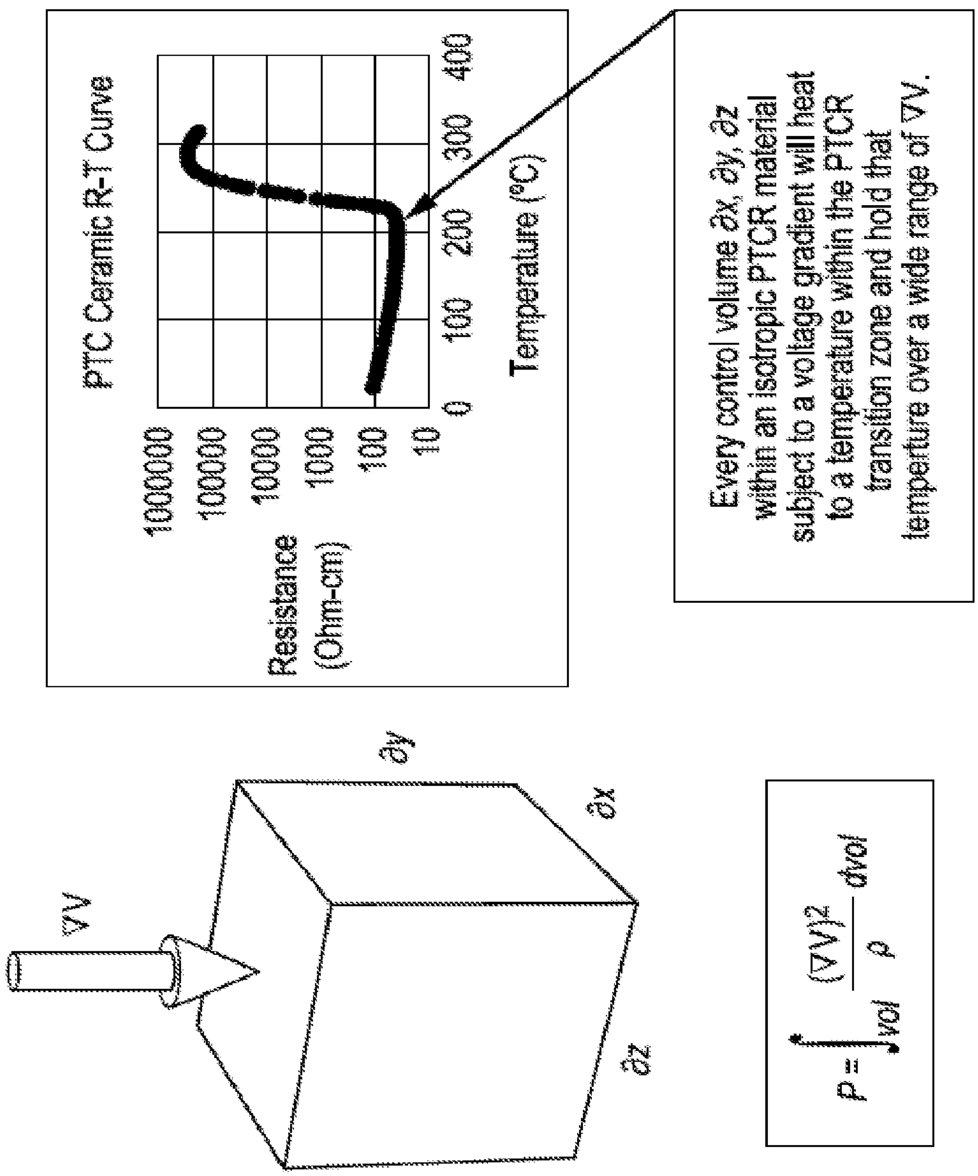

PTC Ceramic R-T Curve
Resistance (Ohm-cm)
1000000
100000
10000
1000
100
10
0
100
200
300
400
Temperature (°C)
Every control volume ∂x, ∂y, ∂z within an isotropic PTCR material subject to a voltage gradient will heat to a temperature within the PTCR transition zone and hold that temperture over a wide range of ∇V.
∇V
∂y
∂x
∂z
$P = \int_{vol} \frac{(\nabla V)^2}{\rho} dvol$

FIG. 1

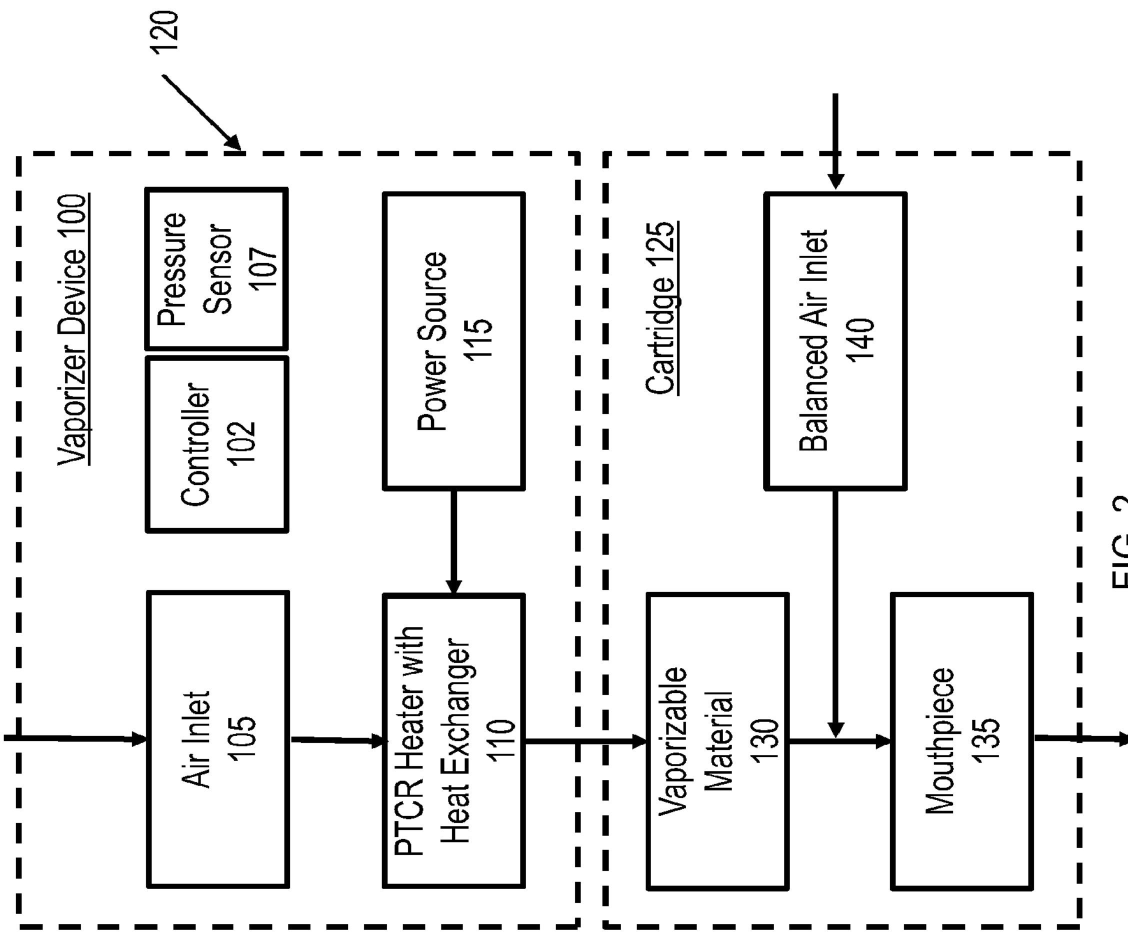

120
Vaporizer Device 100
Pressure Sensor 107
Controller 102
Power Source 115
Air Inlet 105
PTCR Heater with Heat Exchanger 110
Cartridge 125
Balanced Air Inlet 140
Vaporizable Material 130
Mouthpiece 135

FIG. 2

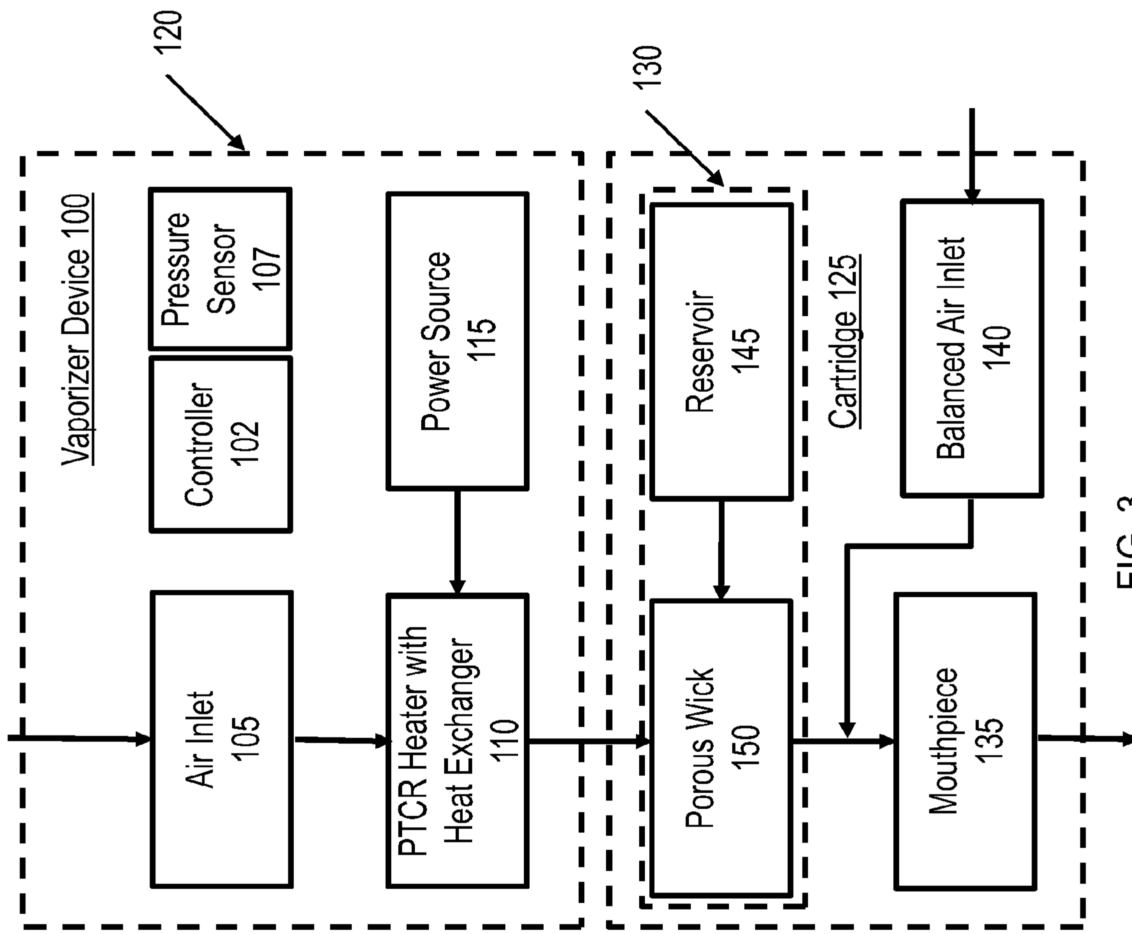

120
130
Vaporizer Device 100
Pressure Sensor 107
Controller 102
Power Source 115
Air Inlet 105
PTCR Heater with Heat Exchanger 110
Reservoir 145
Cartridge 125
Porous Wick 150
Balanced Air Inlet 140
Mouthpiece 135

FIG. 3

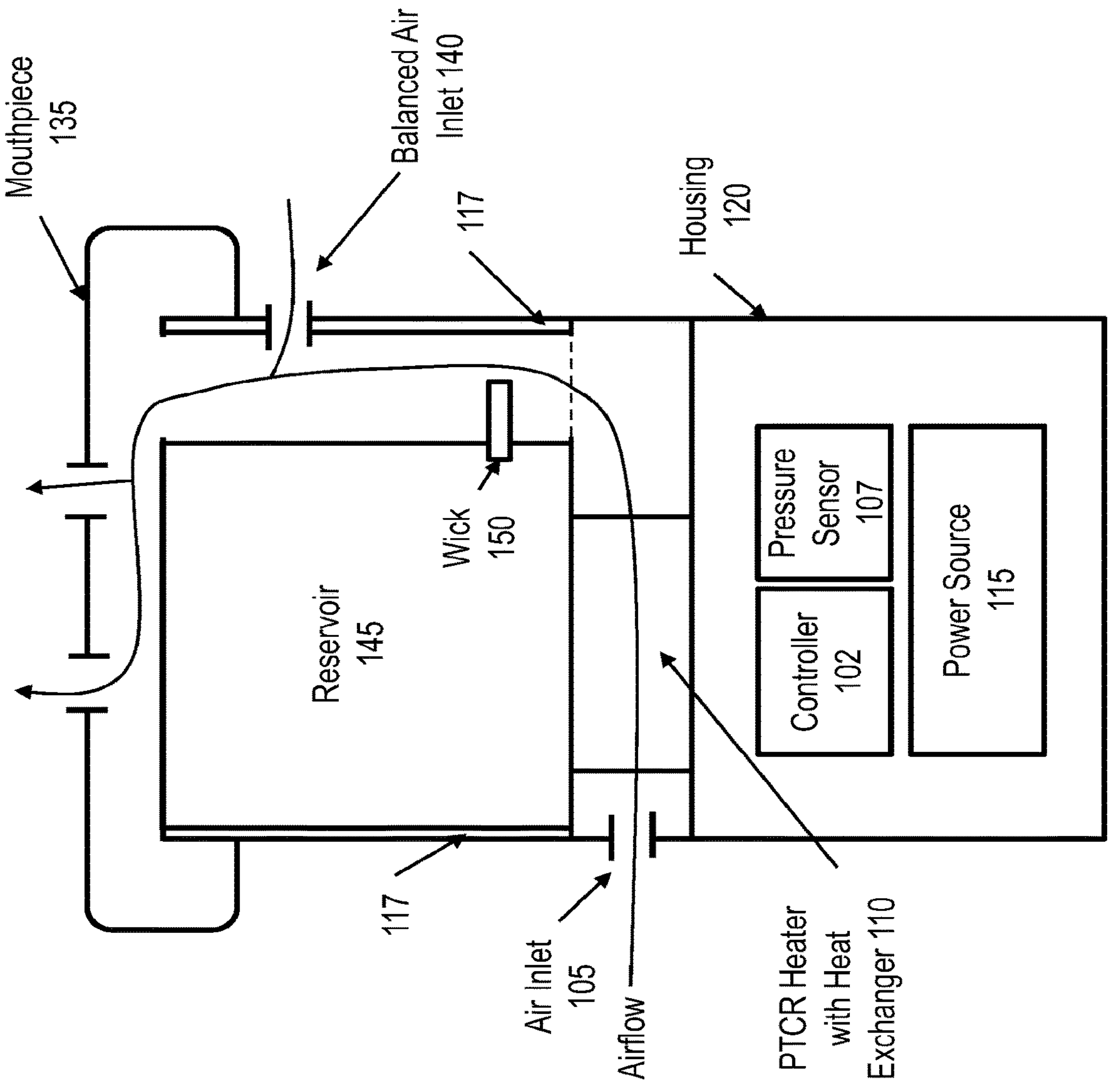

Mouthpiece 135
Balanced Air Inlet 140
117
Housing 120
Wick 150
Reservoir 145
Pressure Sensor 107
Controller 102
Power Source 115
117
Air Inlet 105
Airflow
PTCR Heater with Heat Exchanger 110

FIG. 4

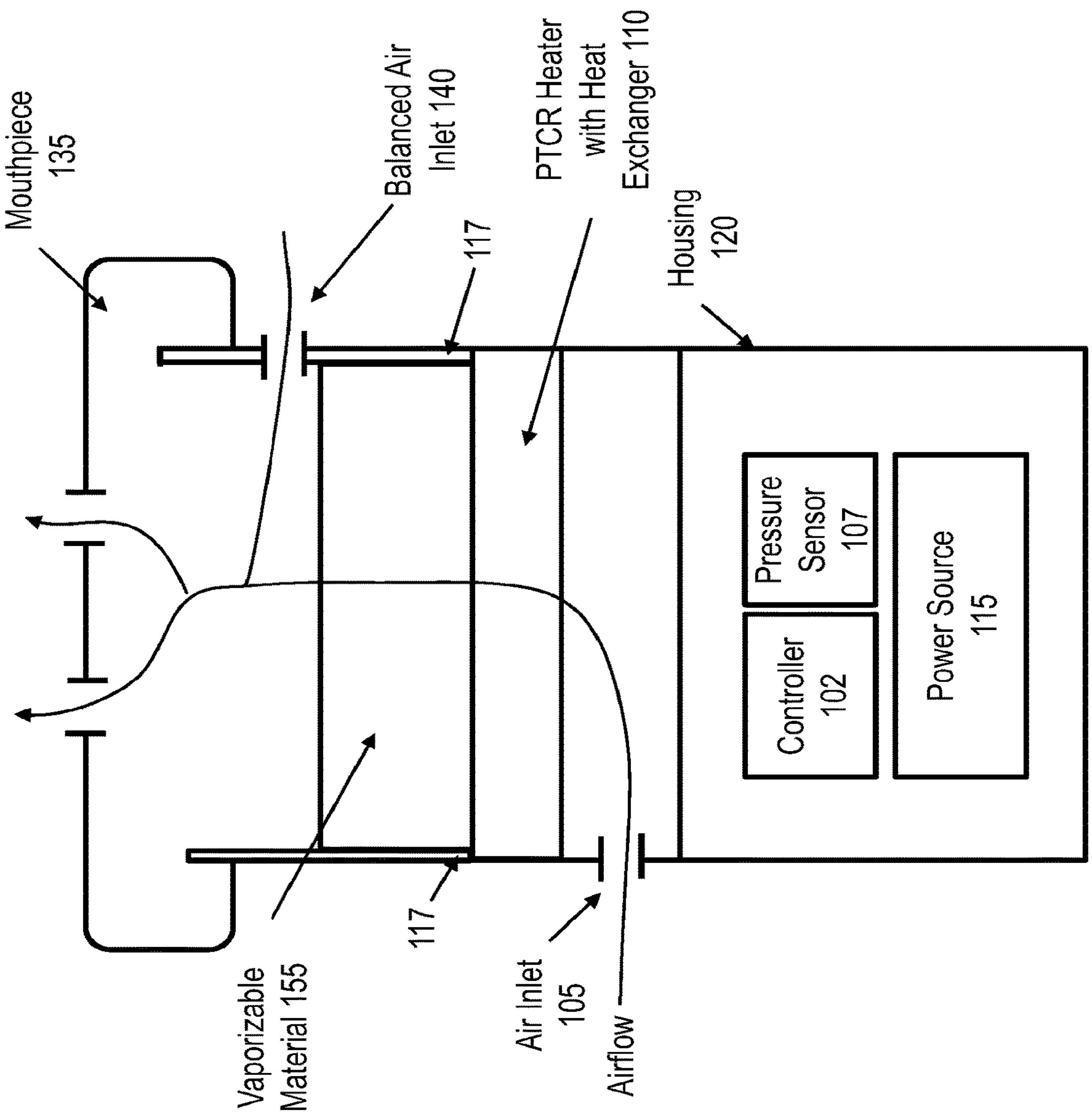

Mouthpiece 135
Balanced Air Inlet 140
PTCR Heater with Heat Exchanger 110
117
Housing 120
Pressure Sensor 107
Controller 102
Power Source 115
Vaporizable Material 155
117
Air Inlet 105
Airflow

FIG. 5

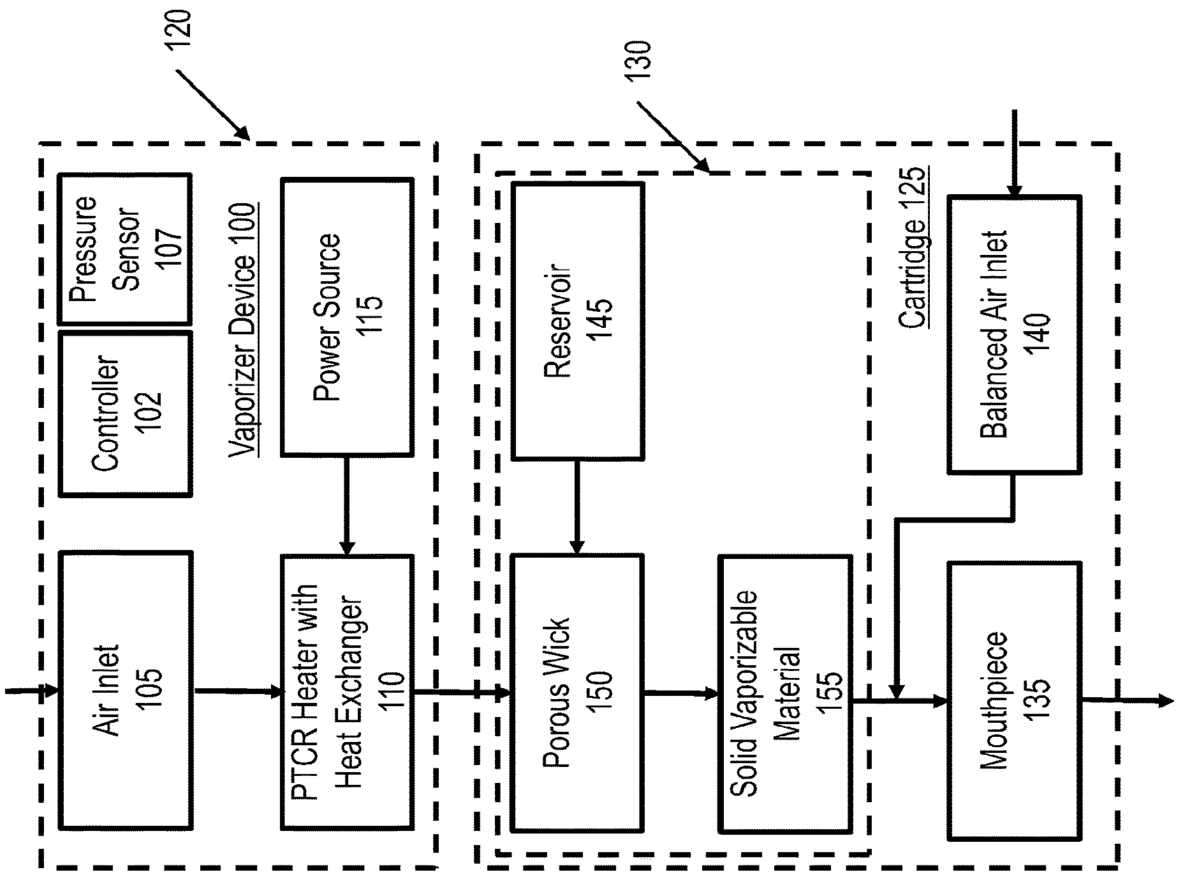

120
130
Pressure Sensor 107
Controller 102
Vaporizer Device 100
Power Source 115
Air Inlet 105
PTCR Heater with Heat Exchanger 110
Reservoir 145
Porous Wick 150
Solid Vaporizable Material 155
Cartridge 125
Balanced Air Inlet 140
Mouthpiece 135

FIG. 6

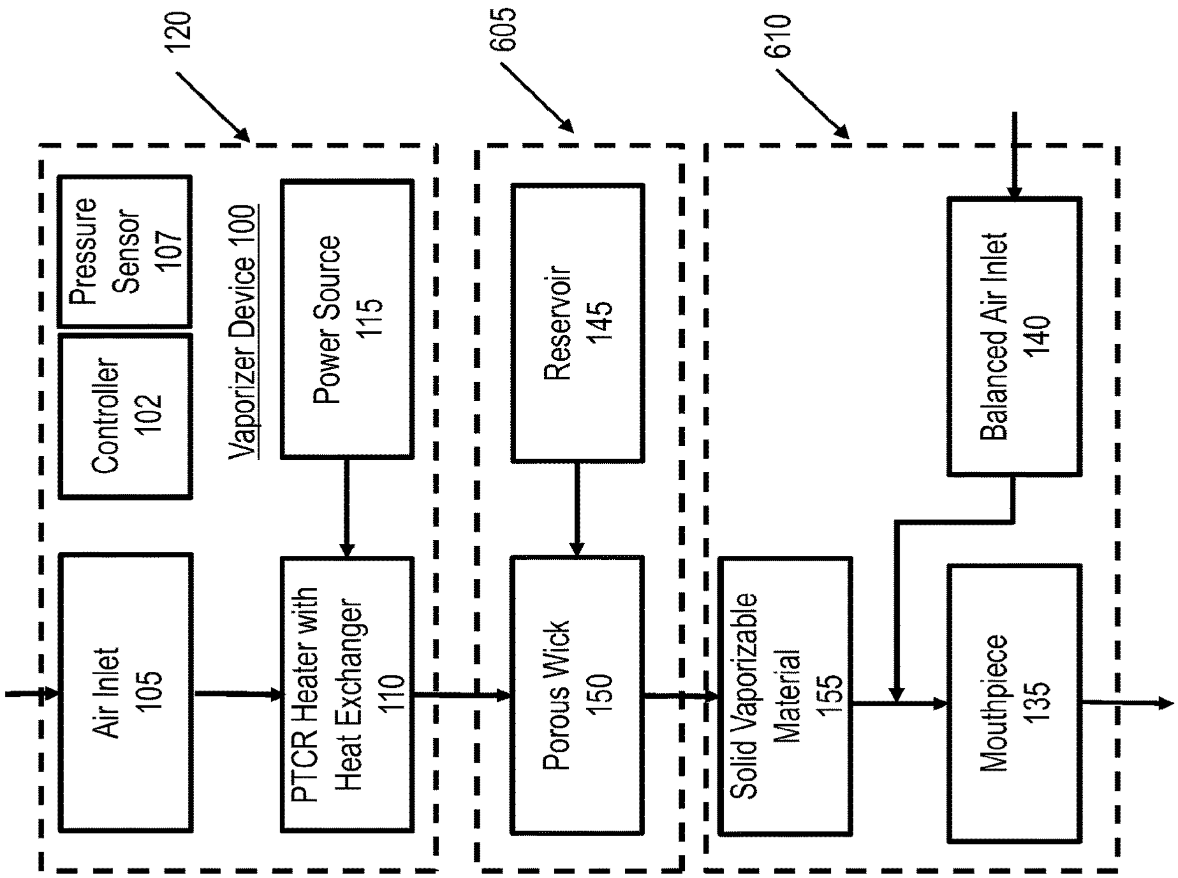

120
605
610
Pressure Sensor 107
Controller 102
Vaporizer Device 100
Power Source 115
Air Inlet 105
PTCR Heater with Heat Exchanger 110
Reservoir 145
Porous Wick 150
Solid Vaporizable Material 155
Balanced Air Inlet 140
Mouthpiece 135

FIG. 7

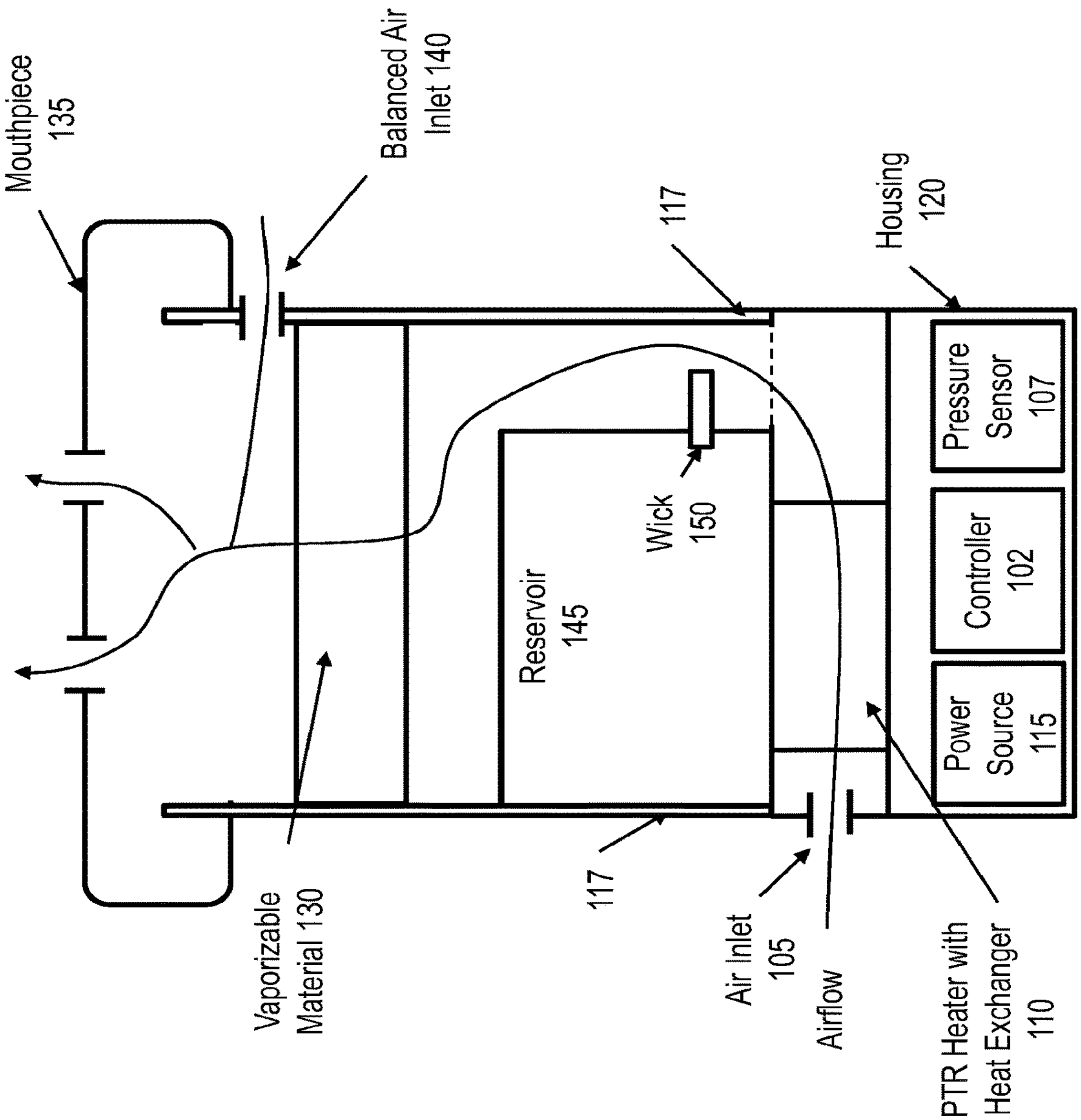

Mouthpiece 135
Balanced Air Inlet 140
117
Housing 120
Pressure Sensor 107
Controller 102
Power Source 115
Wick 150
Reservoir 145
Vaporizable Material 130
117
Air Inlet 105
Airflow
PTR Heater with Heat Exchanger 110

FIG. 8

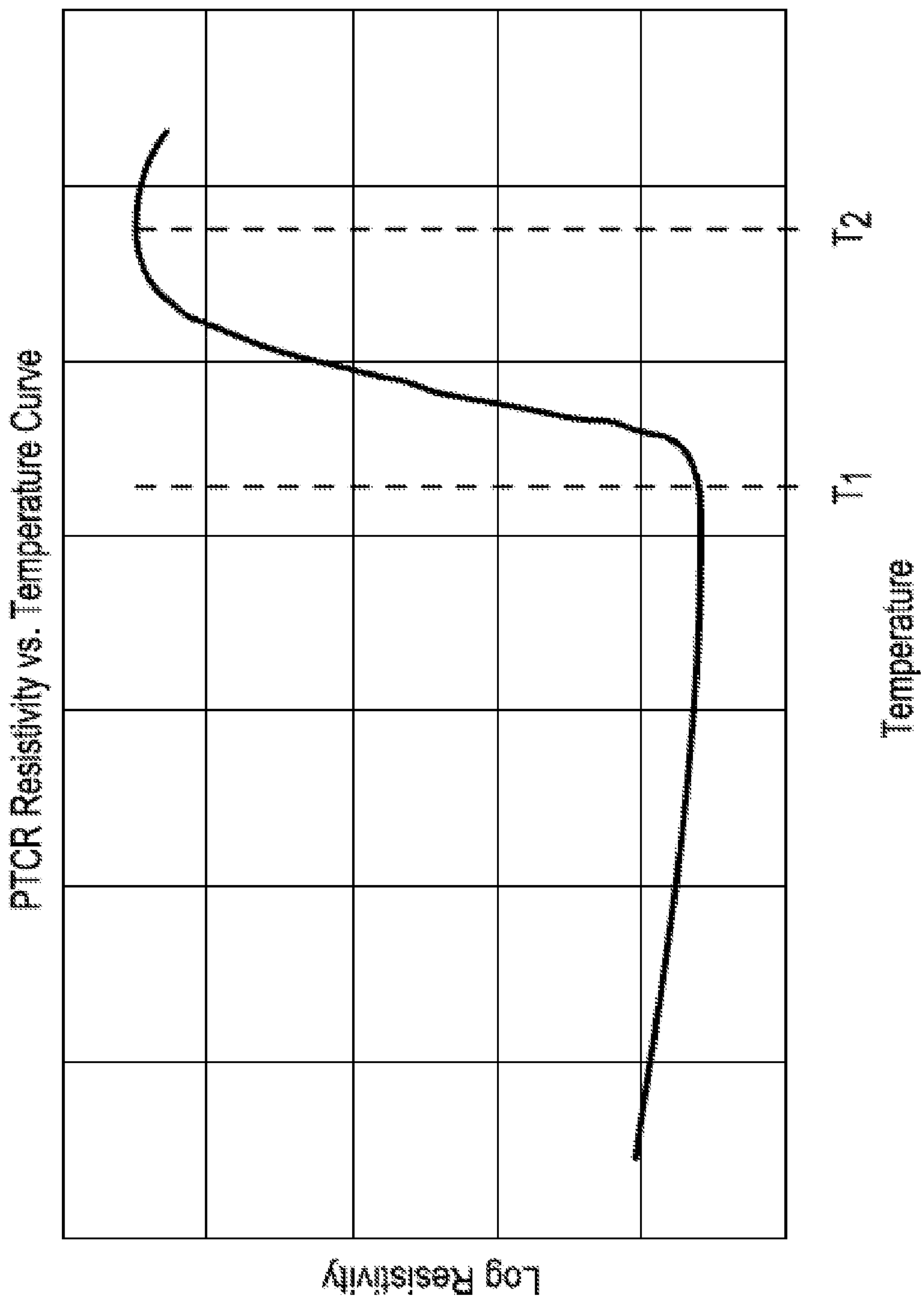
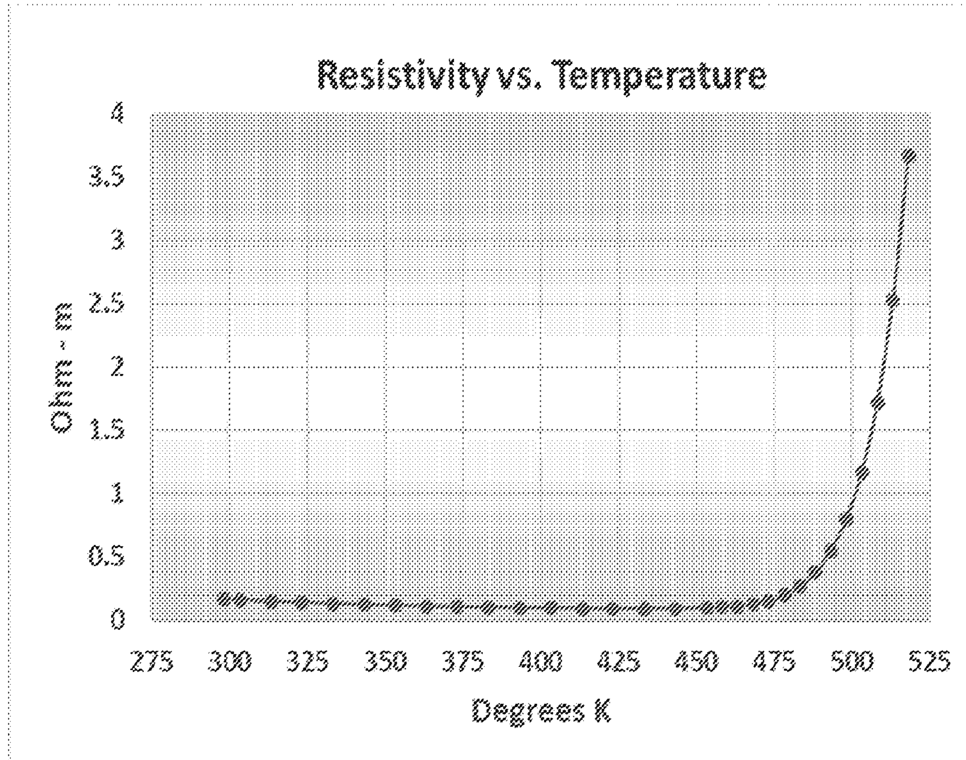

PTCR Resistivity vs. Temperature Curve
Log Resistivity
T1
T2
Temperature

FIG. 9

| Temperature (°C) | Resistivity (ohm-cm) | Temperature (°C) | Resistivity (ohm-cm) | Temperature (°C) | Resistivity (ohm-cm) |
|---|---|---|---|---|---|
| 22.3 | 109.694 | 184.2 | 38.685 | 232.3 | 162.394 |
| 23.6 | 108.330 | 184.7 | 38.673 | 233.2 | 256.665 |
| 33.5 | 98.611 | 187.0 | 38.625 | 233.8 | 331.375 |
| 38.5 | 94.008 | 188.0 | 38.607 | 234.8 | 441.487 |
| 46.9 | 86.630 | 190.0 | 38.578 | 235.6 | 558.977 |
| 47.1 | 86.506 | 190.2 | 38.576 | 236.3 | 678.110 |
| 52.2 | 82.600 | 192.0 | 38.556 | 236.5 | 711.822 |
| 59.5 | 77.991 | 193.0 | 38.547 | 238.3 | 1261.390 |
| 59.8 | 77.795 | 194.0 | 38.541 | 240.8 | 2687.390 |
| 64.8 | 74.769 | 195.6 | 38.532 | 240.9 | 2778.690 |
| 75.2 | 68.082 | 195.8 | 38.532 | 243.9 | 4442.150 |
| 77.7 | 66.681 | 197.3 | 38.527 | 244.2 | 4788.260 |
| 86.5 | 62.716 | 198.6 | 38.527 | 245.2 | 6747.000 |
| 86.6 | 62.653 | 199.1 | 38.528 | 247.1 | 9698.350 |
| 91.1 | 60.966 | 200.6 | 38.535 | 247.9 | 11432.800 |
| 99.4 | 57.955 | 201.2 | 38.538 | 250.7 | 22831.500 |
| 99.9 | 57.775 | 202.2 | 38.547 | 251.7 | 28992.800 |
| 104.7 | 56.019 | 203.1 | 38.556 | 252.5 | 34334.100 |
| 111.4 | 53.450 | 203.9 | 38.570 | 254.5 | 45742.100 |
| 116.9 | 51.472 | 204.5 | 38.583 | 254.8 | 47918.300 |
| 119.0 | 50.738 | 205.9 | 38.620 | 257.3 | 68258.900 |
| 122.5 | 49.605 | 207.7 | 38.711 | 260.8 | 111647.000 |
| 127.5 | 48.097 | 207.9 | 38.722 | 262.1 | 133176.000 |
| 133.9 | 46.362 | 209.0 | 38.831 | 262.8 | 143871.000 |
| 134.9 | 46.125 | 210.7 | 39.097 | 263.3 | 150490.000 |
| 139.4 | 45.173 | 211.7 | 39.351 | 265.1 | 170423.000 |
| 144.3 | 44.277 | 212.7 | 39.692 | 268.9 | 221852.000 |
| 147.3 | 43.769 | 213.6 | 40.122 | 271.4 | 256649.000 |
| 149.1 | 43.456 | 214.3 | 40.449 | 272.2 | 265081.000 |
| 151.8 | 42.994 | 215.6 | 41.185 | 272.5 | 268026.000 |
| 158.1 | 41.887 | 217.6 | 42.459 | 276.8 | 295802.000 |
| 159.1 | 41.714 | 219.3 | 43.660 | 278.5 | 303521.000 |
| 163.5 | 40.937 | 219.4 | 43.788 | 282.3 | 316247.000 |
| 165.2 | 40.655 | 220.8 | 44.857 | 285.1 | 322183.000 |
| 168.3 | 40.128 | 221.4 | 45.434 | 291.0 | 326120.000 |
| 168.8 | 40.046 | 222.4 | 46.404 | 292.2 | 324601.000 |
| 171.6 | 39.604 | 222.9 | 47.021 | 293.4 | 322183.000 |
| 174.1 | 39.274 | 224.4 | 50.439 | 297.5 | 307629.000 |
| 175.3 | 39.148 | 225.6 | 54.008 | 302.3 | 285898.000 |
| 178.1 | 38.925 | 227.2 | 60.796 | 303.8 | 279388.000 |
| 179.2 | 38.862 | 228.0 | 66.314 | 307.4 | 260106.000 |
| 180.1 | 38.821 | 228.4 | 70.170 | 310.1 | 239863.000 |
| 181.9 | 38.752 | 229.4 | 97.759 | 313.2 | 215295.000 |
| 182.1 | 38.747 | 231.0 | 129.069 | 315.2 | 200942.000 |

FIG. 10

| Deg K | Ohm-m |
|---|---|
| 298.15 | 0.168329938 |
| 303.15 | 0.161810538 |
| 313.15 | 0.150027222 |
| 323.15 | 0.13959319 |
| 333.15 | 0.130614905 |
| 343.15 | 0.122664629 |
| 353.15 | 0.115975772 |
| 363.15 | 0.110218721 |
| 373.15 | 0.105160691 |
| 383.15 | 0.100737561 |
| 393.15 | 0.0968975 |
| 403.15 | 0.093703374 |
| 413.15 | 0.091130667 |
| 423.15 | 0.089298908 |
| 433.15 | 0.088613617 |
| 443.15 | 0.090317615 |
| 453.15 | 0.096577771 |
| 458.15 | 0.102238954 |
| 463.15 | 0.111000861 |
| 468.15 | 0.123519669 |
| 473.15 | 0.149909764 |
| 478.15 | 0.194749565 |
| 483.15 | 0.26517015 |
| 488.15 | 0.374116437 |
| 493.15 | 0.543771602 |
| 498.15 | 0.79410177 |
| 503.15 | 1.167231769 |
| 508.15 | 1.720888026 |
| 513.15 | 2.533063907 |
| 518.15 | 3.668688815 |




$\rho$ = 5700 kg/m$^3$

$Cp$ = 520 J/kg K

$K$ = 2.1 W/m K

FIG. 11

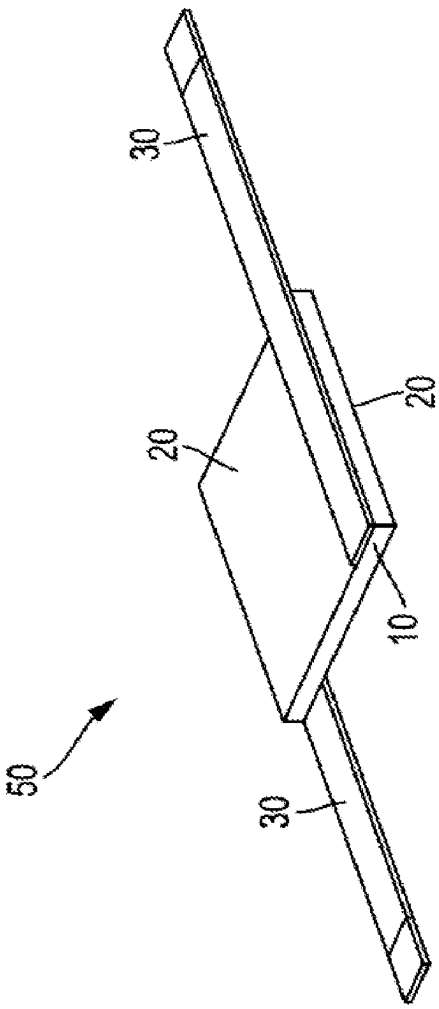



FIG. 12A

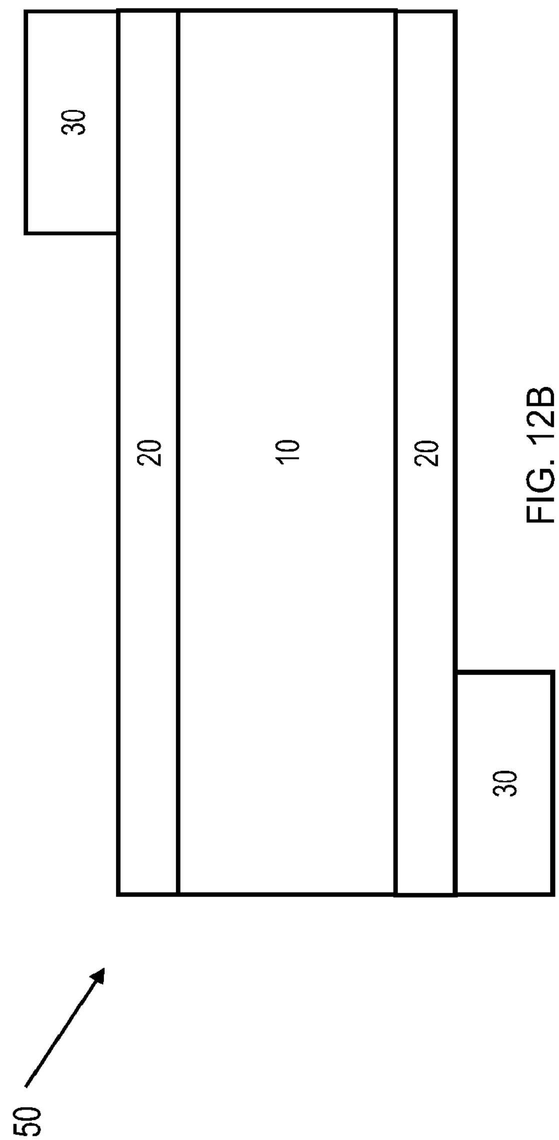



FIG. 12B

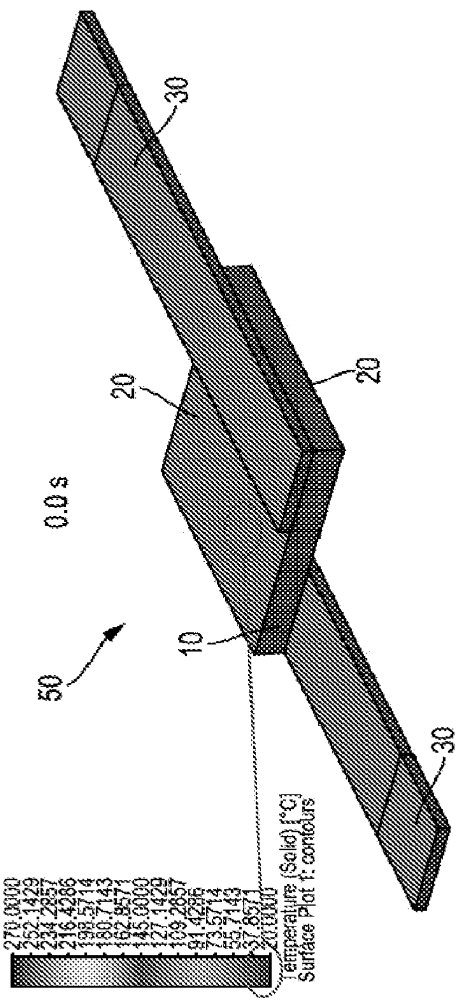



FIG. 13A

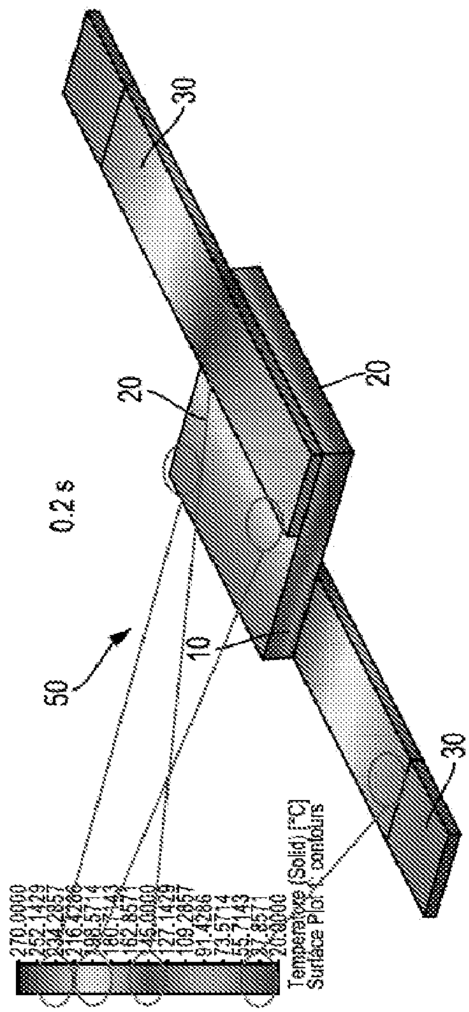



FIG. 13B

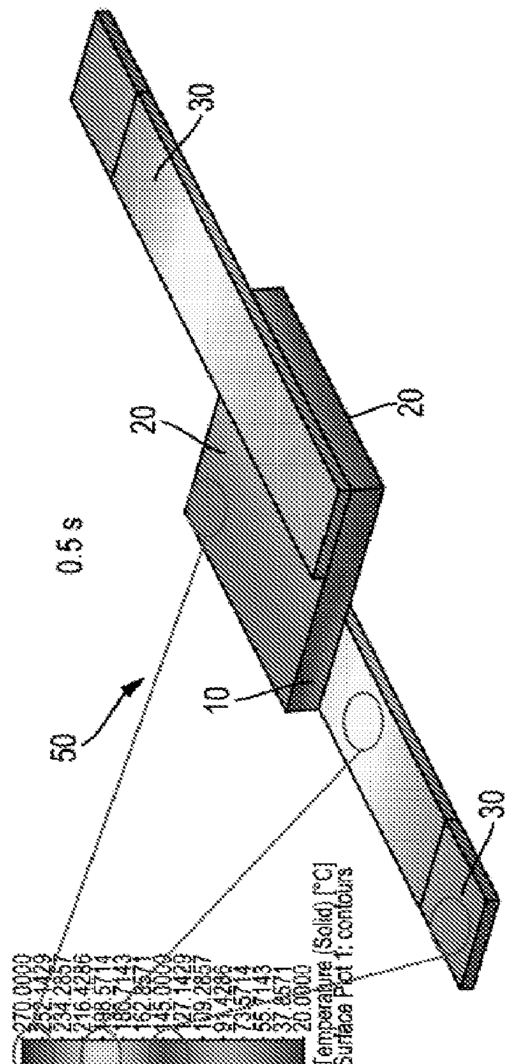



FIG. 13C

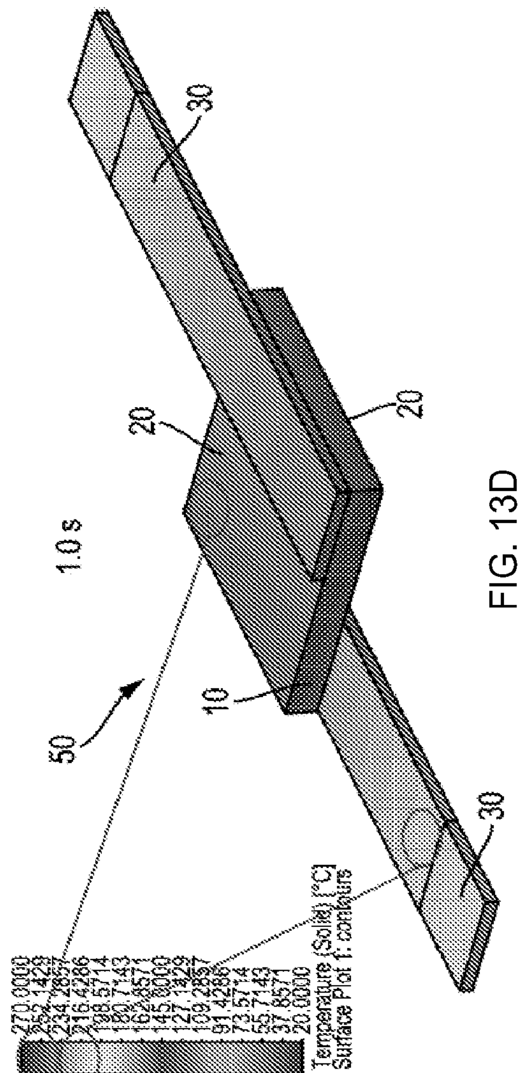



FIG. 13D

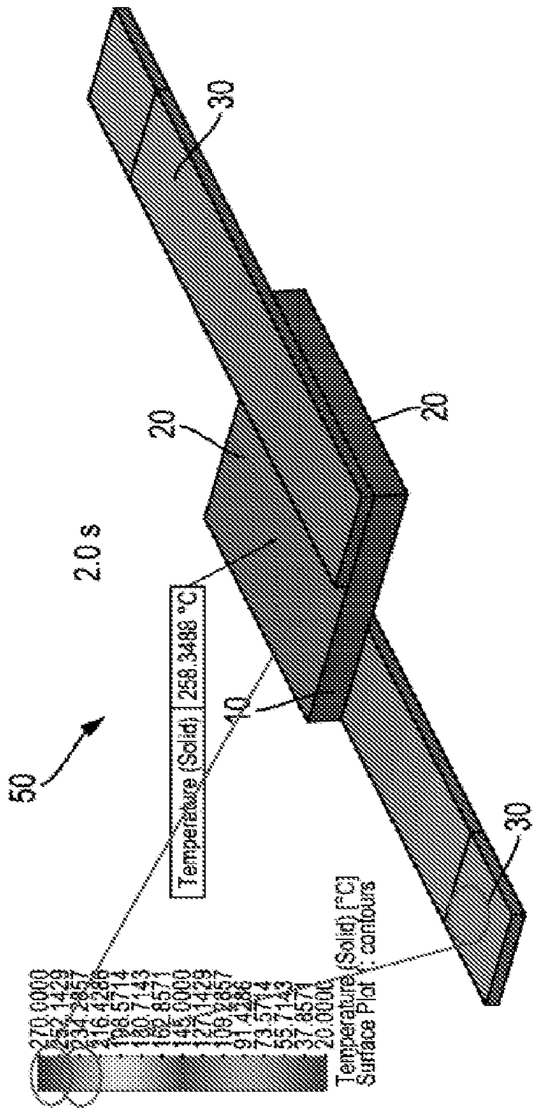

2.0 s
50
20
20
30
30
40
Temperature (Solid) | 258.3488 °C
270.0000
252.1429
234.2857
216.4286
198.5714
180.7143
162.8571
145.0000
127.1429
109.2857
91.4286
73.5714
55.7143
37.8571
20.0000
Temperature (Solid) [°C]
Surface Plot 1: contours

FIG. 13E

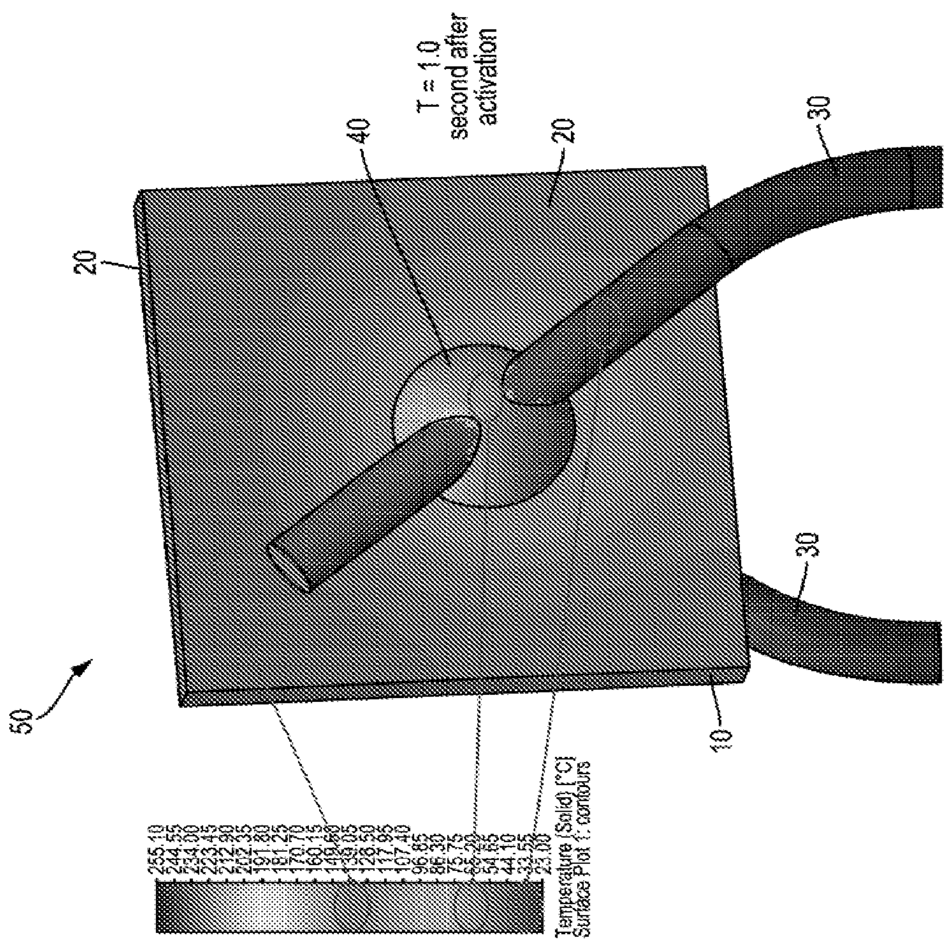

T = 1.0
second after
activation
50
20
40
20
30
30
10
255.10
244.55
234.00
223.45
212.90
202.35
191.80
181.25
170.70
160.15
149.60
139.05
128.50
117.95
107.40
96.85
86.30
75.75
65.20
54.65
44.10
33.55
23.00
Temperature (Solid) [°C]
Surface Plot 1: contours

FIG. 14A

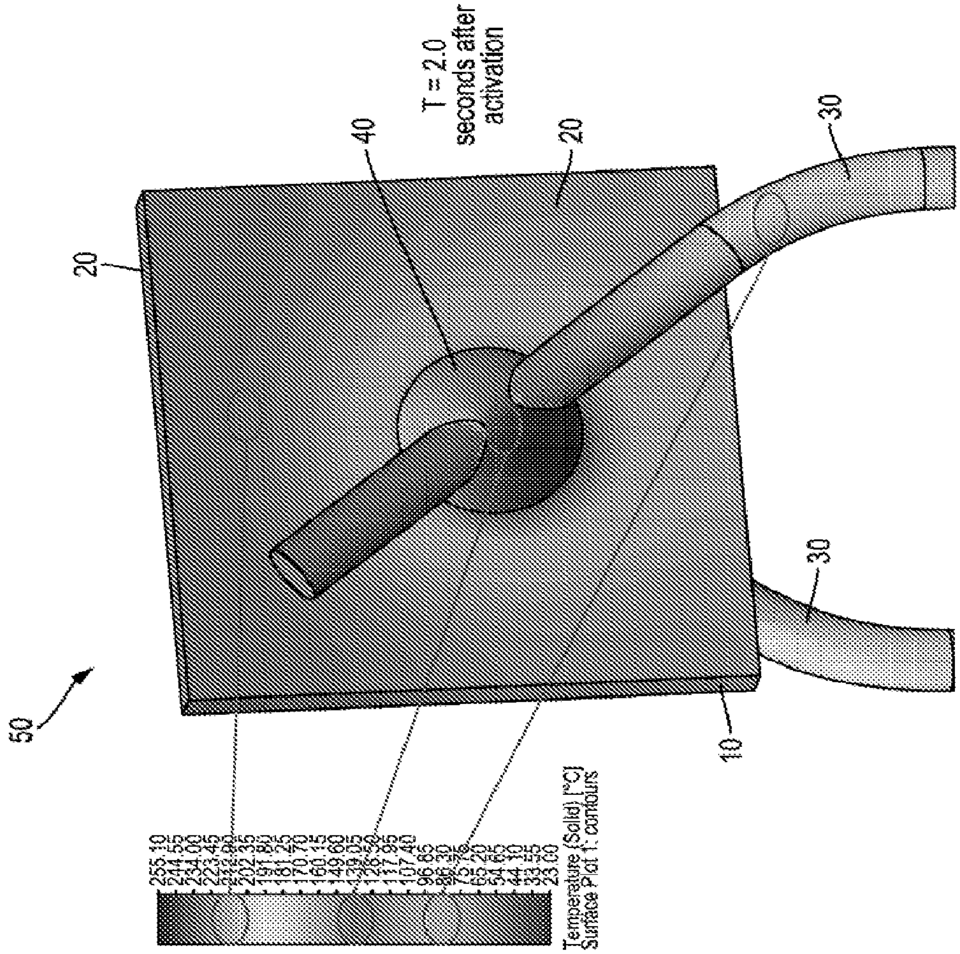

T = 2.0
seconds after
activation
50
20
40
20
30
30
10
Temperature (Solid) [°C]
Surface Plot 1: contours

FIG. 14B

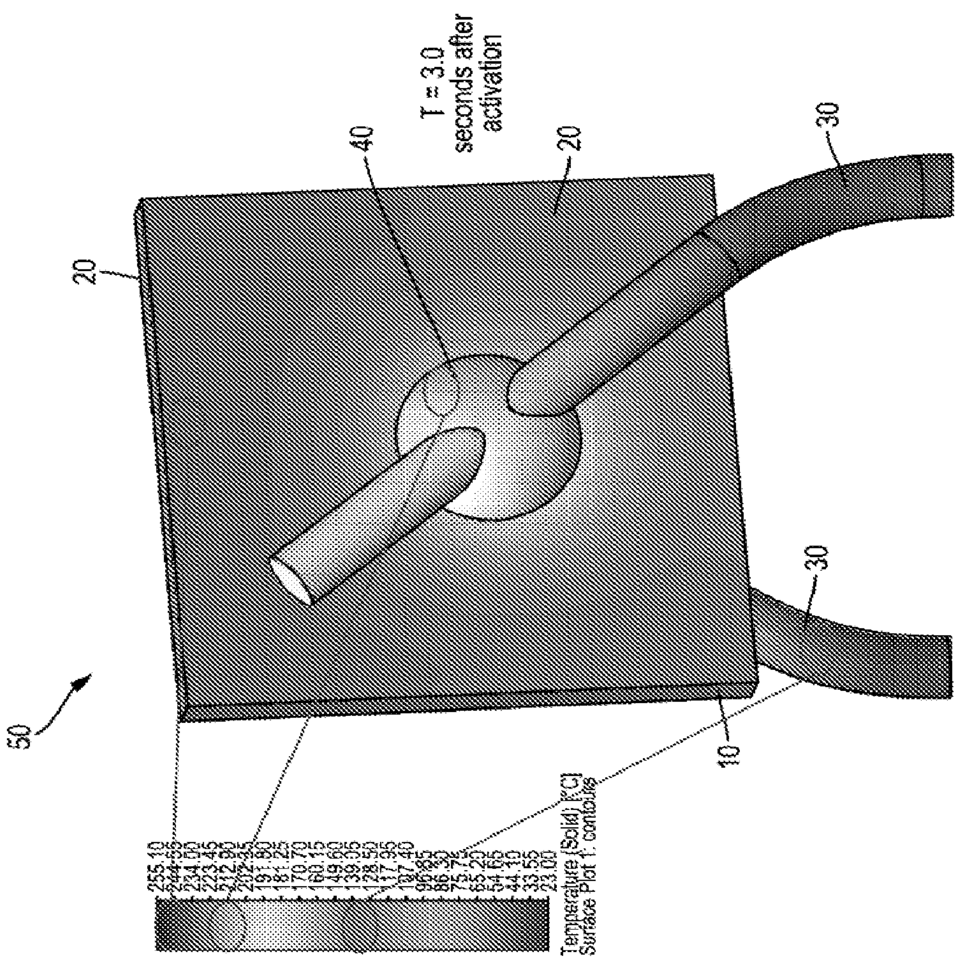

T = 3.0
seconds after
activation
20
40
20
30
30
50
10
255.10
244.55
234.00
223.45
212.90
202.35
191.80
181.25
170.70
160.15
149.60
139.05
128.50
117.95
107.40
96.85
86.30
75.75
65.20
54.65
44.10
33.55
23.00
Temperature (Solid) [°C]
Surface Plot 1: contours

FIG. 14C

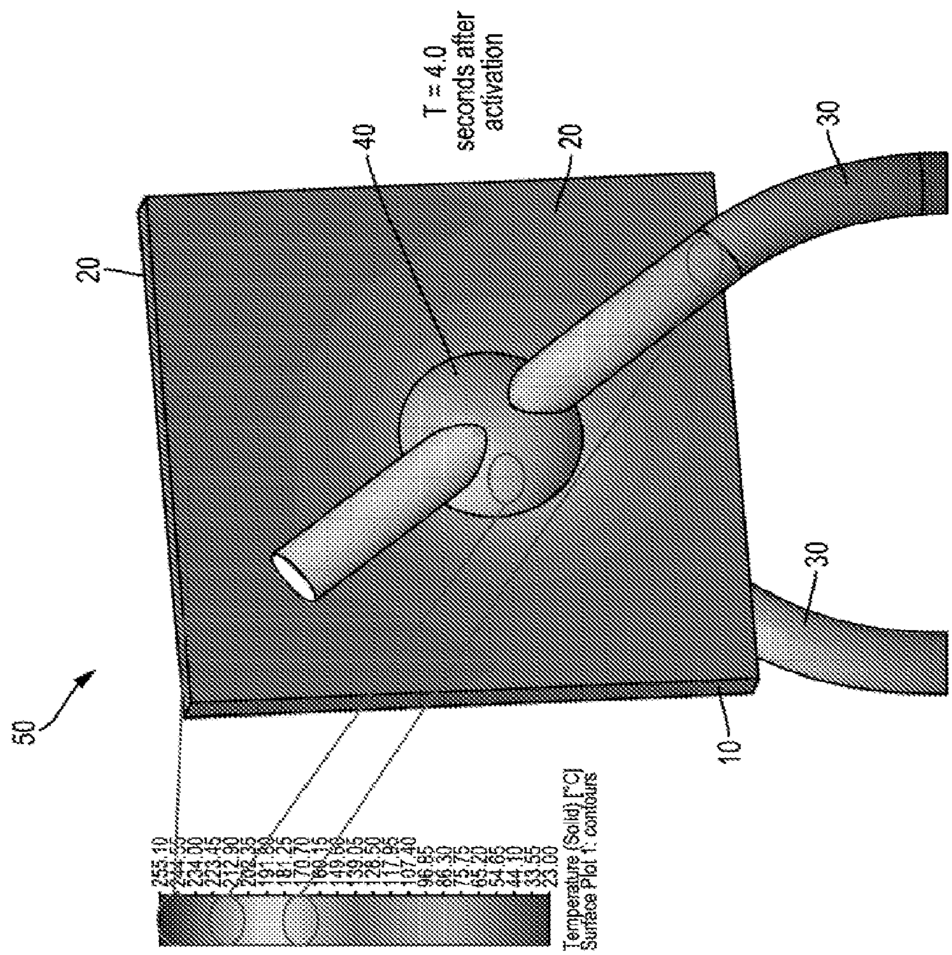

T = 4.0
seconds after
activation
50
20
20
40
30
30
10
255.10
244.55
234.00
223.45
212.90
202.35
191.80
181.25
170.70
160.15
149.60
139.05
128.50
117.95
107.40
96.85
86.30
75.75
65.20
54.65
44.10
33.55
23.00
Temperature (Solid) [°C]
Surface Plot 1: contours

FIG. 14D

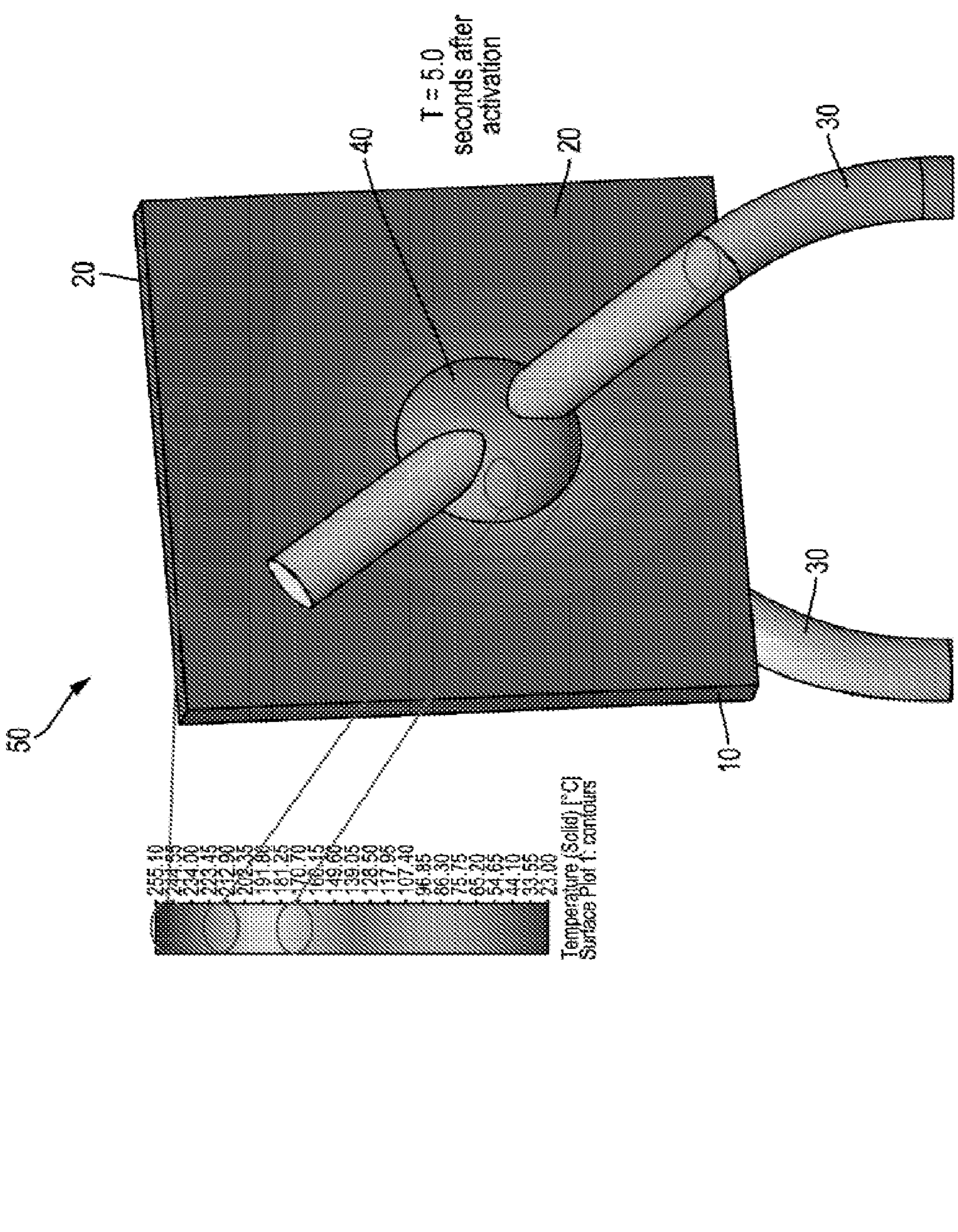

T = 5.0
seconds after
activation
50
20
40
20
30
30
10
255.10
244.55
234.00
223.45
212.90
202.35
191.80
181.25
170.70
160.15
149.60
139.05
128.50
117.95
107.40
96.85
86.30
75.75
65.20
54.65
44.10
33.55
23.00
Temperature (Solid) [°C]
Surface Plot 1: contours

FIG. 14E

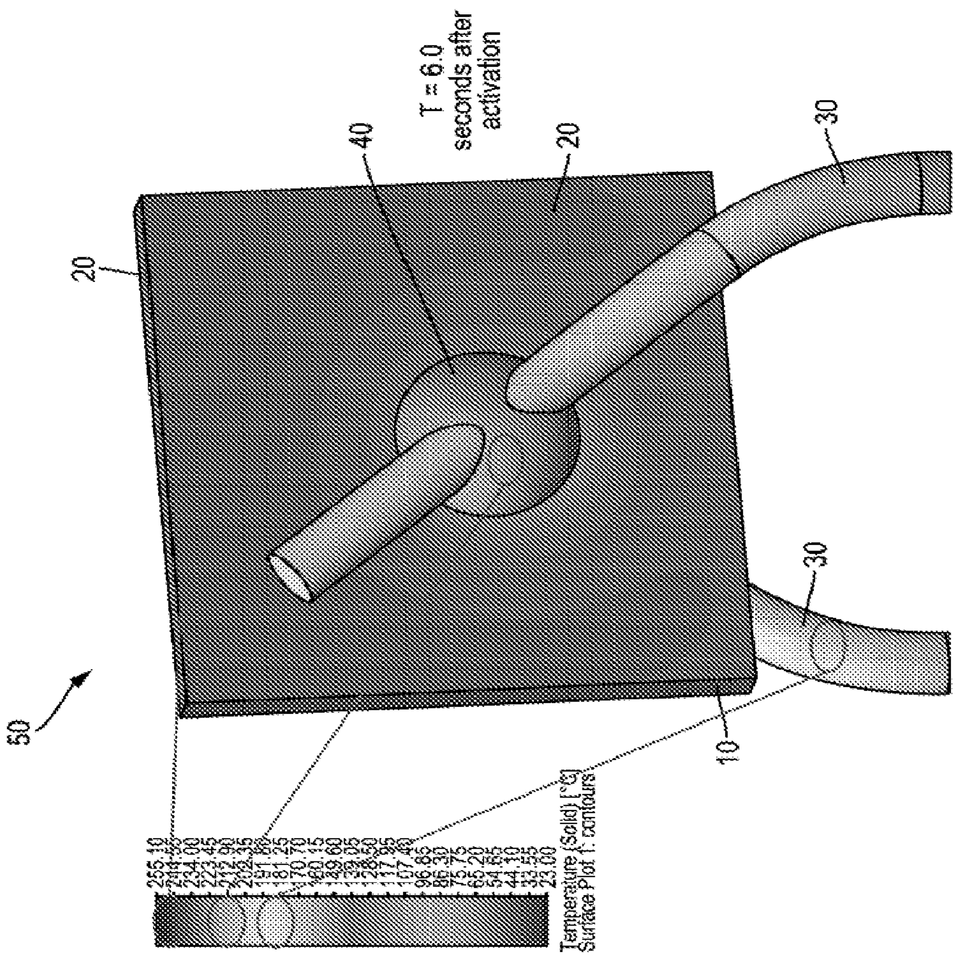

T = 6.0
seconds after
activation
20
20
40
30
30
50
10
255.10
244.55
234.00
223.45
212.90
202.35
191.80
181.25
170.70
160.15
149.60
139.05
128.50
117.95
107.40
96.85
86.30
75.75
65.20
54.65
44.10
33.55
23.00
Temperature (Solid) [°C]
Surface Plot 1: contours

FIG. 14F

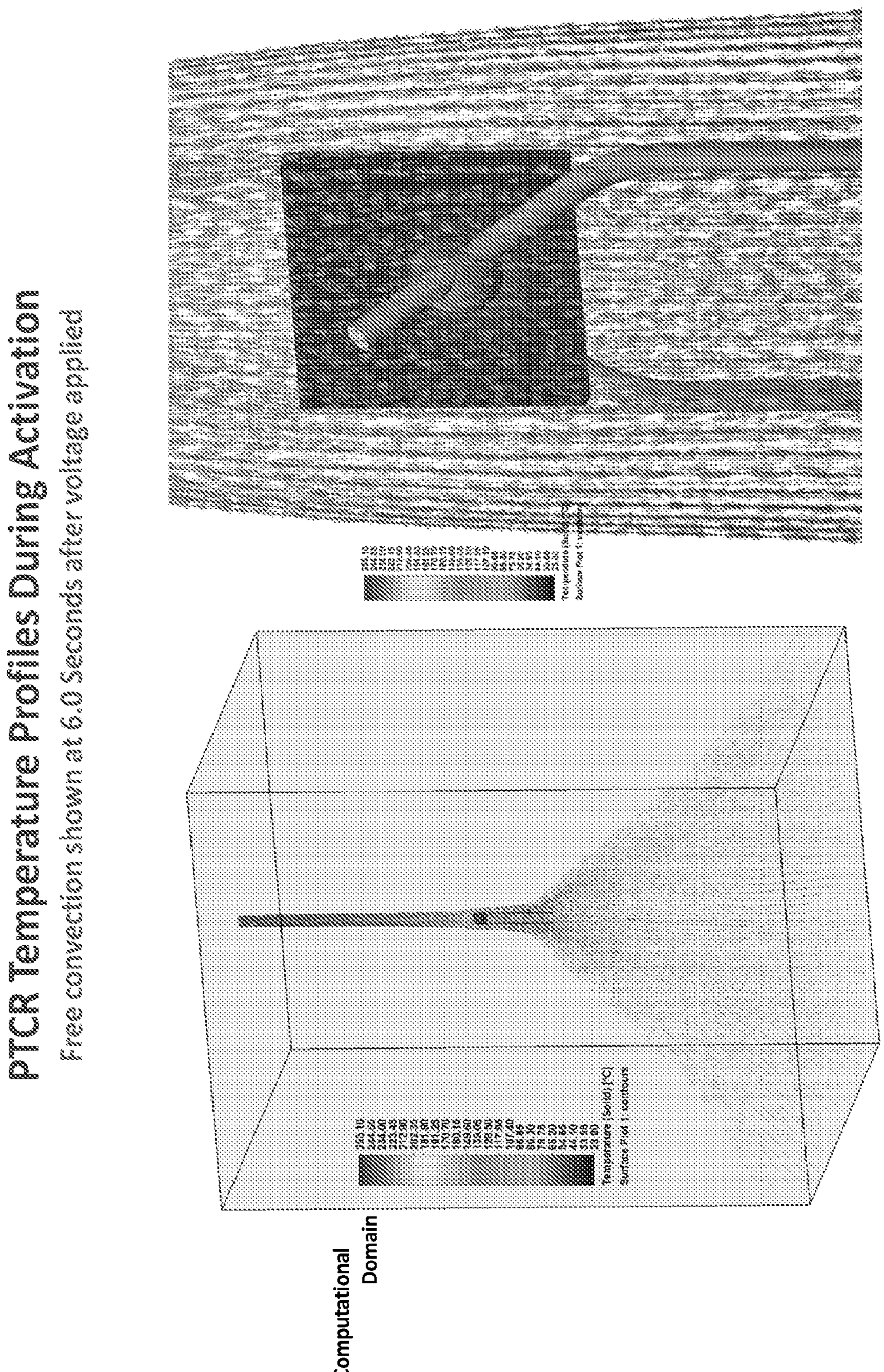

PTCR Temperature Profiles During Activation
Free convection shown at 6.0 Seconds after voltage applied
Computational Domain

FIG. 15

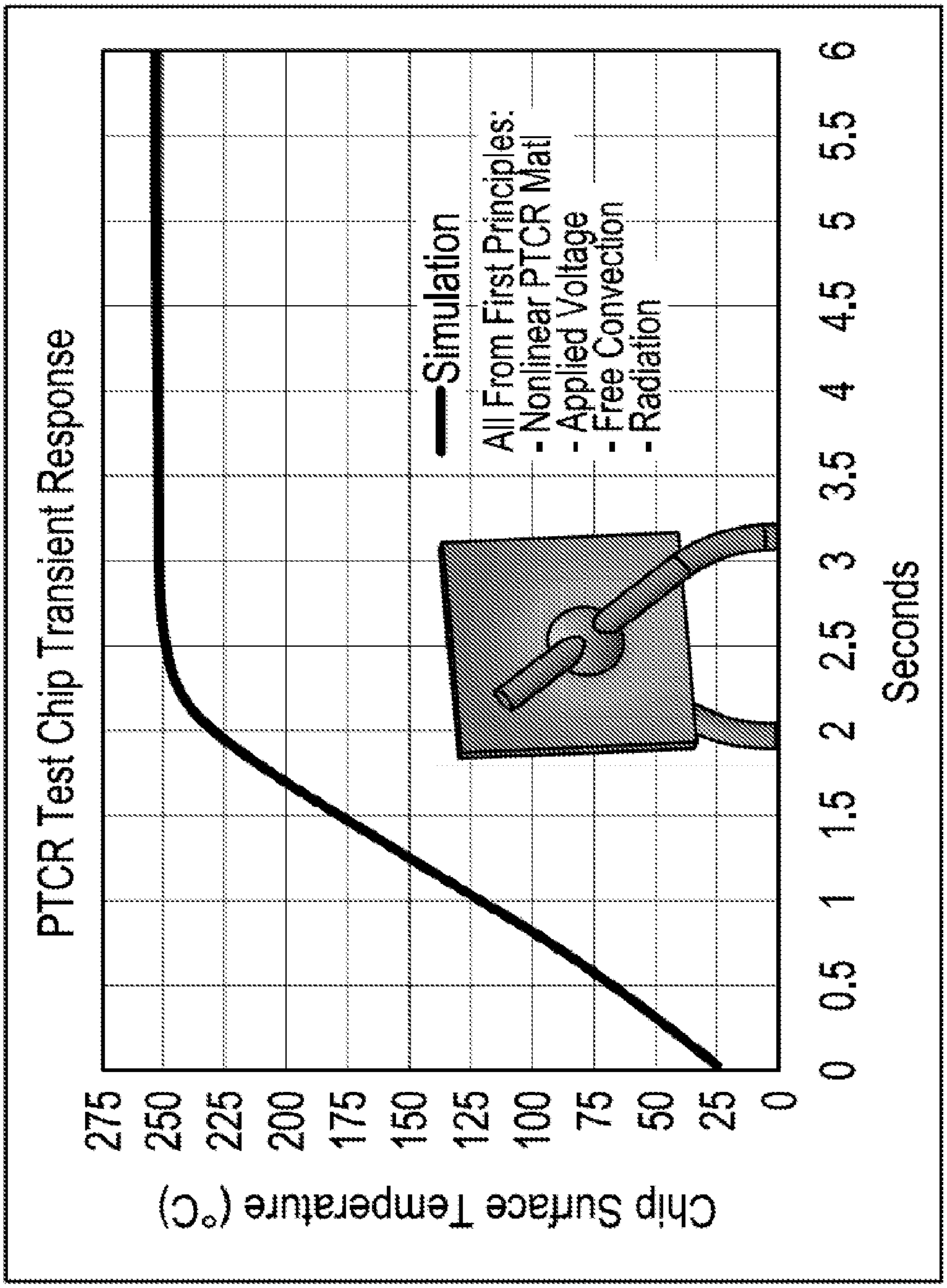

PTCR Test Chip Transient Response
Chip Surface Temperature (°C)
275
250
225
200
175
150
125
100
75
50
25
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Seconds
Simulation
All From First Principles:
- Nonlinear PTCR Mat'l
- Applied Voltage
- Free Convection
- Radiation

FIG. 16A

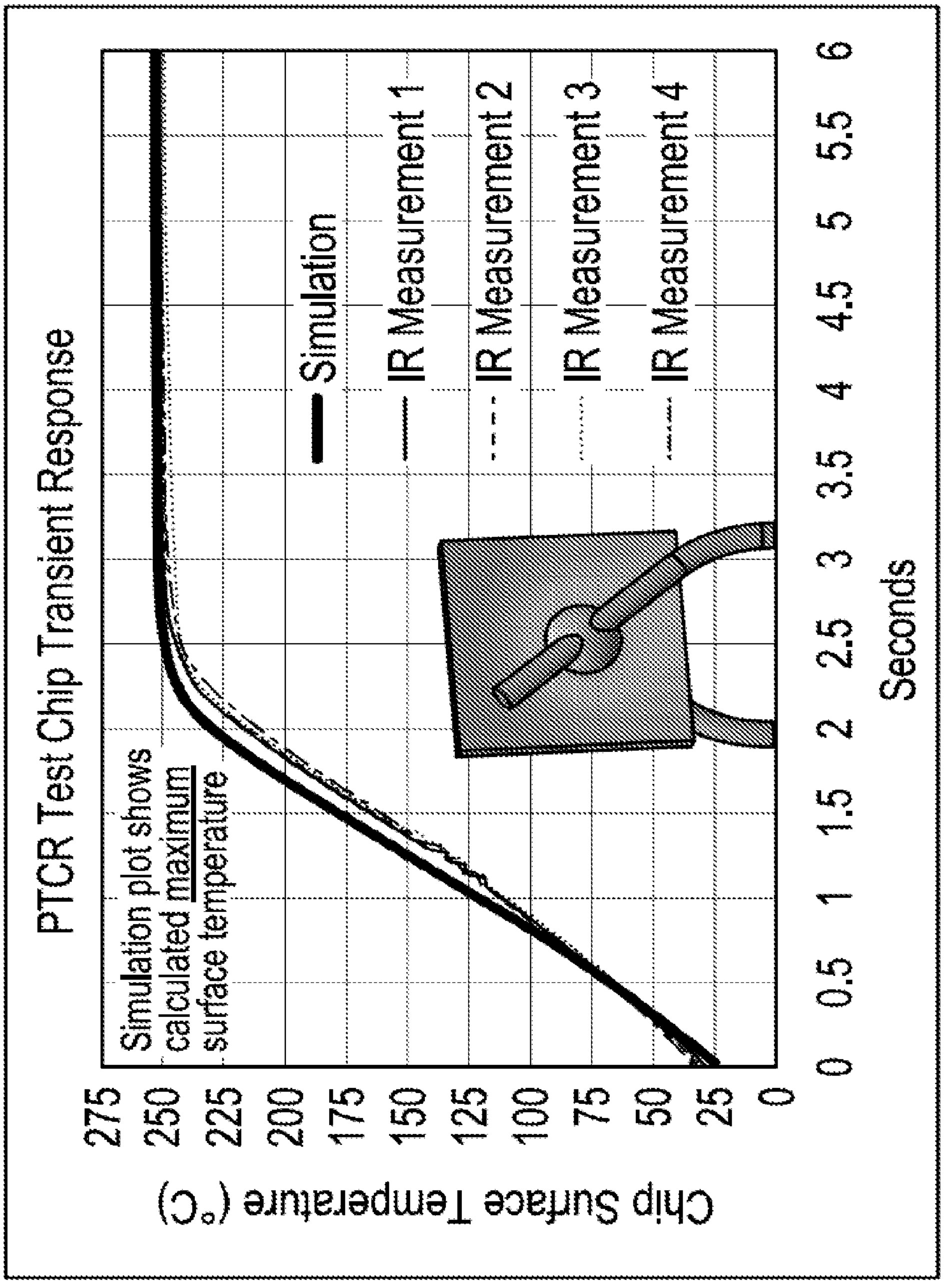

PTCR Test Chip Transient Response
Simulation plot shows calculated maximum surface temperature
Simulation
IR Measurement 1
IR Measurement 2
IR Measurement 3
IR Measurement 4
Chip Surface Temperature (°C)
275
250
225
200
175
150
125
100
75
50
25
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Seconds

FIG. 16B

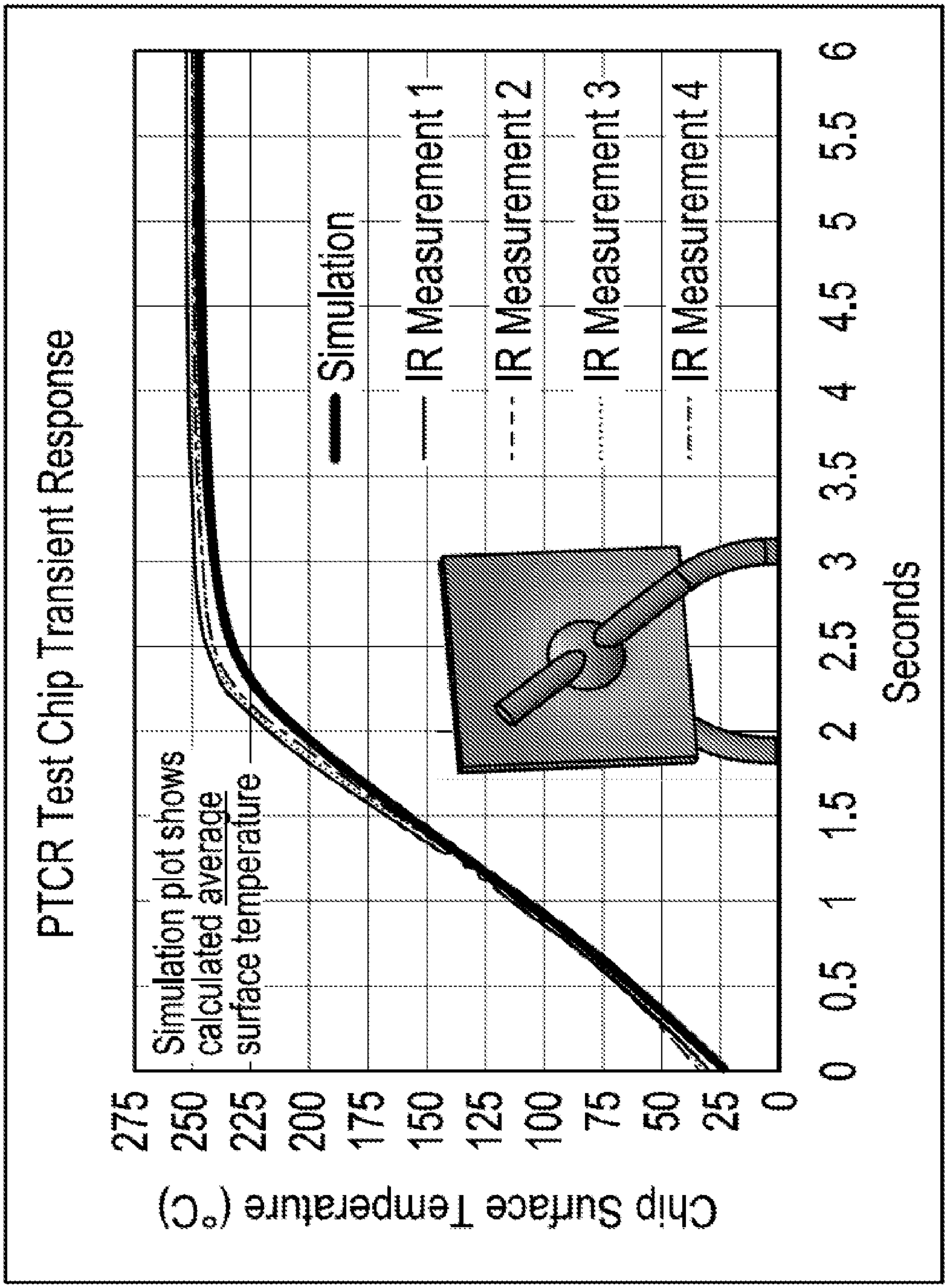

PTCR Test Chip Transient Response
Simulation plot shows
calculated average
surface temperature
Simulation
IR Measurement 1
IR Measurement 2
IR Measurement 3
IR Measurement 4
Chip Surface Temperature (°C)
275
250
225
200
175
150
125
100
75
50
25
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Seconds

FIG. 16C

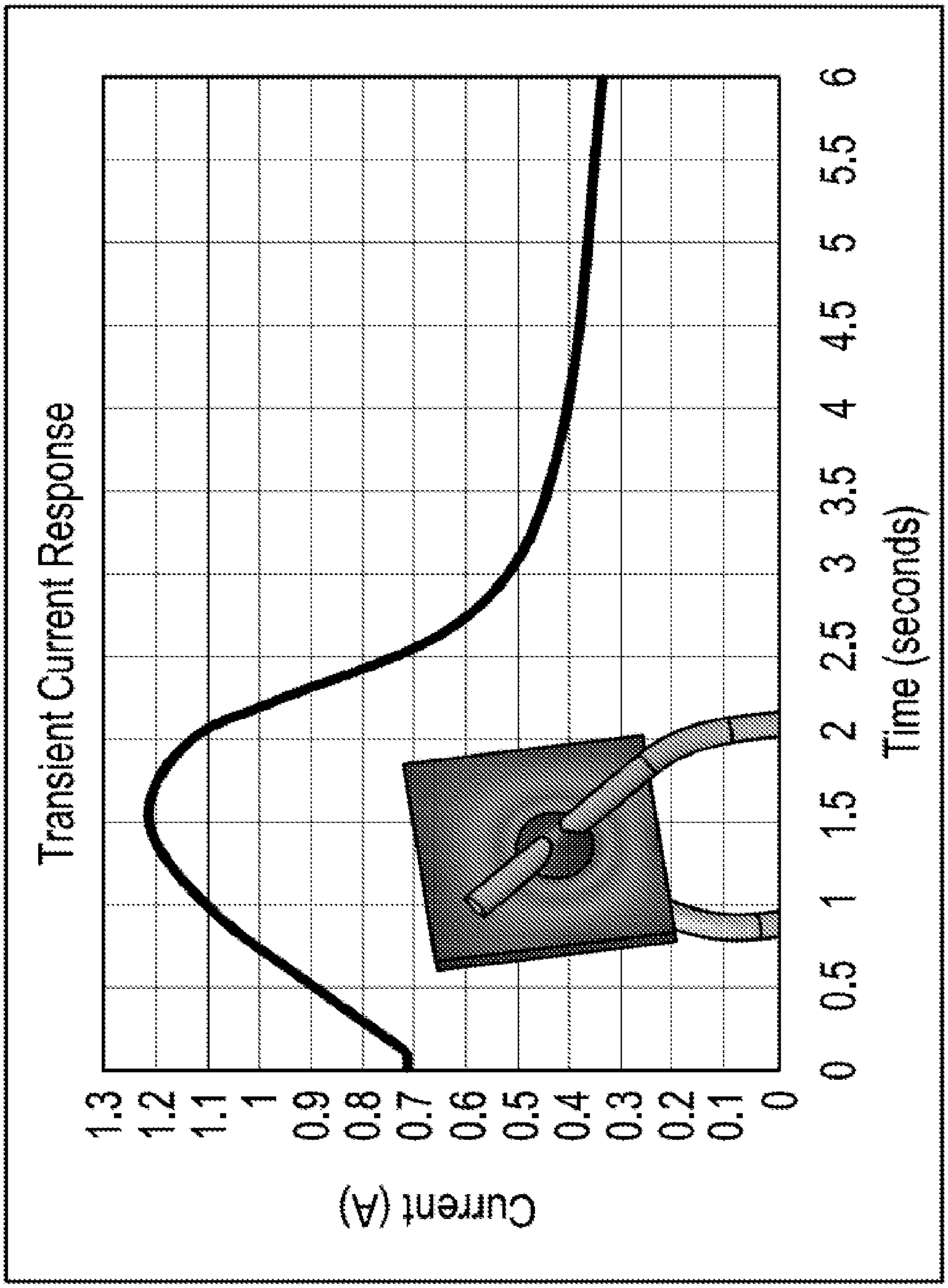

Transient Current Response
Current (A)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
Time (seconds)

FIG. 17

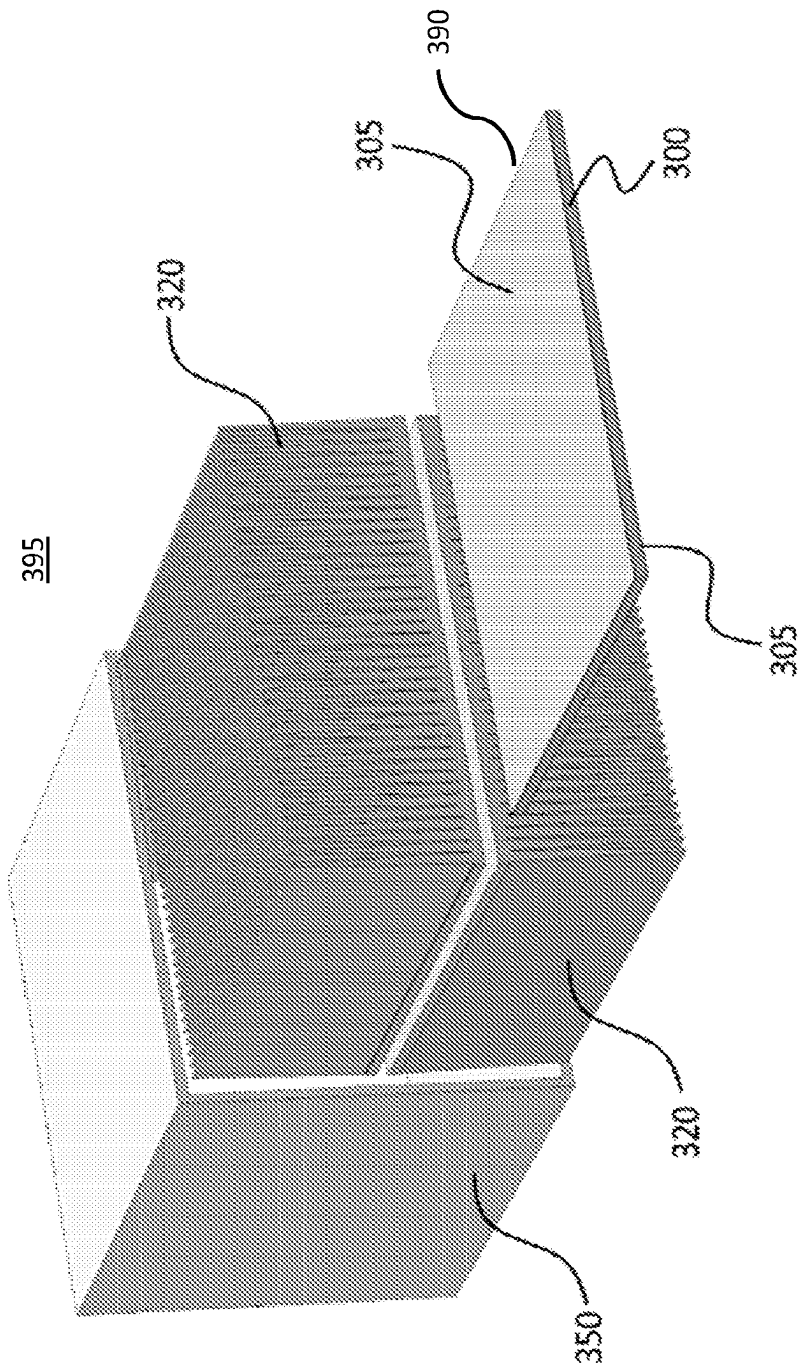



FIG. 18

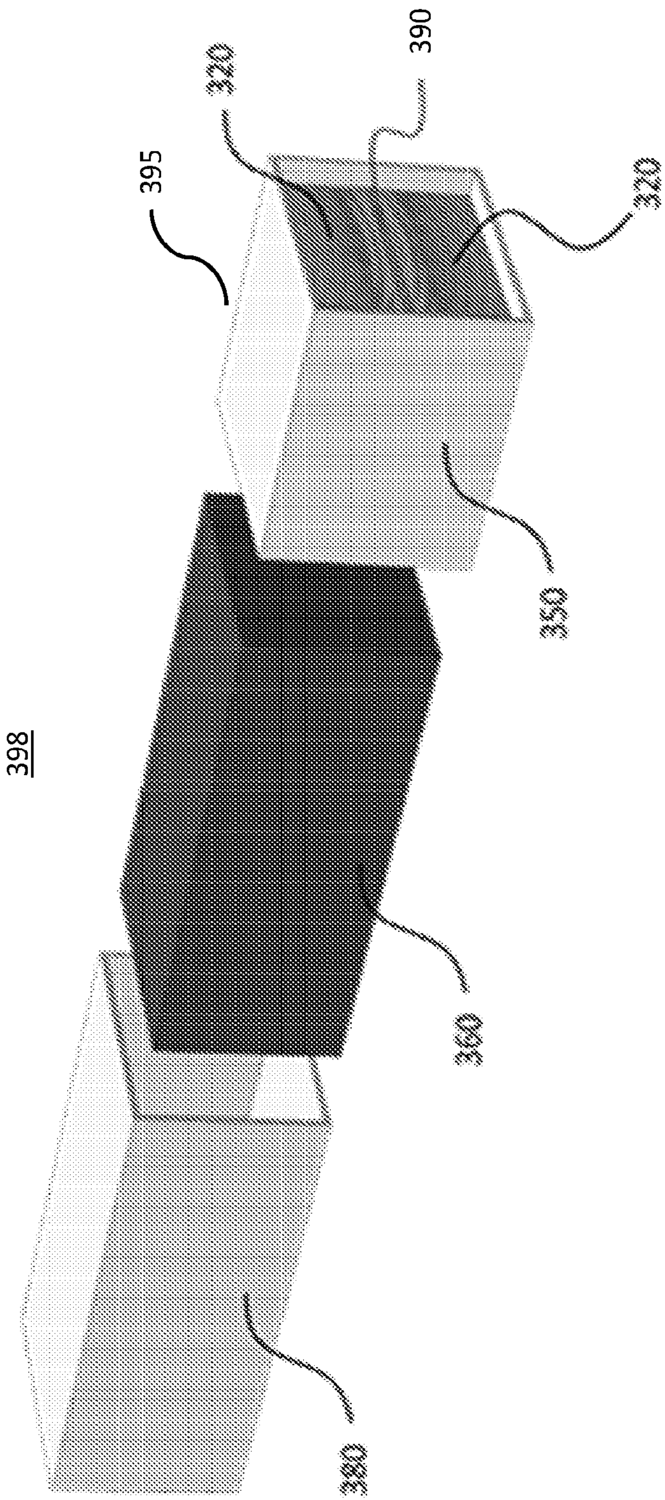



FIG. 19

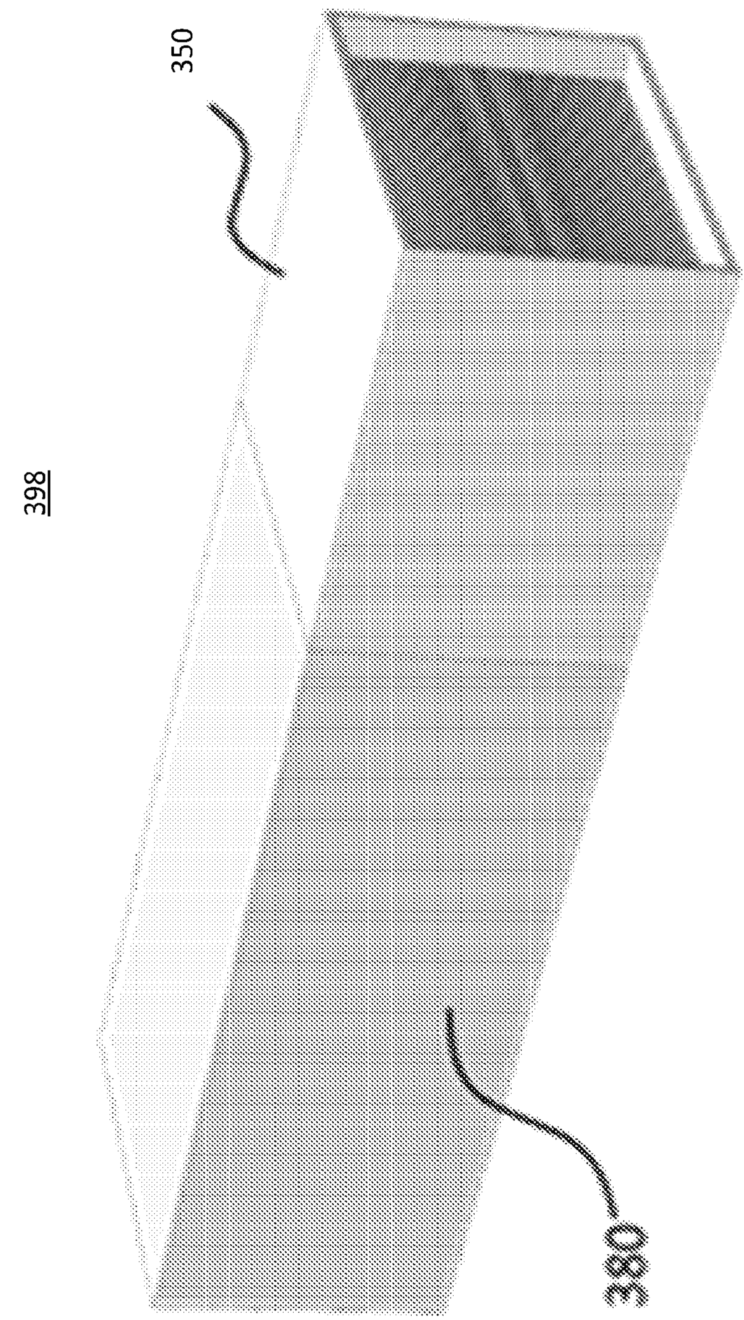



FIG. 20

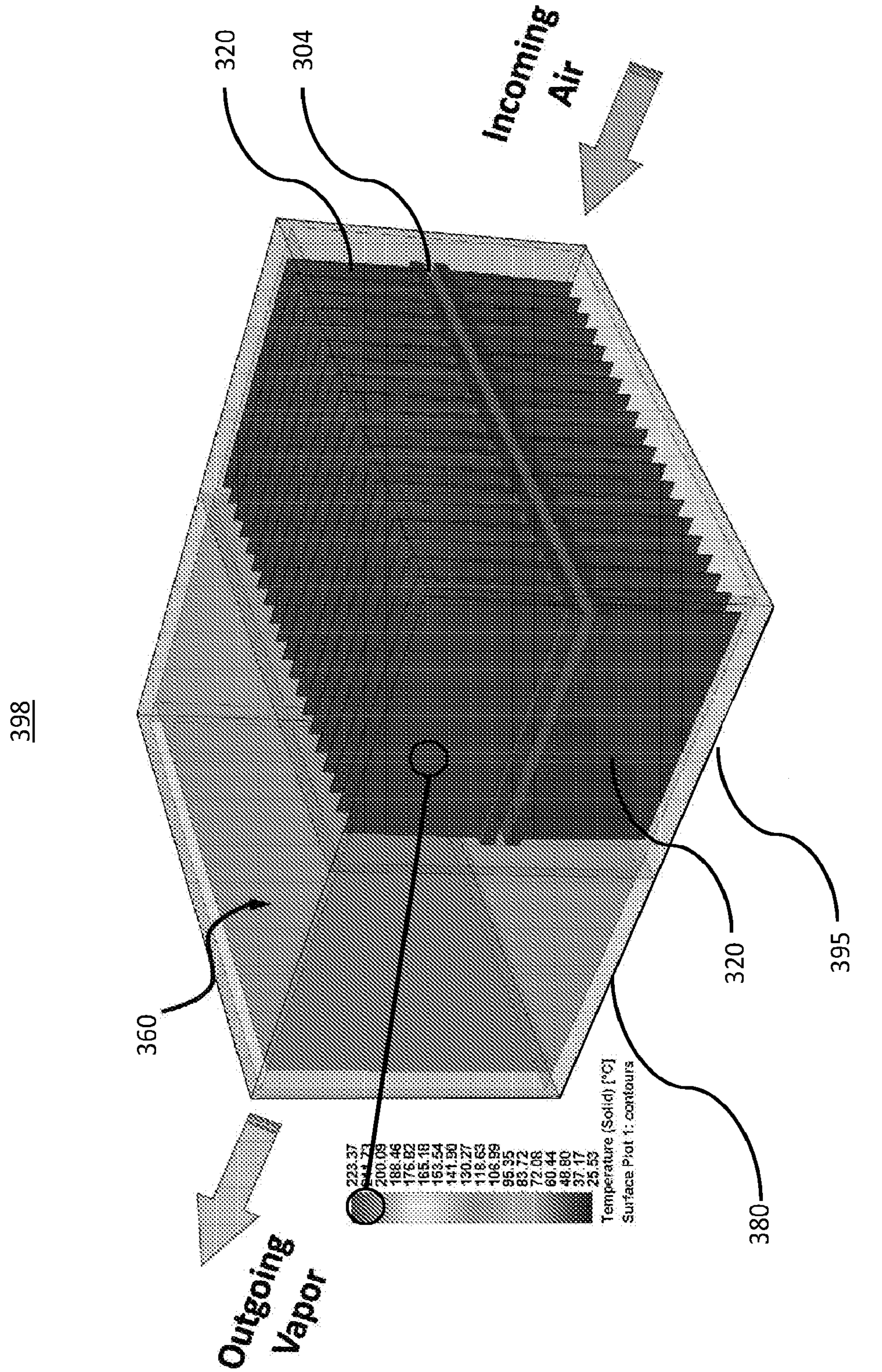

398
320
304
Incoming Air
360
320
395
380
Outgoing Vapor
223.37
200.09
188.46
176.82
165.18
153.54
141.90
130.27
118.63
106.99
95.35
83.72
72.08
60.44
48.80
37.17
25.53
Temperature (Solid) [°C]
Surface Plot 1: contours

FIG. 21

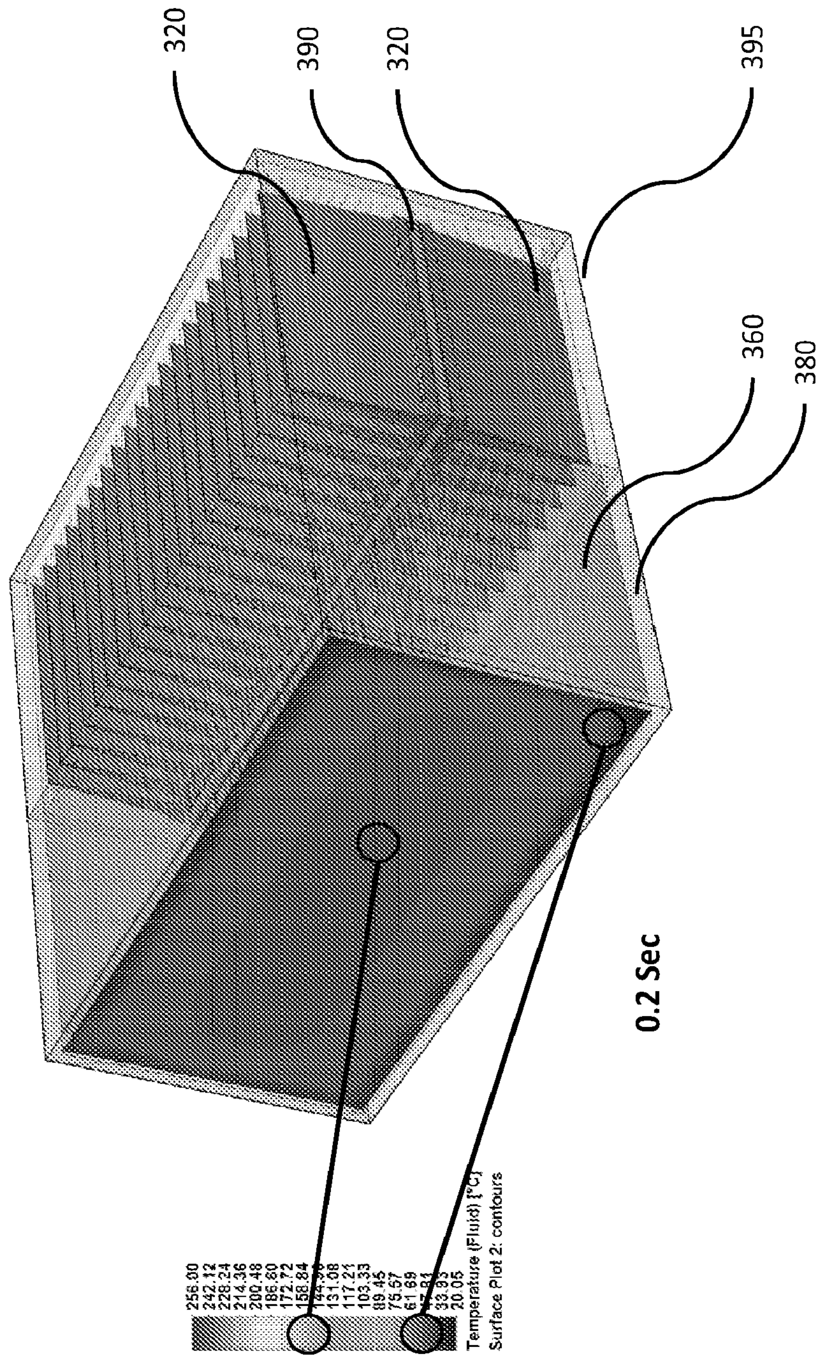

320
390
320
395
360
380
0.2 Sec
Temperature (Fluid) [°C]
Surface Plot 2: contours

FIG. 22

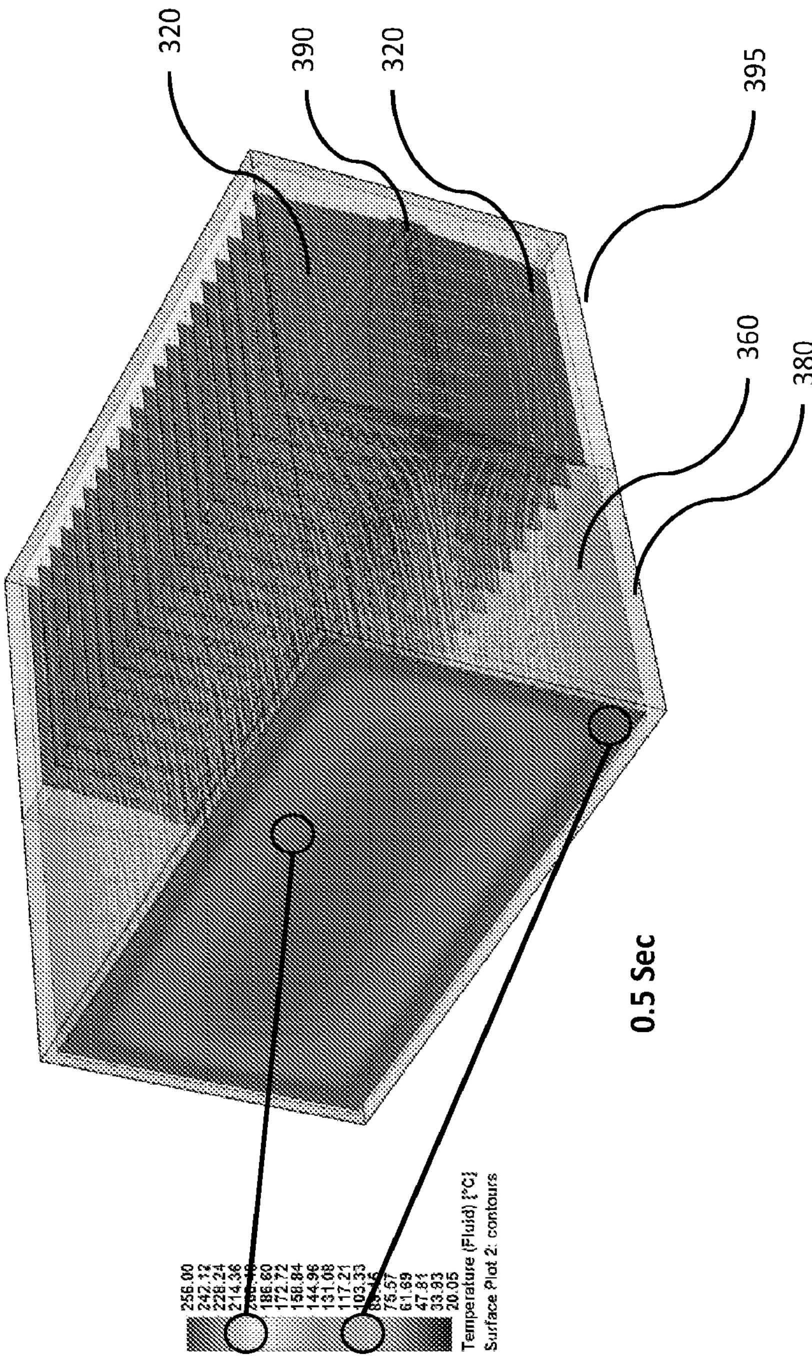

320
390
320
395
360
380
0.5 Sec
256.00
242.12
228.24
214.36
186.60
172.72
158.84
144.96
131.08
117.21
103.33
75.57
61.69
47.81
33.93
20.05
Temperature (Fluid) [°C]
Surface Plot 2: contours

FIG. 23

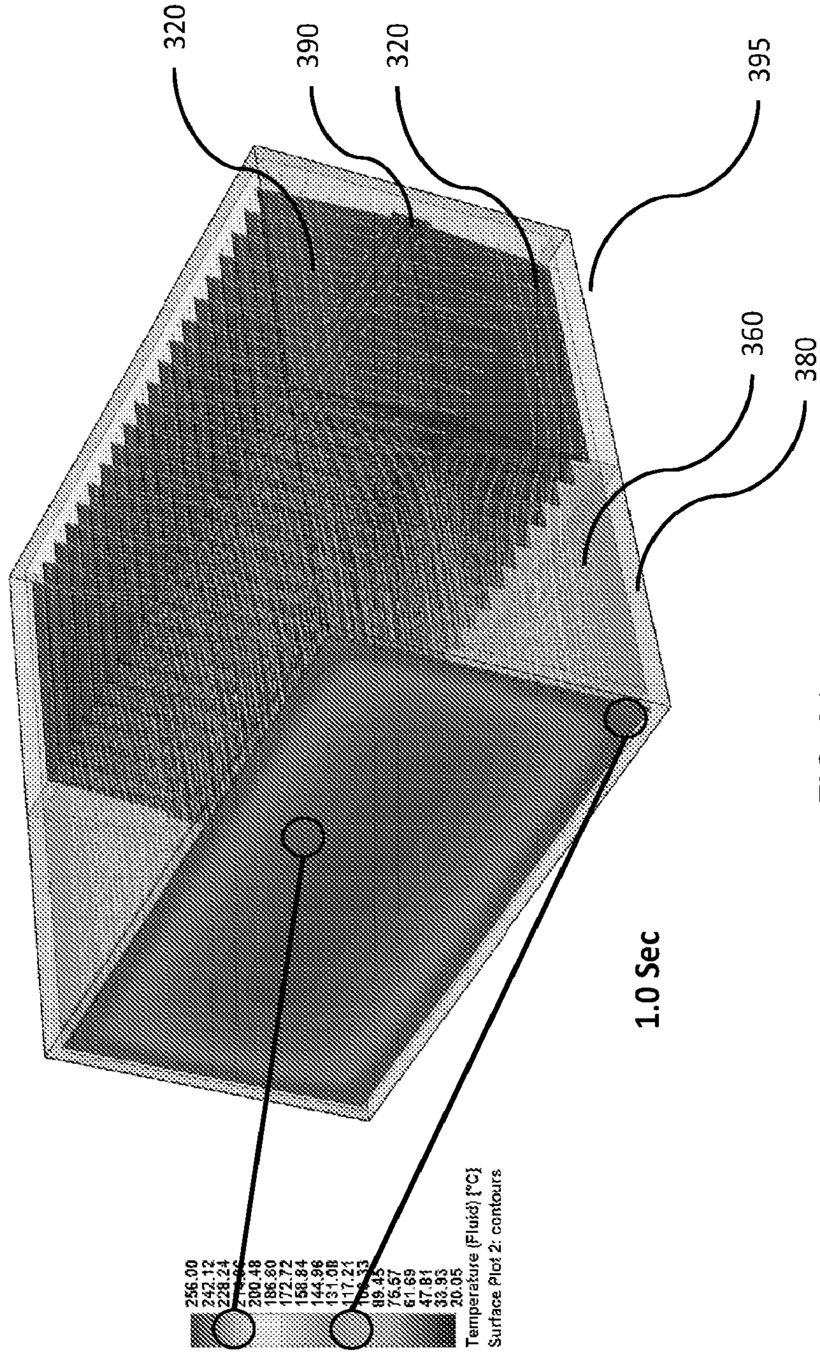

320
390
320
395
360
380
1.0 Sec
256.00
242.12
228.24
200.48
186.60
172.72
158.84
144.96
131.08
117.21
89.45
75.57
61.69
47.81
33.93
20.05
Temperature (Fluid) [°C]
Surface Plot 2: contours

FIG. 24

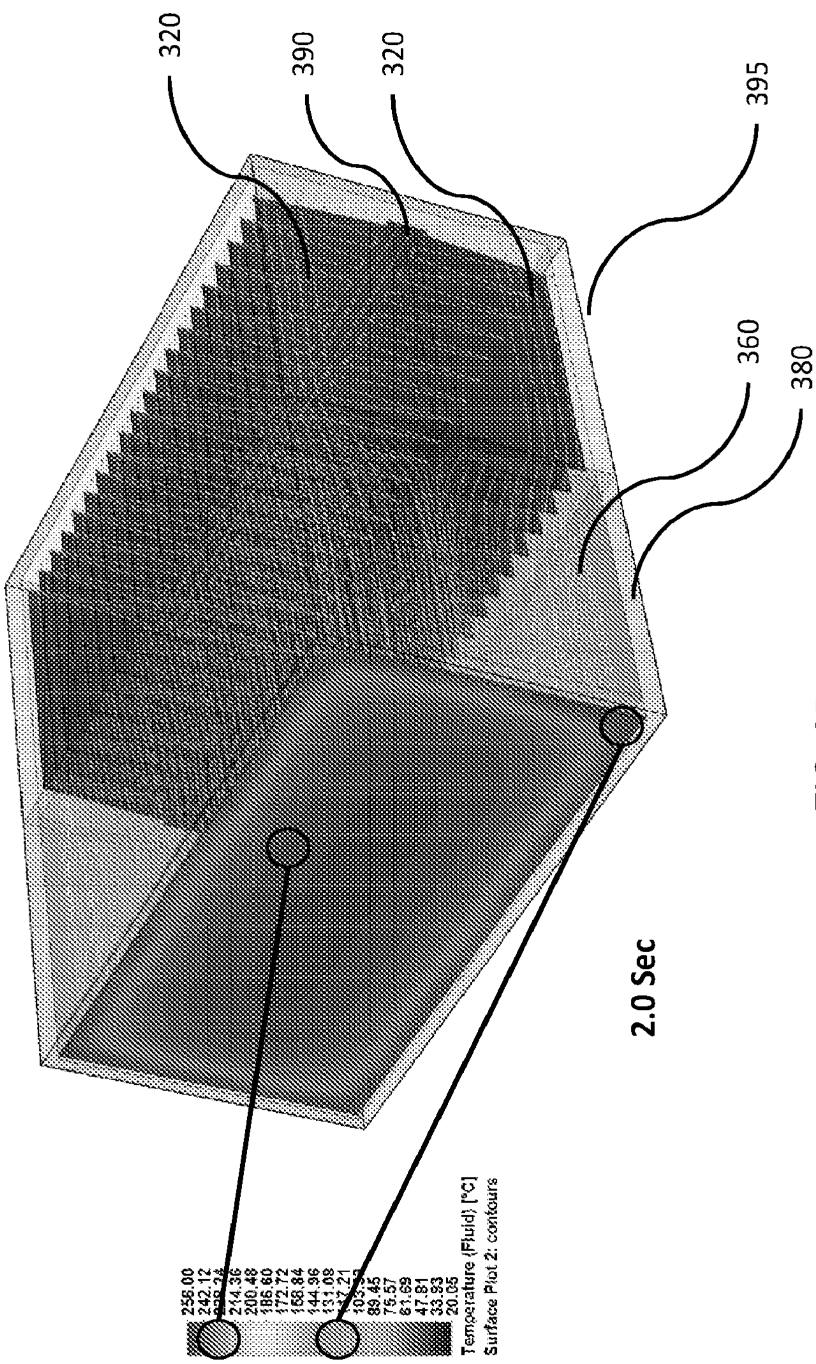

320
390
320
395
360
380
2.0 Sec
256.00
242.12
214.36
200.48
186.60
172.72
158.84
144.96
131.08
89.45
75.57
61.69
47.81
33.93
20.05
Temperature (Fluid) [°C]
Surface Plot 2: contours

FIG. 25

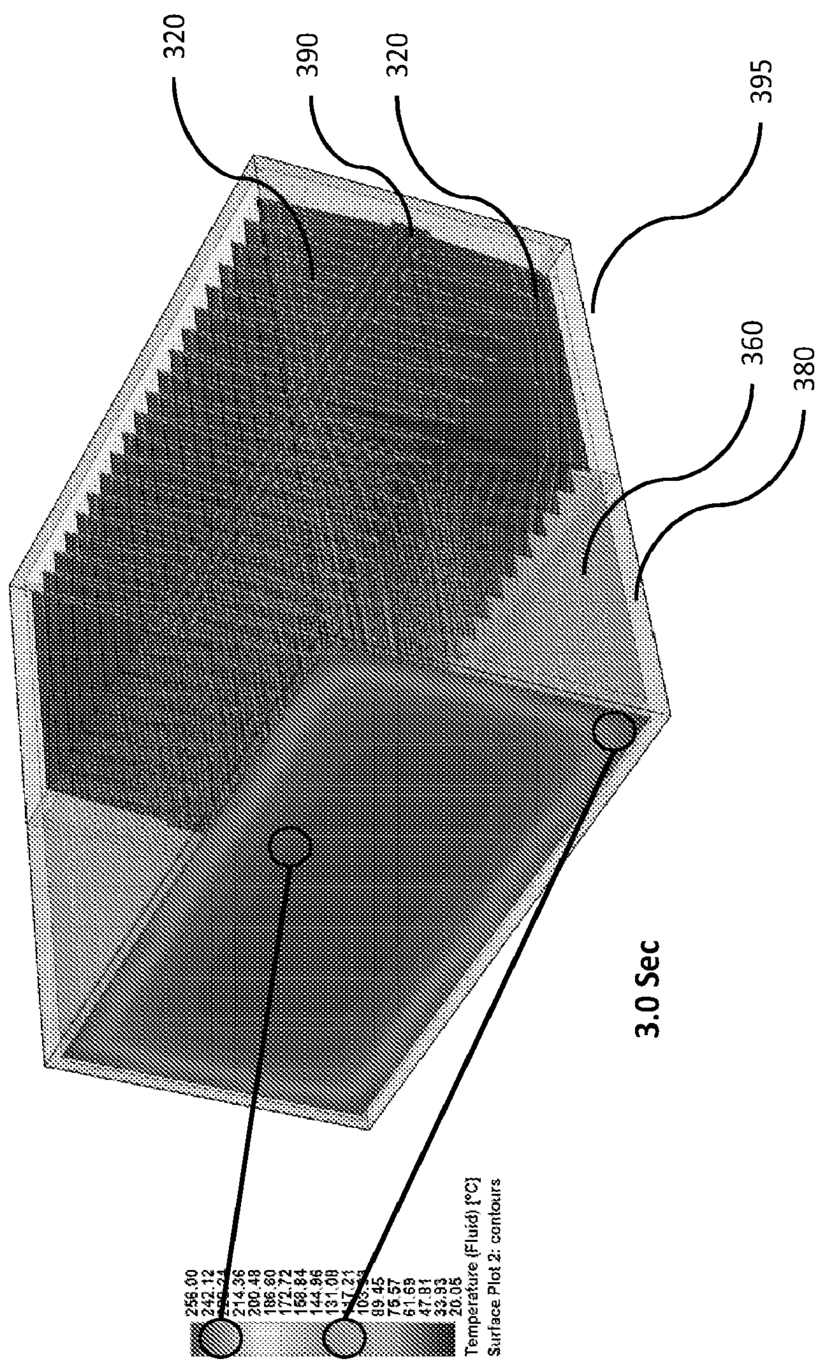

320
390
320
395
360
380
3.0 Sec
256.00
242.12
214.36
200.48
186.60
172.72
158.84
144.96
131.08
89.45
75.57
61.69
47.81
33.93
20.05
Temperature (Fluid) [°C]
Surface Plot 2: contours

FIG. 26

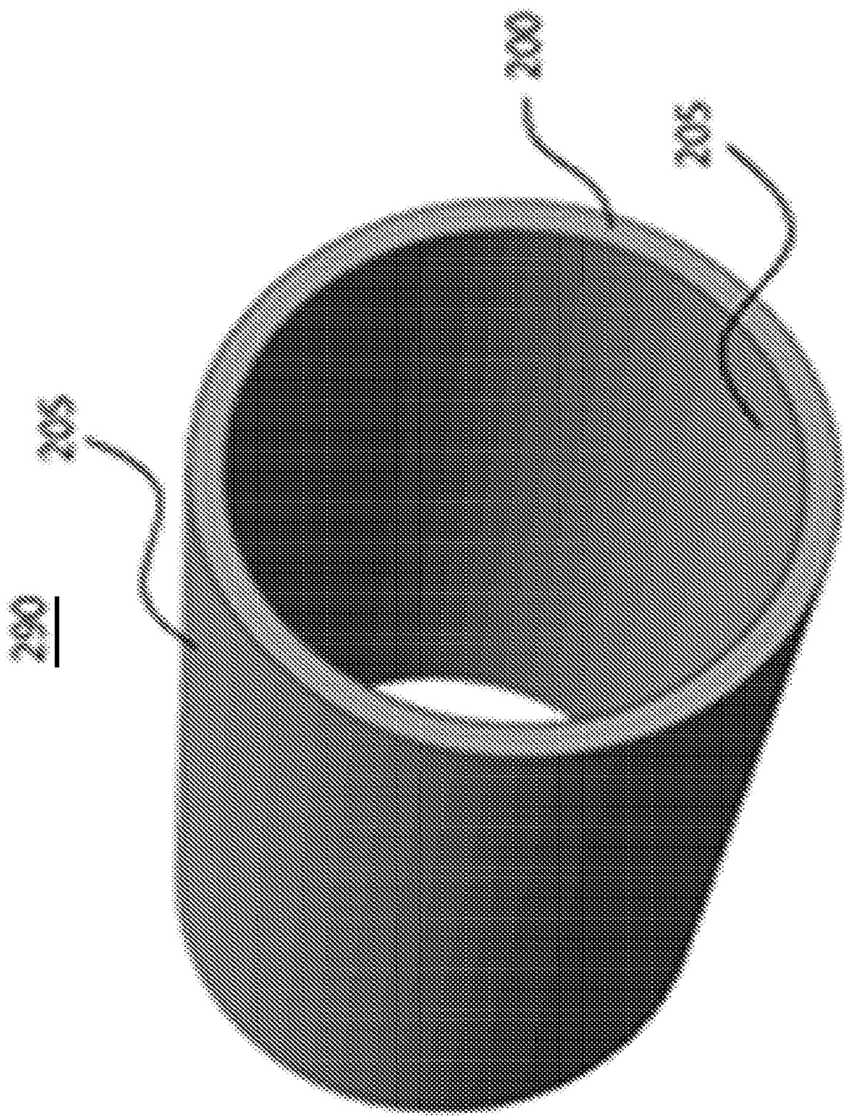



FIG. 27

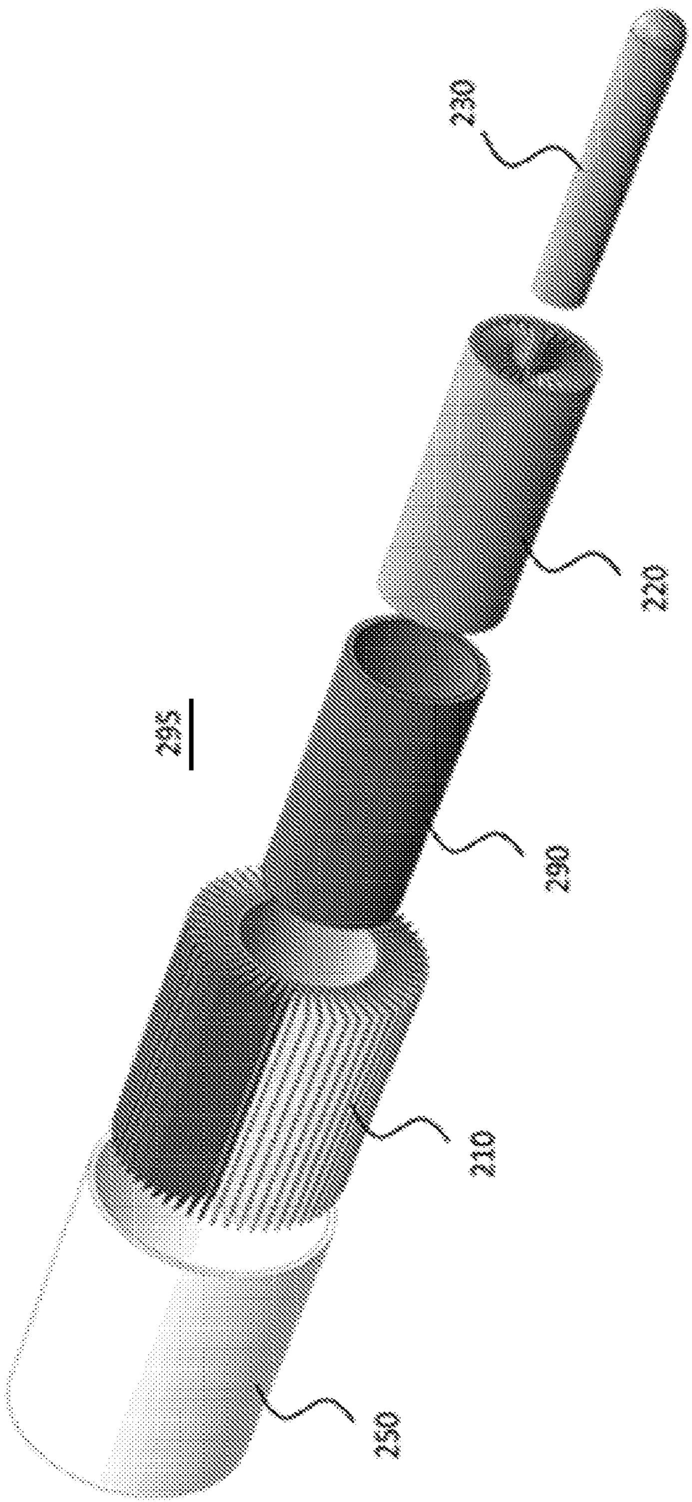



FIG. 28

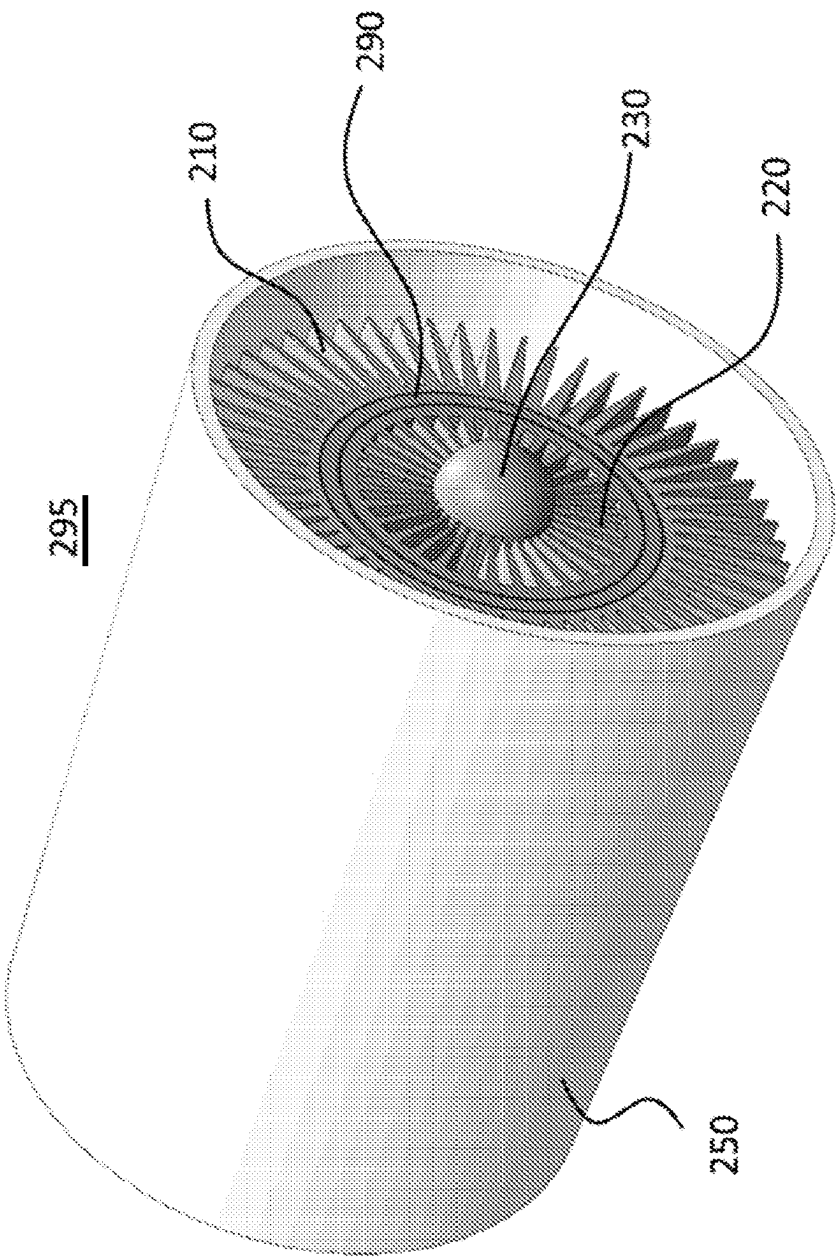



FIG. 29

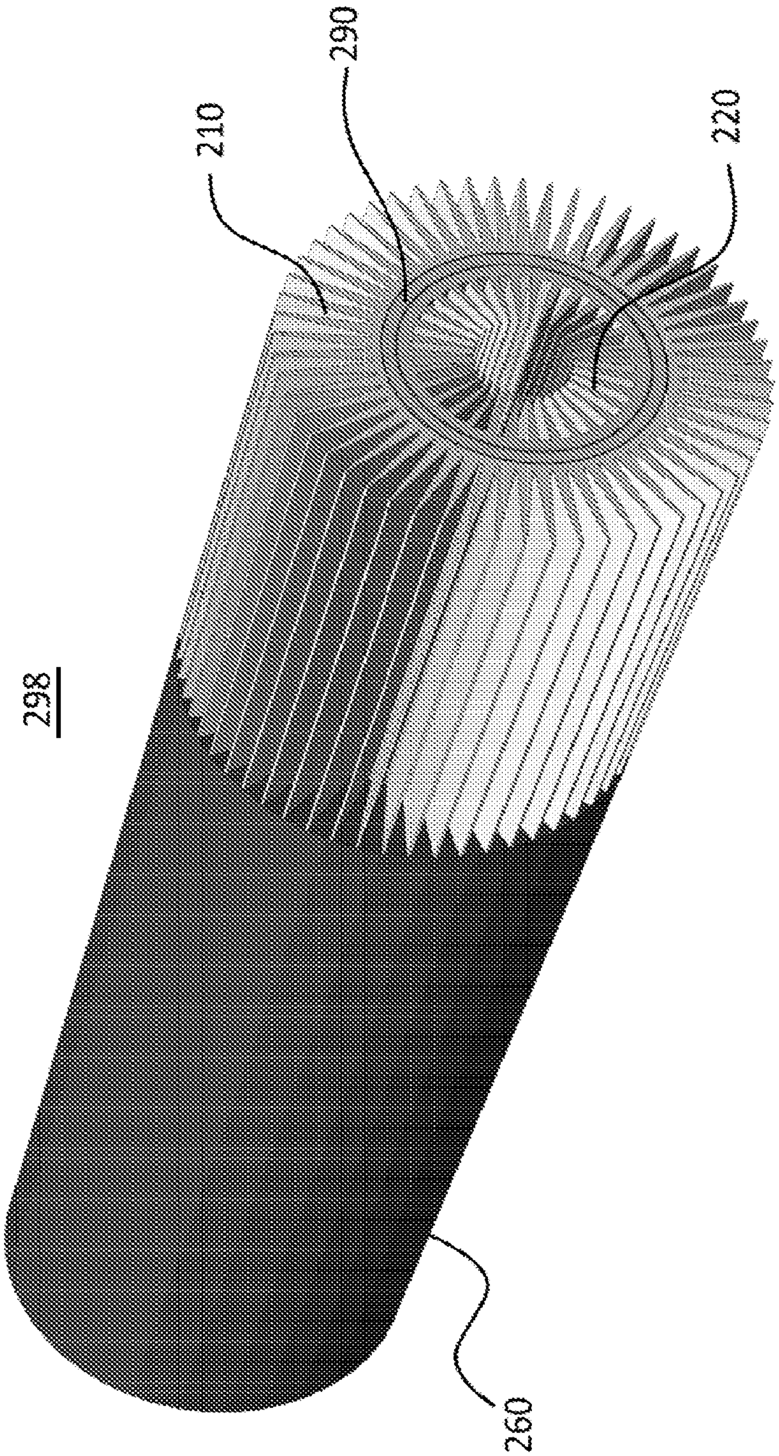



FIG. 30

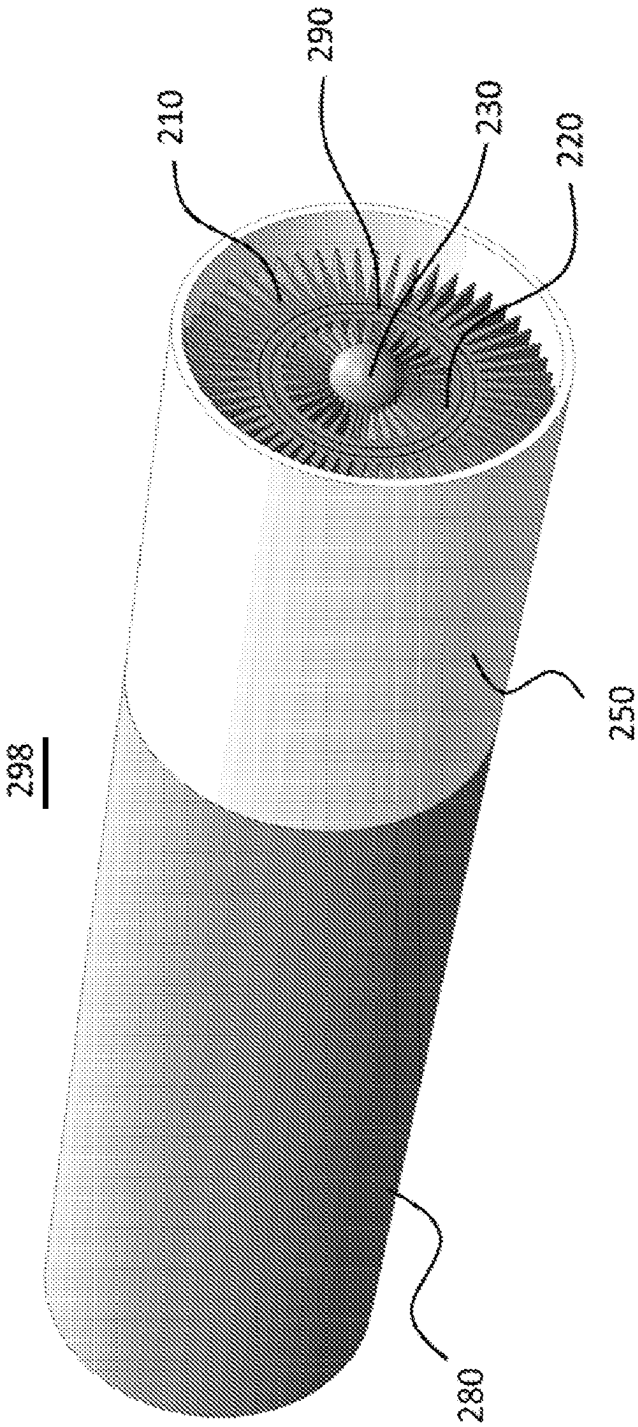



FIG. 31

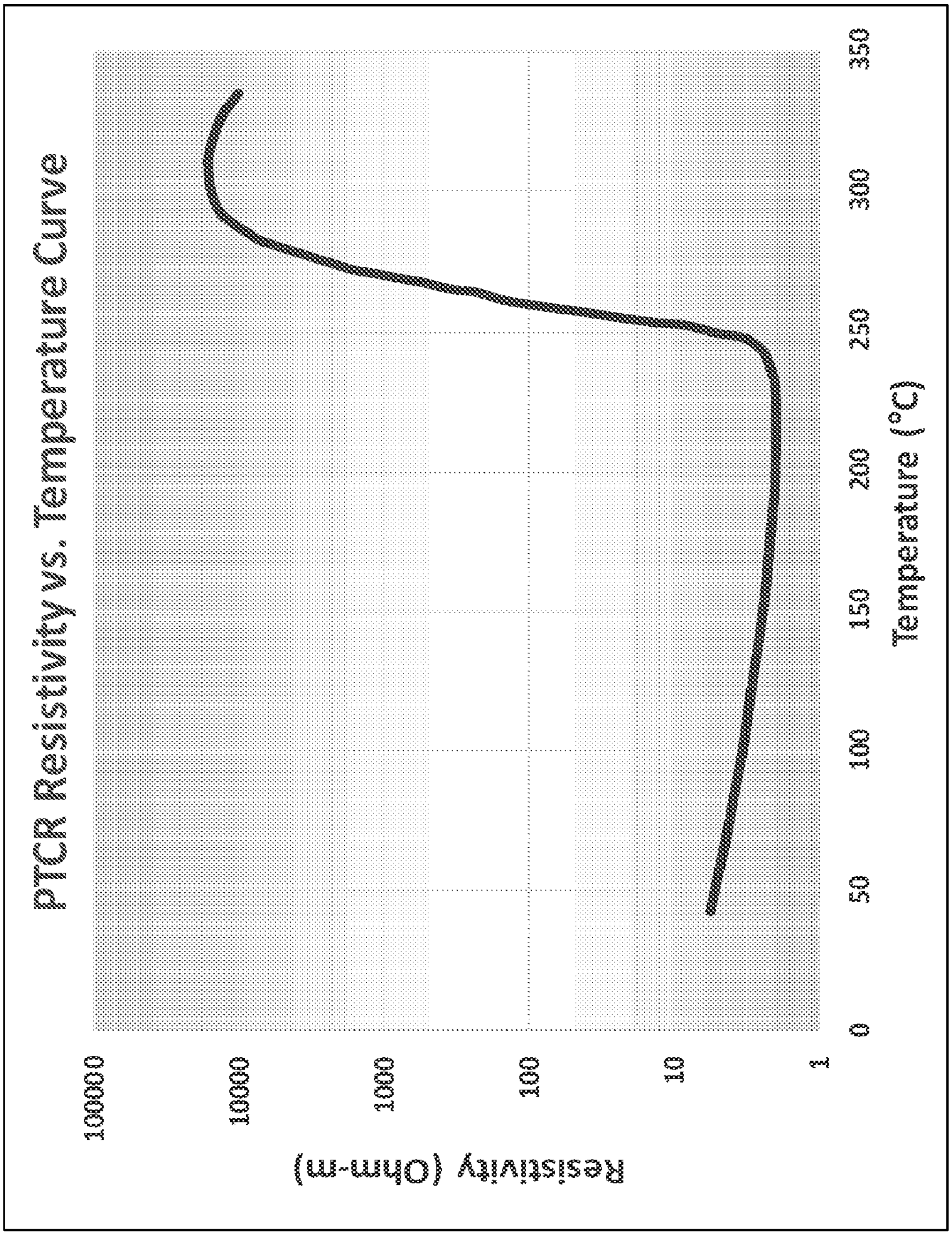

PTCR Resistivity vs. Temperature Curve
Resistivity (Ohm-m)
100000
10000
1000
100
10
1
Temperature (°C)
0
50
100
150
200
250
300
350

FIG. 32

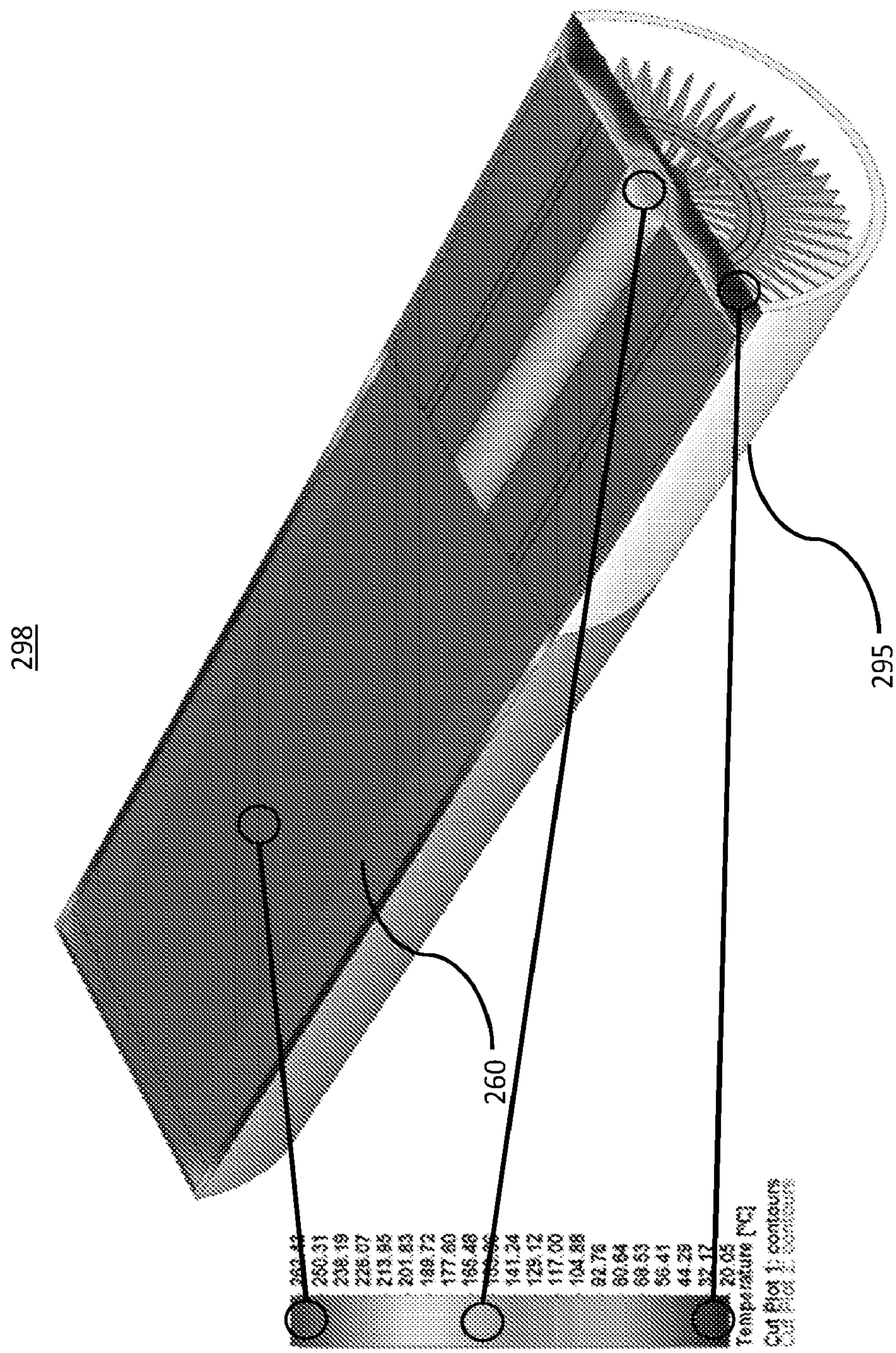

298
295
260
250.31
238.19
226.07
213.95
201.83
189.72
177.60
165.48
141.24
129.12
117.00
104.88
92.76
80.64
68.53
56.41
44.29
20.05
Temperature [°C]
Cut Plot 1: contours

FIG. 33

298

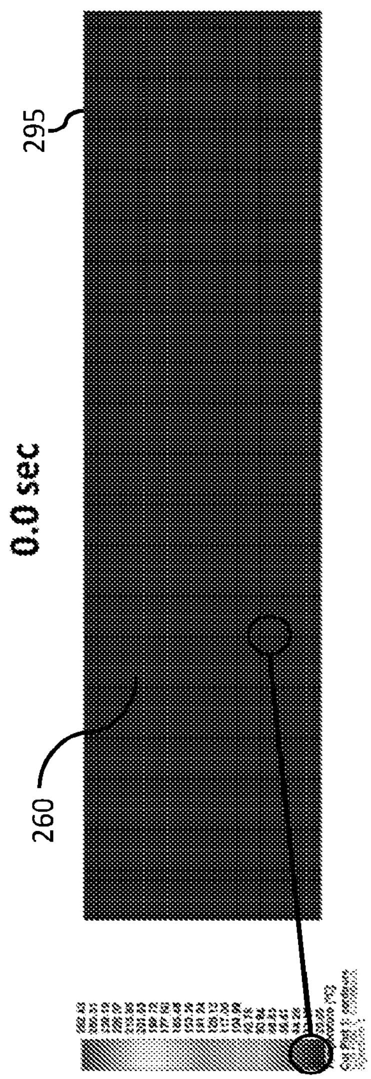



FIG. 34A

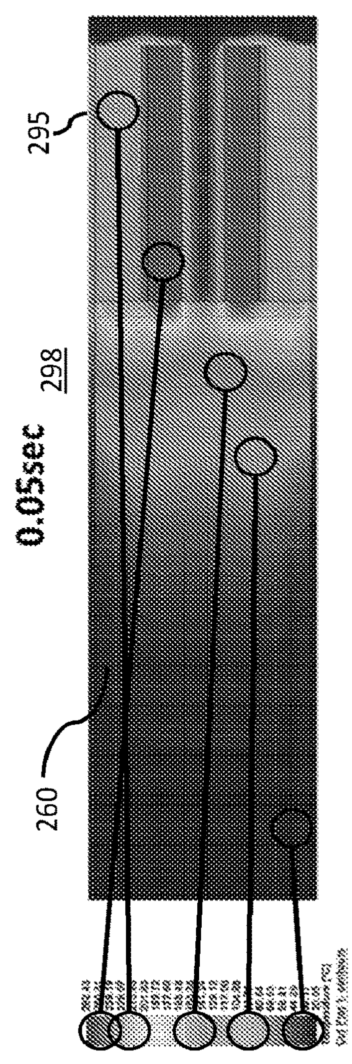



FIG. 34B

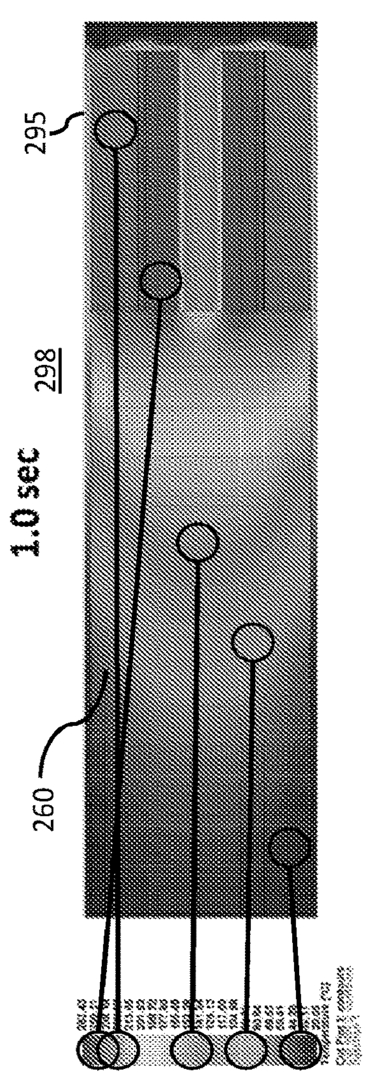



FIG. 34C

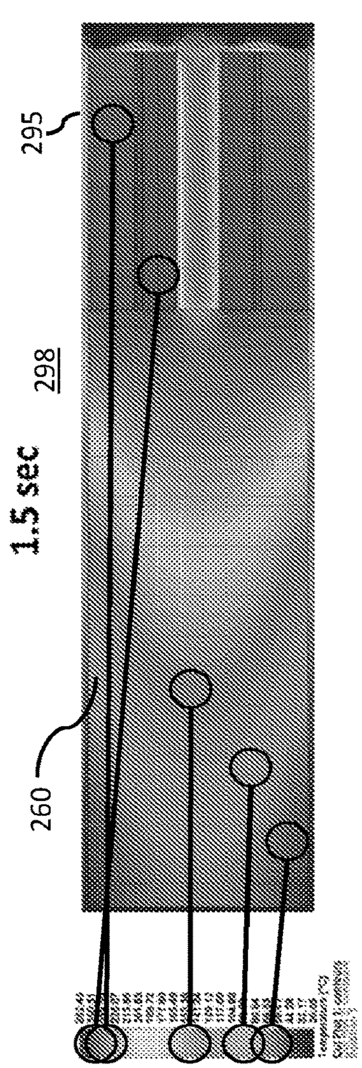



FIG. 34D

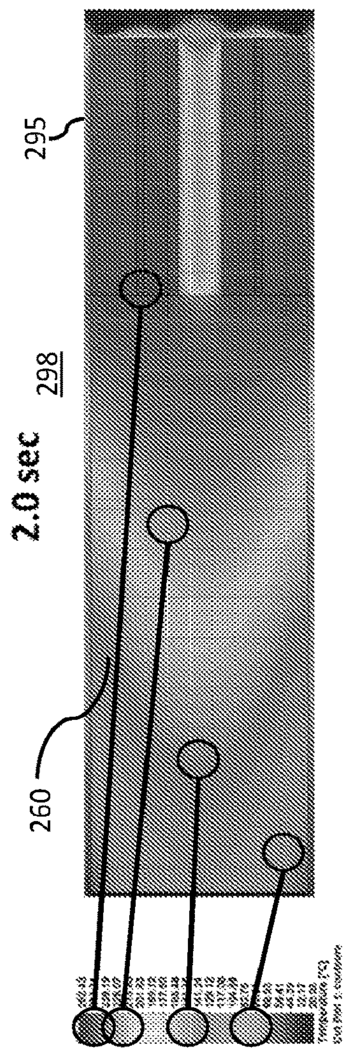


FIG. 34E

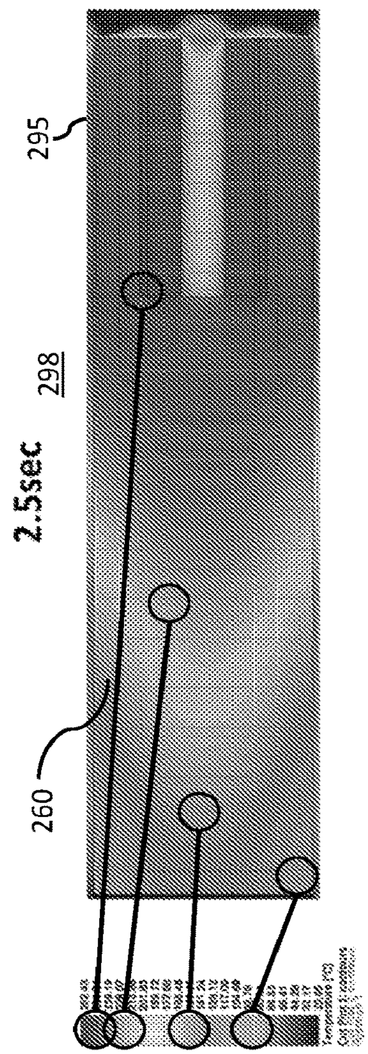


FIG. 34F

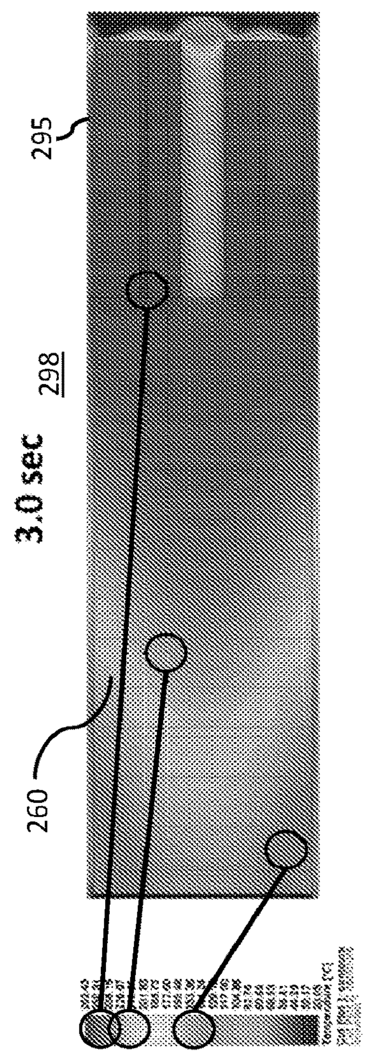


FIG. 34G

# VAPORIZER INCLUDING POSITIVE TEMPERATURE COEFFICIENT OF RESISTIVITY HEATER

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** The present application claims priority to U.S. Provisional Patent Application Ser. No. 62/791,709 filed on Jan. 11, 2019, entitled "Vaporizer Including Positive Temperature Coefficient of Resistivity Heater", and claims priority to U.S. Provisional Patent Application No. 62/816,452 filed on Mar. 11, 2019, entitled "Vaporizer Including Positive Temperature Coefficient of Resistivity Heater", and claims priority to U.S. Provisional Patent Application No. 62/898,522 filed on Sep. 10, 2019, entitled "Vaporizer Including Positive Temperature Coefficient of Resistivity Heater", and claims priority to U.S. Provisional Patent Application No. 62/959,737 filed on Jan. 10, 2020, entitled "Vaporizer Including Positive Temperature Coefficient of Resistivity Heater", all of which are hereby incorporated by reference in their entirety to the extent permitted.

## TECHNICAL FIELD

**[0002]** The subject matter described herein relates to vaporizer devices, such as portable personal vaporizer devices for generating an inhalable aerosol from one or more vaporizable materials and including a heating element utilizing semi-conductive material with nonlinear positive temperature coefficient of resistivity (PTCR).

## BACKGROUND

**[0003]** Vaporizer devices, which can also be referred to as electronic vaporizer devices or e-vaporizer devices, can be used for delivery of an aerosol (also sometimes referred to as "vapor") containing one or more active ingredients by inhalation of the aerosol by a user of the vaporizing device. Electronic cigarettes, which may also be referred to as e-cigarettes, are a class of vaporizer devices that are typically battery powered and that may be used to simulate the experience of cigarette smoking, but without burning of tobacco or other substances. In use of a vaporizer device, the user inhales an aerosol, commonly called vapor, which may be generated by a heating element that vaporizes (which generally refers to causing a liquid or solid to at least partially transition to the gas phase) a vaporizable material, which may be liquid, a solution, a solid, a wax, or any other form as may be compatible with use of a specific vaporizer device.

**[0004]** To receive the inhalable aerosol generated by a vaporizer device, a user may, in certain examples, activate the vaporizer device by taking a puff, by pressing a button, or by some other approach. A puff, as the term is generally used (and also used herein) refers to inhalation by the user in a manner that causes a volume of air to be drawn through the vaporizer device such that the inhalable aerosol is generated by combination of vaporized vaporizable material with the air. A typical approach by which a vaporizer device (e.g., which can include an air inlet, an air outlet in fluid conjunction with a mouthpiece, and with a vaporization chamber between) generates an inhalable aerosol from a vaporizable material involves heating the vaporizable material in a vaporization chamber (also sometimes referred to as a heater chamber) to cause the vaporizable material to be converted to the gas (vapor) phase. A vaporization chamber generally refers to an area or volume in the vaporizer device within which a heat source causes heating of a vaporizable material to produce a mixture of air, and the vaporizable material in some equilibrium between the gas and condensed (e.g., liquid and/or solid) phases.

**[0005]** Certain components of the gas-phase vaporizable material may condense after being vaporized due to cooling and/or changes in pressure to thereby form an aerosol that includes particles of a condensed phase (e.g., liquid and/or solid) suspended in at least some of the air drawn into the vaporizer device via the puff. If the vaporizable material includes a semi-volatile compound (e.g., a compound such as nicotine, which has a relatively low vapor pressure under inhalation temperatures and pressures), the inhalable aerosol may include that semi-volatile compound in some local equilibrium between the gas and condensed phases.

## SUMMARY

**[0006]** In an aspect, a vaporizer device includes a housing including an air inlet. The vaporizer device also includes a heating element within the housing. The heating element including a nonlinear positive temperature coefficient of resistance material. The vaporizer device also includes a heat exchanger thermally coupled to the heating element and arranged to receive an airflow from the air inlet. The heat exchanger is configured to transfer heat between the heating element and the airflow to produce a heated airflow. The heated airflow exiting the heat exchanger is configured to vaporize a vaporizable material.

**[0007]** One or more of the following features can be included in any feasible combination. For example, the heat exchanger can include a first heat exchanger thermally coupled to a first side of the heating element. The heat exchanger can include a second heat exchanger thermally coupled to a second side of the heating element. The heat exchanger can include a plurality of fin features. The heat exchanger can be made from aluminum, copper, steel, stainless steel, or titanium. The heat exchanger can be made from a thermally conductive material extrusion. The device can include a flow diverter located in a path of the airflow configured to divert a portion of the airflow through the heat exchanger. The housing can include a heater assembly cover containing the heat exchanger. The device can include a power source configured to provide electrical energy to heat the heating element. The device can include a cartridge located downstream of the heating element and oriented to receive the heated airflow, wherein downstream is with respect to the airflow. The housing can include a connector configured to couple the housing to a cartridge including a vaporizable material. The vaporizable material can be solid vaporizable material.

**[0008]** The vaporizer device can include a cartridge configured to contain a vaporizable material. The cartridge can include a first air inlet. The housing can include a connector configured to couple the housing to the cartridge. The cartridge can include a solid vaporizable material. The cartridge can include a reservoir, liquid vaporizable material within the reservoir, and a wick in fluidic communication with the liquid vaporizable material, wherein the cartridge is configured to receive the heated airflow and direct the heated airflow over the wick. The cartridge can include a mouthpiece, and the wick can be located in a path of the airflow between the heating element and the mouthpiece. The cartridge can include a second air inlet configured to draw a second airflow into the cartridge for mixing with the heated airflow and within a condensation chamber located in a path of the airflow downstream from the heat exchanger and the vaporizable material. The cartridge can include a reservoir, liquid vaporizable material within the reservoir, and a wick in fluidic communication with the liquid vaporizable material. The wick can be arranged to receive the heated airflow from the heat exchanger to produce vaporized vaporizable material in the form of a vapor and/or a first aerosol. A solid vaporizable material can be arranged to receive the vapor and/or the first aerosol and produce a second aerosol. A mouthpiece can be configured to receive the second aerosol after the vapor and/or the first aerosol passes through the solid vaporizable material.

**[0009]** The vaporizer device can include a first cartridge including the vaporizable material, a first air inlet, and a wick. The vaporizable material can be a liquid vaporizable material and the wick can be in fluidic communication with the liquid vaporizable material. The wick can be arranged to receive the heated airflow through the first air inlet from the heat exchanger to vaporize the vaporizable material to produce a vapor and/or a first aerosol. The vaporizer device can also include a second cartridge that includes a solid vaporizable material and a mouthpiece. The solid vaporizable material can be arranged to receive the vapor and/or the first aerosol to produce a second aerosol. The mouthpiece can be configured to receive the second aerosol after the vapor and/or the first aerosol passes through the solid vaporizable material. The first cartridge can be removably coupled to the housing. The second cartridge can be removably coupled to the housing and/or the first cartridge. The first cartridge and the second cartridge can be disposable cartridges. The second cartridge can include a second air inlet for mixing ambient temperature air with the vaporized vaporizable material after the vaporized vaporizable material passes through the solid vaporizable material. The device can include a fibrous body arranged to receive and cool the second aerosol after the vapor and/or the first aerosol passes through the solid vaporizable material.

**[0010]** The nonlinear positive temperature coefficient of resistance material includes an electrical resistivity transition zone in which the electrical resistivity increases over a temperature range, such that when the heating element is heated above a first temperature within the electrical resistivity transition zone, current flow from a power source is reduced to a level that limits further temperature increases of the heating element. The electrical resistivity transition zone can begin at a first temperature of between 150° C. and 350° C. The electrical resistivity transition zone can begin at a first temperature of between 220° C. and 300° C. The electrical resistivity transition zone can begin at a first temperature between 240° C. and 280° C. The increase in the electrical resistivity over the temperature range of the electrical resistivity transition zone can include an increase factor of at least 10, an increase factor of at least 100, or an increase factor of at least 1000. The increase factor characterizing a relative change in electrical resistivity between electrical resistivity at a first temperature associated with a start of the electrical resistivity transition zone and electrical resistivity at a second temperature associated with an end of the electrical resistivity transition zone. The electrical resistivity transition zone can begin at a first temperature, and the electrical resistivity of the heating element at temperatures below the first temperature can be between 0.2 ohm-cm and 200 ohm-cm, between 2.0 ohm-cm and 20 ohm-cm, or between 20 ohm-cm and 200 ohm-cm.

**[0011]** The device can include a power source configured to provide a current flow at a voltage between 3 Volts and 50 Volts to the heating element, a pressure sensor, and a controller coupled to the pressure sensor and configured to detect inhalation, and in response electrically connect the power source to the heating element. The housing can be cylindrical, the heating element can be cylindrical, and the heat exchanger can be cylindrical. The housing can also be rectangular, the heating element can also be rectangular, and the heat exchanger can also be rectangular. The power source can provide either direct current (DC) or alternating current (AC).

**[0012]** The vaporizer device can include an input configured to electrically connect the power source to the PTCR heating element (PTCR heater) in response to a user input. The input can include a pushbutton. The PTCR heating element of the vaporizer device is self-regulating to maintain a predetermined temperature when activated. The vaporizer device does not require a pressure sensor, and/or a controller coupled to the pressure sensor to electrically connect the power source to the PTCR heating element and regulate a temperature thereof.

**[0013]** A method can include receiving, by the vaporizer device, a user input; heating, using the vaporizer device, a vaporizable material; and producing an inhalable aerosol.

**[0014]** In another aspect, a PTCR heater assembly for heating an airflow of a vaporizer device includes a heater assembly cover and a heat exchanger disposed within the heater assembly cover. The heat exchanger is configured to transfer heat to the airflow. A positive temperature coefficient of resistivity (PTCR) heating element is thermally coupled to the heat exchanger. The PTCR heating element is configured to electrically couple to the power source to receive the current flow and heat the vaporizable material to form an aerosol. The PTCR heating element comprises a PTCR material having an electrical resistivity that varies based on temperature. The electrical resistivity includes an electrical resistivity transition zone in which the electrical resistivity increases over a temperature range, such that when the PTCR heating element is heated above a first temperature within the transition zone, current flow from the power source is reduced to a level that limits further temperature increases of the PTCR heating element.

**[0015]** One or more of the following features can be included in any feasible combination. For example, the heat exchanger can include a first heat exchanger thermally coupled to a first side of the heating element. The heat exchanger can include a second heat exchanger thermally coupled to a second side of the heating element. The heat exchanger can include a plurality of fin features. The heat exchanger can be made from aluminum, copper, steel, stainless steel, or titanium. The heat exchanger can be made from a thermally conductive material extrusion. The heat exchanger can be made from a metal foam, for example, an aluminum foam. The heater assembly cover can comprise a non-electrically conductive material. The heater assembly cover can comprise a non-thermally conductive material. The heater assembly cover can comprise a metal with a non-electrically conductive coating isolating the heater assembly cover from the heat exchanger. The heater assembly cover can comprise polytetrafluoroethylene (PTFE).

**[0016]** The electrical resistivity transition zone can begin at the first temperature of between 150° C. and 350° C. The electrical resistivity transition zone can also begin at the first temperature of between 220° C. and 300° C. The electrical resistivity transition zone can also begin at the first temperature between 240° C. and 280° C. The first temperature can be greater than 225° C. The PTCR heating element can be heated to an operating temperature between 240° C. and 280° C. The PTCR heating element can be heated to an operating temperature between 245° C. and 255° C. The PTCR heating element can be heated to an operating temperature of about 250° C. The PTCR heater assembly can increase in the electrical resistivity over the temperature range of the electrical resistivity transition zone by an increase factor of at least 10, of at least 100, or of at least 1000. The increase factor characterizing a relative change in electrical resistivity between electrical resistivity at the first temperature associated with a start of the electrical resistivity transition zone and electrical resistivity at a second temperature associated with an end of the electrical resistivity transition zone. The electrical resistivity transition zone can begin at the first temperature and end at a second temperature with the difference between the first temperature and the second temperature being 500° C. or less, 200° C. or less, 100° C. or less, or 50° C. or less. The electrical resistivity transition zone can begin at the first temperature and the electrical resistivity of the PTCR heating element at temperatures below the first temperature is between 0.2 ohm-cm and 2.0 ohm-cm, between 2.0 ohm-cm and 20 ohm-cm, or between 20 ohm-cm and 200 ohm-cm.

**[0017]** In another aspect, a vaporizer device for vaporizing a solid vaporizable material with a heated airflow includes a housing including an air inlet and a power source configured to provide a current flow at a voltage, and a PTCR heater assembly within the housing. The PTCR heater assembly includes a heating element within the housing and be configured to electrically couple to the power source to receive the current flow. The PTCR heating element comprises a PTCR material having an electrical resistivity that varies based on temperature. The electrical resistivity includes an electrical resistivity transition zone in which the electrical resistivity increases over a temperature range, such that when the PTCR heating element is heated above a first temperature within the transition zone, current flow from the power source is reduced to a level that limits further temperature increases of the PTCR heating element. The heater assembly also includes a heat exchanger thermally coupled to the heating element and arranged to receive airflow from the air inlet. The heat exchanger is configured to transfer heat between the heating element and the airflow to produce the heated airflow. The heated airflow exiting the heat exchanger is configured to vaporize the solid vaporizable material.

**[0018]** One or more of the following features can be included in any feasible combination. For example, the solid vaporizable material can be included with the vaporizer device. The solid vaporizable material can be a tobacco containing media. The vaporizer device can include an input configured to electrically connect the power source to the PTCR heating element in response to a user input. The input can include a pushbutton. The vaporizer device may not comprise a controller. The vaporizer device may not comprise a pressure sensor. In another aspect, the vaporizer device comprises a pressure sensor, and a controller coupled to the pressure sensor and configured to detect inhalation, and in response, electrically connect the power source to the PTCR heating element. The heat exchanger can include a first heat exchanger thermally coupled to a first side of the heating element. The heat exchanger can include a second heat exchanger thermally coupled to a second side of the heating element. The heat exchanger can include a plurality of fin features. The heat exchanger can be made from aluminum, copper, steel, stainless steel, or titanium. The heat exchanger can be made from a thermally conductive material extrusion. The heat exchanger can be made from a metal foam, for example, an aluminum foam. The PTCR heater assembly can include a heater assembly cover. The heater assembly cover can comprise a non-electrically conductive material. The heater assembly cover can comprise a non-thermally conductive material. The heater assembly cover can comprise a metal with a non-electrically conductive coating isolating the heater assembly cover from the heat exchanger. The heater assembly cover can comprise polytetrafluoroethylene (PTFE).

**[0019]** The electrical resistivity transition zone can begin at the first temperature of between 150° C. and 350° C. The electrical resistivity transition zone can also begin at the first temperature of between 220° C. and 300° C. The electrical resistivity transition zone can also begin at the first temperature between 240° C. and 280° C. The first temperature can be greater than 225° C. The PTCR heating element can be heated to an operating temperature between 240° C. and 280° C. The PTCR heating element can be heated to an operating temperature between 245° C. and 255° C. The PTCR heating element can be heated to an operating temperature of about 250° C. The PTCR heater assembly can increase in the electrical resistivity over the temperature range of the electrical resistivity transition zone by an increase factor of at least 10, an increase factor of at least 100, or an increase factor of at least 1000. The increase factor characterizing a relative change in electrical resistivity between electrical resistivity at the first temperature associated with a start of the electrical resistivity transition zone and electrical resistivity at a second temperature associated with an end of the electrical resistivity transition zone. The electrical resistivity transition zone can begin at the first temperature and end at a second temperature with the difference between the first temperature and the second temperature being 500° C. or less, 200° C. or less, 100° C. or less, or 50° C. or less. The electrical resistivity transition zone can begin at the first temperature and the electrical resistivity of the PTCR heating element at temperatures below the first temperature is between 0.2 ohm-cm and 2.0 ohm-cm, between 2.0 ohm-cm and 20 ohm-cm, or between 20 ohm-cm and 200 ohm-cm.

**[0020]** In another aspect, a method of vaporizing a vaporizable material includes receiving, by a vaporizer device, a user input, and heating an airflow to produce a heated airflow using a PTCR heater assembly including a heat exchanger thermally coupled to a PTCR heating element. The PTCR heating element configured to electrically couple to a power source. The PTCR heating element includes an electrical resistivity that varies based on temperature. The electrical resistivity includes an electrical resistivity transition zone including an increase in electrical resistivity over a temperature range from a first temperature to a second temperature such that, when the PTCR heating element is heated between the first temperature and the second temperature, current flow from the power source is reduced to a level that limits further temperature increases of the PTCR heating element from current flow. The method also includes vaporizing the vaporizable material with the heated airflow. The vaporizable material can comprise nicotine.

**[0021]** The details of one or more variations of the subject matter described herein are set forth in the accompanying drawings and the description below. Other features and advantages of the subject matter described herein will be apparent from the description and drawings, and from the claims.

## DESCRIPTION OF THE DRAWINGS

**[0022]** FIG. **1** illustrates the behavior of thermal power generation within an isotropic PTCR material;

**[0023]** FIG. **2** is a block diagram illustrating an example vaporizer device according to some implementations of the current subject matter that can provide for uniform heating of vaporizable material utilizing convective heating;

**[0024]** FIG. **3** is a block diagram of an example vaporizer device and cartridge with liquid vaporizable material that can provide for uniform heating of vaporizable material utilizing convective heating;

**[0025]** FIG. **4** is a cross section view of an example vaporizer device with liquid vaporizable material;

**[0026]** FIG. **5** is a cross section view of an example vaporizer device with solid vaporizable material (e.g., heat-not-burn product);

**[0027]** FIG. **6** is a block diagram of an example vaporizer device and cartridge with liquid vaporizable material and solid vaporizable material that can provide for uniform heating of vaporizable material utilizing convective heating;

**[0028]** FIG. **7** is a block diagram of an example vaporizer device with multiple cartridges;

**[0029]** FIG. **8** is a cross section view of an example vaporizer device with both liquid vaporizable material and solid vaporizable material;

**[0030]** FIG. **9** is a plot illustrating an example resistivity vs. temperature curve for a nonlinear positive temperature coefficient of resistivity (PTCR) material;

**[0031]** FIG. **10** presents a table of resistivity vs. temperature curve data for the nonlinear PTCR semiconducting material illustrated in FIG. **9**;

**[0032]** FIG. **11** is a plot illustrating an example resistivity vs. temperature curve for a nonlinear positive temperature coefficient of resistivity (PTCR) material;

**[0033]** FIG. **12**A is a diagram illustrating an example PTCR heating element that can enable improved vaporizer heating;

**[0034]** FIG. **12**B is a cross section of the example PTCR heating element illustrated in FIG. **9**A;

**[0035]** FIG. **13**A-FIG. **13**E illustrate modeled temperatures of the example PTCR heater;

**[0036]** FIG. **14**A-FIG. **14**F illustrate modeled temperatures of an example PTCR heater;

**[0037]** FIG. **15** illustrates modeled temperatures of an example heater 6.0 seconds after application of a voltage in a free convective state;

**[0038]** FIG. **16**A illustrates a modeled surface temperature as a function of time for an example heater;

**[0039]** FIG. **16**B illustrates a modeled and measured maximum surface temperatures as a function of time of an example heater;

**[0040]** FIG. **16**C illustrates a modeled and measured average surface temperatures as a function of time of an example heater;

**[0041]** FIG. **17** illustrates a transient current response as a function of time for an example heater;

**[0042]** FIG. **18** is a perspective view of an example vaporizer assembly including a PTCR heater and heat exchanger elements that can enable convective heating and improved uniform heating of vaporizable materials;

**[0043]** FIG. **19** is an exploded view of a rectangular PTCR vaporization device including an exploded view of the example vaporizer assembly;

**[0044]** FIG. **20** is a perspective view of an example PTCR vaporization assembly;

**[0045]** FIG. **21** is a perspective, transparent view of an example PTCR vaporization assembly and disposable rectangular product;

**[0046]** FIG. **22** is a perspective, transparent view of an example PTCR vaporization assembly and disposable rectangular product 0.2 seconds after activation;

**[0047]** FIG. **23** is a perspective, transparent view of an example PTCR vaporization assembly and disposable rectangular product 0.5 seconds after activation;

**[0048]** FIG. **24** is a perspective, transparent view of an example PTCR vaporization assembly and disposable rectangular product 1.0 seconds after activation;

**[0049]** FIG. **25** is a perspective, transparent view of an example PTCR vaporization assembly and disposable rectangular product 2.0 seconds after activation;

**[0050]** FIG. **26** is a perspective, transparent view of an example PTCR vaporization assembly and disposable rectangular product 3.0 seconds after activation;

**[0051]** FIG. **27** is a perspective view of an example PTCR heater with cylindrical geometry;

**[0052]** FIG. **28** is an exploded view illustrating a cylindrical example PTCR heater;

**[0053]** FIG. **29** is a perspective view of the example assembled PTCR heater;

**[0054]** FIG. **30** is a perspective view of the example PTCR vaporization device with external covers and cylindrical flow diverter removed;

**[0055]** FIG. **31** is a perspective view of the example PTCR vaporization device;

**[0056]** FIG. **32** is a plot of the logarithm of resistivity of a cylindrical example vaporization device with PTCR heater as a function of temperature;

**[0057]** FIG. **33** is a cross sectional plot showing temperature simulations of the example implementation of the cylindrical vaporization device with PTCR heater; and

**[0058]** FIGS. **34**A-**34**G are cut plots showing transient response of temperature as color for an example implementation of the cylindrical vaporization device with PTCR heater.

**[0059]** Like reference symbols in the figures indicate like elements when possible.

## DETAILED DESCRIPTION

**[0060]** Some aspects of the current subject matter relate to a vaporizer heater that utilizes a nonlinear positive temperature coefficient of resistivity (PTCR) heating element, also referred to as a PTCR heater, for use as a convective heater. In such a convective heater for a vaporizer, air is heated by the heating element and passed over or through a vaporizable material to form a vapor and/or aerosol for inhalation.

In implementations, the vaporizable material may include a solid vaporizable material (e.g., loose-leaf materials commonly utilized in heat-not-burn (HNB) vaporizers) and/or a liquid vaporizable material (e.g., pre-filled cartridges, pods, and the like). A PTCR heating element used for convective heating can enable more uniform heating of the vaporizable material. Improved uniformity in heating can provide a number of advantages, including avoiding differential temperature within vaporizable materials that act as an insulator, prevention of contamination of the heating element, and the like. And because the heating element can be formed from PTCR material, the heating element can be temperature self-limiting and, given a known range of applied voltages, will not heat beyond a specific temperature, thereby avoiding formation of unwanted, and potentially dangerous, chemical byproducts.

**[0061]** The thermal power generation within an isotropic PTCR material can be characterized such that, for every control volume $\partial x$, $\partial y$, $\partial z$ within an isotropic PTCR material subject to a voltage gradient $\nabla V$, the control volume $\partial x$, $\partial y$, $\partial z$ will heat to a temperature within the PTCR transition zone and hold that temperature within a wide range of $\nabla V$ as illustrated in FIG. 1A. Thermal power generation can be expressed as:

$$P = \int_{vol} \frac{(\nabla V)^2}{\rho} dvol,$$

where P is thermal power generation, vol is the control volume (e.g., $\partial x$, $\partial y$, $\partial z$), and $\rho$ is resistivity.

**[0062]** By utilizing a PTCR heating element some implementations can enable temperature to be controlled over a range of applied voltages and without the need for temperature sensors, electronic circuitry, microprocessors and/or algorithms providing power control to the heating element.

**[0063]** As used herein, the term solid vaporizable material generally refers to vaporizable material that includes solid materials. For example, some vaporizer devices heat materials having origin as plant leaves or other plant components in order to extract plant specific flavor aromatics and other products as vapor. These plant materials may be chopped and blended into a homogenized construct with a variety of plant products that may include tobacco, in which case nicotine and/or nicotine compounds may be produced and delivered in aerosol form to the user of such a vaporizer device. The homogenized construct may also include vaporizable liquids such as propylene glycol and glycerol in order to enhance the vapor density and aerosol produced when heated. In order to avoid production of unwanted harmful or potentially harmful constituents (HPHCs) vaporizer devices of this type benefit from heaters having temperature control means. Such vaporizer devices that heat plant leaves or homogenized construct as described above such that temperatures are kept below combustion levels are generally referred to as heat not burn (HNB) devices.

**[0064]** As used herein, the term liquid vaporizable material generally refers to vaporizable material without solid materials. The liquid vaporizable material can include, for example, a liquid, a solution, a wax, or any other form as may be compatible with use of a specific vaporizer device. In implementations, a liquid vaporizable material can include any form suitable to utilize a wick or wicking element to draw the vaporizable material into a vaporization chamber. The liquid vaporizable material can include a component of plant origin, such as nicotine and/or a nicotine compound. The liquid vaporizable material can include vaporizable liquids such as propylene glycol and glycerol.

**[0065]** Vaporizer devices operate by heating the vaporizable material to an appropriate temperature to create an aerosol but without burning or charring of the vaporizable material. One class vaporizer device is more sophisticated in that it utilizes relatively tight temperature control in order to prevent overheating and the related formation of HPHCs. Such sophistication, typically requiring electronic circuitry including a microprocessor, is typically difficult in HNB devices because of the inherent non-uniformity and related spatially inconsistent thermal properties of the vaporizable materials to be heated. This results in over temperature regions and potential HPHC production. And some existing solution fail to control local temperatures within vaporizer devices, resulting in a high probability of producing vaporizable material over temperature regions and HPHCs.

**[0066]** Another class of vaporizer device is simpler in that no means of temperature control is provided, such that the construction of the vaporizer device may be less expensive but includes a danger of overheating and thereby causing unwanted chemical byproducts.

**[0067]** In HNB vaporizer devices (e.g., where the vaporizable material is solid), some existing methods lack the ability to impose uniform temperatures for one or more of the following reasons. For example, to-be-heated solid vaporizable materials have low thermal diffusivity such that diffusion of high temperatures from a heating element into the solid vaporizable materials can be both slow and result in high thermal gradients. As a result, non-uniform heating can be an unavoidable consequence. As another example, if heating element temperature control is employed, the heating element temperature control typically addresses an average temperature such that heating of non-uniform solid vaporizable material via high temperatures within the heating element can result in high temperatures within the solid vaporizable materials. As yet another example, in order to allow for heating of the insulative materials, some existing HNB devices require preheating times that may equal or exceed 30 seconds with accompanying cost in both energy consumption, battery drain, and user inconvenience.

**[0068]** In vaporizer devices where fluids are vaporized by causing a heating element to come into contact with the fluids to be vaporized, contamination of the heating element can occur leading to potential for compromising performance. A solution to this problem can be to incorporate the heating element into a disposable part of the vaporizer such that the heating element is replaced with each new disposable part and thereby limiting, but not eliminating, heating element contamination.

**[0069]** To overcome the difficulty of uniform heating of vaporizable materials, some implementations of the current subject matter can provide for the preheating of air using one or a plurality of PTCR heating elements in conjunction with a heat exchanger. As a user draws air into a vaporizer device, the incoming airflow is heated to a controlled temperature as it passes over the heat exchanger and then passes through or over the to-be-heated vaporizable material. The vaporizable material can be a solid material (e.g., as in a HNB material) or a liquid (e.g., fluid with a porous wick). In implementations, the airflow can pass over the heat exchanger and then pass over and/or through a porous wick saturated with liquid vaporizable material, then through a solid vaporizable material (e.g., a HNB material), and then to the user. In implementations, geometry for influx of cooling air may be included between the wick and the user, for example, a balanced air inlet (i.e. a second air inlet). In addition, the current subject matter can provide for a PTCR heater having intrinsic temperature control such, for a given range of supply voltage (which can be variable by a factor of ten or more in some implementations), a designed peak temperature will not be exceeded. Such an approach can result in improved uniform heating of vaporizable material as compared to some conventional approaches.

**[0070]** In addition, using this convective heating approach, the PTCR heating element can be placed upstream of the wick, fluid container, and/or vaporizable material, such that the PTCR heating element is completely removed from any disposable part of the mechanism. By including the PTCR heating element in a non-disposable portion of the vaporizer device, unnecessary waste can be avoided.

**[0071]** FIG. **2** is a block diagram illustrating an example vaporizer device **100** according to some implementations of the current subject matter that can provide for uniform heating of vaporizable material utilizing convective heating. The example vaporizer device **100** includes an air inlet **105**, a PTCR heater with heat exchanger **110**, and a power source **115**, such as a battery, capacitor, and/or the like. The example vaporizer device **100** can include a housing **120**, which can couple to one or more of the PTCR heater with heat exchanger **110** and power source **115**. In implementations, the example vaporizer device **100** can include an optional controller **102** and an optional pressure sensor **107**. In implementations, the housing **120** can define the air inlet **105**.

**[0072]** The PTCR heater with heat exchanger **110** can include a heating element formed of PTCR material, which is described in more detail below. The heat exchanger can be thermally coupled to the heating element and can be configured to transfer heat between the heating element and airflow that passes over and/or through the PTCR heater with heat exchanger **110** to produce a heated airflow. The PTCR heater with heat exchanger **110** can include multiple heat exchangers, for example, coupled to different sides of the heating element and can include a flow diverter for diverting the airflow through and/or over fins of the heat exchanger to improve heat transfer. A more detailed discussion of example PTCR heaters with heat exchanger **110** is found below with reference to FIGS. **9-34**G.

**[0073]** The example vaporizer device **100** can include a connector **117** (shown in FIGS. **4**, **5**, and **8**) for coupling the housing **120** to one or more cartridges **125** that include a vaporizable material **130**. In implementations, the cartridge **125** can include a mouthpiece **135**. In implementations, the coupling is removable such that the cartridge **125** can be coupled and decoupled from the vaporizer device **100** via connector **117** easily and by a user.

**[0074]** When the vaporizer device **100** is coupled to the cartridge **125**, the vaporizer device **100** and cartridge **125** can be arranged to define an airflow path from the air inlet **105**, through and/or over the PTCR heater with heat exchanger **110**, through a first air inlet of the cartridge, through the vaporizable material **130**, and out the mouthpiece **135**.

**[0075]** The optional controller **102** (e.g., a processor, circuitry, etc., capable of executing logic) is for controlling delivery of heat to cause a vaporizable material to be converted from a condensed form (e.g., a solid, a liquid, a solution, a suspension, a part of an at least partially unprocessed plant material, etc.) to the gas phase. The optional controller may be part of one or more printed circuit boards (PCBs) consistent with certain implementations of the current subject matter.

**[0076]** Power source **115** can include any source suitable for applying electrical power to the PTCR heater with heat exchanger **110**. For example, the power source **115** can include a batter, a capacitor (even with resistor-capacitor (RC) decay), and/or the like. In implementations, the power source **115** can provide a voltage, which can be chosen from a wide range of voltages. For example, in some implementations, the power source **115** can provide a voltage between 3 volts and 50 volts or more. In implementations, voltage supplied to the PTCR heater with heat exchanger **110** can vary by an order of magnitude with little effect on the PTCR heater with heat exchanger **110** performance. In implementations, the power source **115** can include multiple power sources, which can be selected based on operating conditions and/or desired vaporizer device performance.

**[0077]** In operation, a user can draw air through the mouthpiece **135** (e.g., puff), which can be detected by the optional controller **102** using the optional pressure sensor **107**. In response to detecting a puff, the optional controller **102** can cause application of current from the power source **115** to the PTCR heater with heat exchanger **110**, thereby causing the PTCR heater with heat exchanger **110** to warm. Because the PTCR heater with heat exchanger **110** is formed of PTCR material, heating will be self-limiting and the heating element will not overheat.

**[0078]** The airflow passes through the air inlet **105** and over and/or through the PTCR heater with heat exchanger **110**, causing air in the airflow to uniformly heat. The heated airflow continues on to the vaporizable material **130** causing the vaporizable material **130** to also uniformly heat and to form a vapor (gas). The vaporizable material **130** can include a liquid, a solution, a solid, a wax, or any other form. In implementations, incoming air passing along the airflow path passes over, through, and the like, a region or chamber (e.g., an atomizer), where gas phase vaporizable material is entrained into the air.

**[0079]** The entrained gas-phase vaporizable material may condense as it passes through the remainder of the airflow path such that an inhalable dose of the vaporizable material in an aerosol form can be delivered to mouthpiece **135** for inhalation by the user in the form of a vapor and/or aerosol. In implementations, cartridge **125** includes a balanced air inlet (i.e. a second air inlet) **140** that can serve to provide ambient temperature air for mixing with the heated airflow entering the cartridge through a first air inlet. The ambient temperature air can be mixed with the heated airflow in a condensation chamber. The balanced air inlet **140** is positioned after the heated airflow passes through the vaporizable material (e.g., downstream from the heat exchanger and the vaporizable material), thereby cooling the heated airflow prior to inhalation by the user. In implementations, the balanced air inlet **140** is integrated with mouthpiece **135**.

**[0080]** Activation of the PTCR heating element may be caused by automatic detection of the puff based on one or more of signals generated by one or more sensors, such as optional pressure sensor **107** or sensors disposed to detect pressure along the airflow path relative to ambient pressure (or optionally to measure changes in absolute pressure), one or more motion sensors of the vaporizer, one or more flow sensors of the vaporizer, a capacitive lip sensor of the vaporizer; in response to detection of interaction of a user with one or more input devices (e.g., buttons or other tactile control devices of the vaporizer such as a manual toggle switch, pushbutton switch, pressure switch, and the like), receipt of signals from a computing device in communication with the vaporizer; and/or via other approaches for determining that a puff is occurring or imminent.

**[0081]** As alluded to in the previous paragraph, a vaporizer consistent with implementations of the current subject matter may be configured to connect (e.g., wirelessly or via a wired connection) to a computing device (or optionally two or more devices) in communication with the vaporizer. To this end, the optional controller **102** may include communication hardware. The optional controller **102** may also include a memory. A computing device can be a component of a vaporizer system that also includes the vaporizer, and can include its own communication hardware, which can establish a wireless communication channel with the communication hardware of the vaporizer. For example, a computing device used as part of a vaporizer system may include a general purpose computing device (e.g., a smartphone, a tablet, a personal computer, some other portable device such as a smartwatch, or the like) that executes software to produce a user interface for enabling a user of the device to interact with a vaporizer. In other implementations of the current subject matter, such a device used as part of a vaporizer system can be a dedicated piece of hardware such as a remote control or other wireless or wired device having one or more physical or soft (e.g., configurable on a screen or other display device and selectable via user interaction with a touch-sensitive screen or some other input device like a mouse, pointer, trackball, cursor buttons, or the like) interface controls. The vaporizer can also include one or more output features or devices for providing information to the user.

**[0082]** A computing device that is part of a vaporizer system as defined above can be used for any of one or more functions, such as controlling dosing (e.g., dose monitoring, dose setting, dose limiting, user tracking, etc.), controlling sessioning (e.g., session monitoring, session setting, session limiting, user tracking, and the like), controlling nicotine delivery (e.g., switching between nicotine and non-nicotine vaporizable material, adjusting an amount of nicotine delivered, and the like), obtaining locational information (e.g., location of other users, retailer/commercial venue locations, vaping locations, relative or absolute location of the vaporizer itself, and the like), vaporizer personalization (e.g., naming the vaporizer, locking/password protecting the vaporizer, adjusting one or more parental controls, associating the vaporizer with a user group, registering the vaporizer with a manufacturer or warranty maintenance organization, and the like), engaging in social activities (e.g., games, social media communications, interacting with one or more groups, and the like) with other users, or the like. The terms "sessioning", "session", "vaporizer session," or "vapor session," are used generically to refer to a period devoted to the use of the vaporizer. The period can include a time period, a number of doses, an amount of vaporizable material, and/or the like.

**[0083]** In the example in which a computing device provides signals related to activation of the PTCR heating element, or in other examples of coupling of a computing device with a vaporizer for implementation of various control or other functions, the computing device executes one or more computer instructions sets to provide a user interface and underlying data handling. In one example, detection by the computing device of user interaction with one or more user interface elements can cause the computing device to signal the vaporizer to activate the PTCR heating element to a full operating temperature for creation of an inhalable dose of vapor/aerosol. Other functions of the vaporizer may be controlled by interaction of a user with a user interface on a computing device in communication with the vaporizer.

**[0084]** The temperature of a PTCR heating element of a vaporizer may depend on a number of factors, including conductive heat transfer to other parts of the electronic vaporizer and/or to the environment, latent heat losses due to vaporization of a vaporizable material from the wicking element and/or the atomizer as a whole, and convective heat losses due to airflow (e.g., air moving across the heating element or the atomizer as a whole when a user inhales on the electronic vaporizer). As noted above, to reliably activate the PTCR heating element or heat the PTCR heating element to a desired temperature, a vaporizer may, in some implementations of the current subject matter, make use of signals from optional pressure sensor **107** to determine when a user is inhaling. The optional pressure sensor **107** can be positioned in the airflow path and/or can be connected (e.g., by a passageway or other path) to an airflow path connecting air inlet **105** for air to enter the device and an outlet (e.g., in mouthpiece **135**) via which the user inhales the resulting vapor and/or aerosol such that the optional pressure sensor experiences pressure changes concurrently with air passing through the vaporizer device from the air inlet **105** to the air outlet. In implementations of the current subject matter, the PTCR heating element may be optionally activated in association with a user's puff, for example by automatic detection of the puff, for example by the optional pressure sensor **107** detecting a pressure change in the airflow path. In implementations, a switch is an input device that may be used to electrically complete a circuit between the power source and the PTCR heating element. In implementations, an input device that includes a relay, a solenoid, and/or a solid-state device that may be used to electrically complete a circuit between the power source and the PTCR heating element to activate the vaporizer device.

**[0085]** Typically, the optional pressure sensor **107** (as well as any other sensors) can be positioned on or coupled (e.g., electrically or electronically connected, either physically or via a wireless connection) to the optional controller **102** (e.g., a printed circuit board assembly or other type of circuit board). To take measurements accurately and maintain durability of the vaporizer, it can be beneficial to provide a resilient seal to separate an airflow path from other parts of the vaporizer. The seal, which can be a gasket, may be configured to at least partially surround the optional pressure sensor **107** such that connections of the optional pressure sensor **107** to internal circuitry of the vaporizer are separated from a part of the optional pressure sensor **107** exposed to the airflow path. In an example of a cartridge-based vaporizer, the seal or gasket may also separate parts of one or more electrical connections between a vaporizer body and a vaporizer cartridge. Such arrangements of a gasket or seal in a vaporizer can be helpful in mitigating against potentially disruptive impacts on vaporizer components resulting from interactions with environmental factors such as water in the vapor or liquid phases, other fluids such as the vaporizable material, etc., and/or to reduce escape of air from the designed airflow path in the vaporizer. Unwanted air, liquid or other fluid passing and/or contacting circuitry of the vaporizer can cause various unwanted effects, such as alter pressure readings, and/or can result in the buildup of unwanted material, such as moisture, the vaporizable material, etc., in parts of the vaporizer where they may result in poor pressure signal, degradation of the optional pressure sensor or other components, and/or a shorter life of the vaporizer. Leaks in the seal or gasket can also result in a user inhaling air that has passed over parts of the vaporizer device containing or constructed of materials that may not be desirable to be inhaled.

**[0086]** In implementations, the cartridge **125** can include a fibrous body for cooling the heated airflow after it passes through the vaporizable material **130**.

**[0087]** As noted above, the vaporizable material **130** can include solid vaporizable material (e.g., HNB materials) and/or liquid vaporizable material (e.g., a liquid, a solution, and the like). FIG. **3** is a block diagram of an example vaporizer device **100** and cartridge **125** with liquid vaporizable material that can provide for uniform heating of vaporizable material utilizing convective heating. The vaporizable material **130** includes an atomizer including a porous wick **150** in fluidic communication with a fluid tank or reservoir **145**. The porous wick **150** is located within the path of the heated airflow between the PTCR heater with heat exchanger **110** and the mouthpiece **135**. The porous wick **150** is located such that, in operation, heated airflow passes over and/or through the porous wick **150**, which is saturated with the vaporizable fluid, causing vaporization of the liquid vaporizable material saturating the porous wick **150** thereby forming a vapor and/or aerosol. In implementations, the porous wick **150** may allow air to enter the reservoir **145** to replace the volume of liquid removed. In other words, capillary action pulls liquid vaporizable material into the wick **150** for vaporization by the heated airflow, and air may, in some implementations of the current subject matter, return to the reservoir **145** through the wick to at least partially equalize pressure in the reservoir **145**. Other approaches to allowing air back into the reservoir **145** to equalize pressure are also within the scope of the current subject matter. FIG. **4** is a cross section view of an example vaporizer device with liquid vaporizable material and FIG. **5** is a cross section view of an example vaporizer device with solid vaporizable material (e.g., HNB product).

**[0088]** In implementations, the vaporizable material **130** can include both a liquid vaporizable material and a solid vaporizable material. For example, FIG. **6** is a block diagram of an example vaporizer device **100** and cartridge **125** with liquid vaporizable material and solid vaporizable material that can provide for uniform heating of vaporizable material utilizing convective heating. The vaporizable material **130** includes a reservoir **145** containing liquid vaporizable material within the reservoir **145**, a wick **150** in fluidic communication with the liquid vaporizable material, and a solid vaporizable material **155** located downstream (with respect to airflow) of the porous wick **150**. The porous wick **150** is arranged to receive the heated airflow from the heater with heat exchanger **110** to vaporize the vaporizable material to produce a vapor and/or a first aerosol. The solid vaporizable material **155** is arranged to receive the vapor and/or the first aerosol from the wick and to produces second aerosol. The mouthpiece **135** is configured to receive the second aerosol after the vaporized vaporizable material passes through the solid vaporizable material **155**. By combining both liquid vaporizable material and solid vaporizable material, improved flavoring can be achieved. In addition, by utilizing convective heating via PTCR material for vaporizing both liquid vaporizable material and solid vaporizable material, only a single heater is required to heat both materials.

**[0089]** In implementations, the liquid vaporizable material and the solid vaporizable material can be included in different cartridges. For example, FIG. **7** is a block diagram of an example vaporizer device **100** with multiple cartridges. A first cartridge **605** includes liquid vaporizable material (including reservoir **145** and porous wick **150**) and a second cartridge **610** includes solid vaporizable material **130** that can provide for uniform heating of vaporizable material utilizing convective heating. The first cartridge **605** can removably couple to the vaporizer device **100** and the second cartridge **610** can removably couple to the first cartridge **605**. As illustrated, the first cartridge **605** includes the reservoir **145** (e.g., tank), liquid vaporizable material within the reservoir **145**, and the wick **150** in fluidic communication with the liquid vaporizable material. When the first cartridge **605** is coupled to the vaporizer device **100**, the wick **150** is arranged to receive the heated airflow from the heater with heat exchanger **110** to vaporize the vaporizable material to produce a vapor and/or a first aerosol. The second cartridge **610** includes the solid vaporizable material **130**, balanced air inlet **140**, and mouthpiece **135**. When the second cartridge **610** is coupled to the first cartridge, the solid vaporizable material **130** is arranged to receive the vapor and/or the first aerosol from the wick **150** and to produce a second aerosol. The mouthpiece **135** is configured to receive the second aerosol after the vapor and/or the first aerosol passes through the solid vaporizable material **155**. In implementations, the balanced air inlet (i.e. the second air inlet) **140** can provide ambient temperature air for cooling the heated second aerosol having passed through the solid vaporizable material **155**. FIG. **8** is a cross section view of an example vaporizer device with both liquid vaporizable material and solid vaporizable material.

**[0090]** This convective heating approach can provide several advantages for vaporizing solid materials (e.g., HNB materials), as compared to conventional conductive heating approaches. For example, instead of poor conduction into insulative material (e.g., solid vaporizable material) in a direction normal to airflow, producing volatiles and differential porosity of the to-be-heated vaporizable material, some implementations of the current subject matter can provide incoming preheated air that enters the vaporizable material uniformly as a wave uniformly covering the cross-section of the vaporizable material. Volatiles are then released, coincident with increase in porosity, in a direction parallel to the flow of heated air. As another example, because of the cross-sectional uniform release of volatiles and coincident increase of porosity, the problem of differential flow path can be eliminated in some implementations. As yet another example, the problem of deteriorating conductive heat transfer through the product can be removed in some implementations of the current subject matter. As yet another example, some implementations of the current subject matter can eliminate a previously required preheating period, such that the current subject matter may provide aerosol on-demand from heated vaporizable material.

**[0091]** Similarly, this convective heating approach can provide several advantages for vaporizing liquid vaporizable materials. For example, instead of applying heat directly to the liquid vaporizable material using a heater element in direct contact with the liquid vaporizable material, some implementations of the current subject matter can provide incoming preheated air as a wave uniformly covering the cross-section of the porous wick saturated with the fluid to be vaporized, thereby avoiding differential temperatures and potential for heating element contamination.

**[0092]** As another example, by placing the wick in close proximity and upstream (with respect to the airflow) to the solid vaporizable material (e.g., loose leaf tobacco), unwanted aerosol condensation within the device can be minimized.

**[0093]** In addition, intrinsic temperature control behavior of the PTCR heater can simplify the electrical power delivery circuitry in that no specific thermal feedback is required. Electrical power delivery circuitry to PTCR heater can be further simplified by eliminating the need, typical of electrical power delivery systems, for the power source to provide relatively constant voltage. In implementations, applied voltage may vary by more than an order of magnitude without significantly affecting resulting heater element temperatures.

**[0094]** An example PTCR heater will now be described in more detail. PTCR includes semiconducting materials that possess an electrical resistivity that changes nonlinearly with increasing temperature. Typical PTCR material resistivity is relatively low while temperature remains below a temperature transition zone. Above the temperature transition zone, the PTCR material resistivity is higher than the resistivity of the same PTCR material at temperatures below the temperature transition zone. The resistivity change can be orders of magnitude increase over a temperature transition zone of 50 degrees Celsius or less.

**[0095]** A heating element can utilize nonlinear PTCR material to enable intrinsic temperature control. For example, a heating element at an ambient temperature can be connected to a power source providing a voltage gradient and resulting current flow. Because the resistivity of the heating element is relatively low at ambient temperature (e.g., ambient temperature is below the transition zone), current will flow through the heating element. As current flows through the nonlinear PTCR material, heat is generated by resistance (e.g., dissipation of electrical power). The generated heat raises the temperature of the heating element, thereby causing the resistivity of the heating element to change. When the temperature of the heating element reaches the transition zone, the resistivity increases significantly over a small temperature range. The change in resistivity can be caused by the physical properties of the material. For example, a phase transition may occur in the material. Such an increase in resistivity (resulting in an overall increase in resistance) reduces current flow such that heat generation is reduced. The transition zone includes a temperature at which there is an inflection point such that heat generation will be insufficient to further raise the temperature of the heating element, thereby limiting the temperature of the heating element. So long as the power source remains connected and supplying current, the heating element will maintain a uniform temperature with minimal temperature variance. In this instance the applied power to the PTCR heating element can be represented by the equation $P_I$=Volts$^2$/Resistance. The heat loss of the PTCR heating element can be represented by $P_L$ and includes any combination of conductive, convective, radiative, and latent heat. During steady-state operation $P_I=P_L$. As $P_L$ increases, the temperature of the PTCR heating element drops thereby reducing the resistance thereby increasing the current flow through the PTCR heating element. As $P_L$ decreases, the temperature of the PTCR heating element increases thereby increasing the resistance thereby decreasing the current flow through the PTCR heating element. As $P_L$ approaches 0, the resistance of the PTCR heating element increase logarithmically. The operating temperature at which a PTCR heating element is limited can be affected by the element materials, element geometry, element resistivity as a function of temperature characteristics, power source, circuit characteristics (e.g., voltage gradient, current, time-variance properties), and the like.

**[0096]** FIG. **9** is a plot illustrating an example resistivity vs. temperature curve for a nonlinear PTCR material. The vertical axis is logarithmic. A heating element constructed (e.g., formed) of a nonlinear PTCR material (referred to as a PTCR heater) can include advantageous characteristics. For example, with application of sufficient voltage gradient (e.g., $\nabla V$), a PTCR heater will generate heat and increase in temperature until the transition zone is reached. In the curve illustrated in FIG. **9**, the transition zone spans between temperatures $T_1$ and $T_2$. In the curve illustrated in FIG. **9**, the resistivity versus temperature curve appears nonlinear between $T_1$ and $T_2$, but in other embodiments, the resistivity versus temperature curve may be near linear or linear or other shapes. At some temperature above $T_1$ the resistivity of the nonlinear PTCR material will have increased to the point where further temperature increase will cease because the overall resistance will increase to a point such that current flow is limited. In other words, implementations of a PTCR heater can be considered to be temperature self-limiting and, given a known range of applied voltages, will not heat beyond a temperature just above the low point $T_1$ of the temperature transition zone.

**[0097]** Performance of a PTCR heater can depend on PTCR behavior as in FIG. **9** and on heater geometry. A PTCR heater having relatively long and narrow geometry and with electrical contacts for applying differential voltage at each end of the longer dimension of the PTCR heater can be ineffective in that resistivity of nonlinear PTCR materials is typically too high at temperatures below $T_1$. Nonlinear PTCR materials having steep transition zones where the temperature difference between $T_1$ and $T_2$ is less than 10° C. may cause all voltage drop to be within a small fraction of the length of said long and narrow geometry and given inevitable spatial nonuniformities within any material. Therefore, some implementations of a PTCR heater include an electrode construct for a PTCR heater such that a nonlinear PTCR material is provided within a parallel circuit. In some implementations that can provide improved uniformity in heating, the PTCR heater geometry can include a thin section of nonlinear PTCR material sandwiched between electrical conductors or electrically conductive coatings to which differential voltages may be applied.

**[0098]** FIG. **10** presents a table of resistivity vs. temperature curve data for the nonlinear PTCR semiconducting material illustrated in FIG. **9**. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 100 ohm-cm at 100° C. and a resistivity of between 50000 ohm-cm and 150000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 20 ohm-cm and 200 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 200000 ohm-cm at 265° C. In implementations, the PTCR heating element has a resistivity of less than 100 ohm-cm at 100° C. and a resistivity greater than 100000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of less than 100 ohm-cm at 100° C. and a resistivity greater than 250000 ohm-cm at 275° C. In implementations, the PTCR heating element has a resistivity of less than 100 ohm-cm at 100° C. and a resistivity greater than 300000 ohm-cm at 295° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 110 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 110 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 325000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 150 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 150 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 350000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 200 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 200 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 375000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 300 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 300 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 400000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 400 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 400 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 450000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 500 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 500 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 500000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 110 ohm-cm at 25° C. and a resistivity of between 50 ohm-cm and 110 ohm-cm at 100° C. and a resistivity of between 150000 ohm-cm and 325000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 150 ohm-cm at 25° C. and a resistivity of between 50 ohm-cm and 150 ohm-cm at 100° C. and a resistivity of between 150000 ohm-cm and 350000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 200 ohm-cm at 25° C. and a resistivity of between 50 ohm-cm and 200 ohm-cm at 100° C. and a resistivity of between 150000 ohm-cm and 375000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 300 ohm-cm at 25° C. and a resistivity of between 50 ohm-cm and 300 ohm-cm at 100° C. and a resistivity of between 150000 ohm-cm and 400000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 400 ohm-cm at 25° C. and a resistivity of between 50 ohm-cm and 400 ohm-cm at 100° C. and a resistivity of between 150000 ohm-cm and 450000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 500 ohm-cm at 25° C. and a resistivity of between 50 ohm-cm and 500 ohm-cm at 100° C. and a resistivity of between 150000 ohm-cm and 500000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 110 ohm-cm at 25° C. and a resistivity of between 90 ohm-cm and 110 ohm-cm at 100° C. and a resistivity of between 200000 ohm-cm and 325000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 150 ohm-cm at 25° C. and a resistivity of between 90 ohm-cm and 150 ohm-cm at 100° C. and a resistivity of between 200000 ohm-cm and 350000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 200 ohm-cm at 25° C. and a resistivity of between 90 ohm-cm and 200 ohm-cm at 100° C. and a resistivity of between 200000 ohm-cm and 375000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 300 ohm-cm at 25° C. and a resistivity of between 90 ohm-cm and 300 ohm-cm at 100° C. and a resistivity of between 200000 ohm-cm and 400000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 400 ohm-cm at 25° C. and a resistivity of between 90 ohm-cm and 400 ohm-cm at 100° C. and a resistivity of between 200000 ohm-cm and 450000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 500 ohm-cm at 25° C. and a resistivity of between 90 ohm-cm and 500 ohm-cm at 100° C. and a resistivity of between 200000 ohm-cm and 500000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 110 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 50 ohm-cm at 150° C. and a resistivity of between 50000 ohm-cm and 125000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 150 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 100 ohm-cm at 150° C. and a resistivity of between 50000 ohm-cm and 150000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 200 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 150 ohm-cm at 150° C. and a resistivity of between 50000 ohm-cm and 175000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 300 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 200 ohm-cm at 150° C. and a resistivity of between 50000 ohm-cm and 200000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 400 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 250 ohm-cm at 150° C. and a resistivity of between 50000 ohm-cm and 250000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 500 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 300 ohm-cm at 150° C. and a resistivity of between 50000 ohm-cm and 300000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 110 ohm-cm at 50° C. and a resistivity of between 20 ohm-cm and 50 ohm-cm at 150° C. and a resistivity of between 75000 ohm-cm and 125000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 150 ohm-cm at 50° C. and a resistivity of between 20 ohm-cm and 100 ohm-cm at 150° C. and a resistivity of between 75000 ohm-cm and 150000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 200 ohm-cm at 50° C. and a resistivity of between 20 ohm-cm and 150 ohm-cm at 150° C. and a resistivity of between 75000 ohm-cm and 175000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 300 ohm-cm at 50° C. and a resistivity of between 20 ohm-cm and 200 ohm-cm at 150° C. and a resistivity of between 75000 ohm-cm and 200000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 400 ohm-cm at 50° C. and a resistivity of between 20 ohm-cm and 250 ohm-cm at 150° C. and a resistivity of between 75000 ohm-cm and 250000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 500 ohm-cm at 50° C. and a resistivity of between 20 ohm-cm and 300 ohm-cm at 150° C. and a resistivity of between 75000 ohm-cm and 300000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 75 ohm-cm and 110 ohm-cm at 50° C. and a resistivity of between 30 ohm-cm and 50 ohm-cm at 150° C. and a resistivity of between 100000 ohm-cm and 125000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 75 ohm-cm and 150 ohm-cm at 50° C. and a resistivity of between 30 ohm-cm and 100 ohm-cm at 150° C. and a resistivity of between 100000 ohm-cm and 150000 ohm-cm at 260° C. 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In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 110 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 50 ohm-cm at 150° C. and a resistivity of between 100000 ohm-cm and 325000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 150 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 100 ohm-cm at 150° C. and a resistivity of between 100000 ohm-cm and 350000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 200 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 150 ohm-cm at 150° C. and a resistivity of between 100000 ohm-cm and 375000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 300 ohm-cm at 25° C. and a resistivity of between 10 ohm-cm and 200 ohm-cm at 150° C. and a resistivity of between 100000 ohm-cm and 400000 ohm-cm at 280° C. 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In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 110 ohm-cm at 25° C. and a resistivity of between 30 ohm-cm and 50 ohm-cm at 150° C. and a resistivity of between 200000 ohm-cm and 325000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 150 ohm-cm at 25° C. and a resistivity of between 30 ohm-cm and 100 ohm-cm at 150° C. and a resistivity of between 200000 ohm-cm and 350000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 200 ohm-cm at 25° C. and a resistivity of between 30 ohm-cm and 150 ohm-cm at 150° C. and a resistivity of between 200000 ohm-cm and 375000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 90 ohm-cm and 300 ohm-cm at 25° C. and a resistivity of between 30 ohm-cm and 200 ohm-cm at 150° C. and a resistivity of between 200000 ohm-cm and 400000 ohm-cm at 280° C. 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200000 ohm-cm and 500000 ohm-cm at 280° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 110 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 110 ohm-cm at 100° C. and a resistivity of between 50000 ohm-cm and 125000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 150 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 150 ohm-cm at 100° C. and a resistivity of between 50000 ohm-cm and 150000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 200 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 200 ohm-cm at 100° C. and a resistivity of between 50000 ohm-cm and 175000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 300 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 300 ohm-cm at 100° C. and a resistivity of between 50000 ohm-cm and 200000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 400 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 400 ohm-cm at 100° C. and a resistivity of between 50000 ohm-cm and 250000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 10 ohm-cm and 500 ohm-cm at 50° C. and a resistivity of between 10 ohm-cm and 500 ohm-cm at 100° C. and a resistivity of between 50000 ohm-cm and 300000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 110 ohm-cm at 50° C. and a resistivity of between 50 ohm-cm and 110 ohm-cm at 100° C. and a resistivity of between 75000 ohm-cm and 125000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 150 ohm-cm at 50° C. and a resistivity of between 50 ohm-cm and 150 ohm-cm at 100° C. and a resistivity of between 75000 ohm-cm and 150000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 200 ohm-cm at 50° C. and a resistivity of between 50 ohm-cm and 200 ohm-cm at 100° C. and a resistivity of between 75000 ohm-cm and 175000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 300 ohm-cm at 50° C. and a resistivity of between 50 ohm-cm and 300 ohm-cm at 100° C. and a resistivity of between 75000 ohm-cm and 200000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 400 ohm-cm at 50° C. and a resistivity of between 50 ohm-cm and 400 ohm-cm at 100° C. and a resistivity of between 75000 ohm-cm and 250000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 50 ohm-cm and 500 ohm-cm at 50° C. and a resistivity of between 50 ohm-cm and 500 ohm-cm at 100° C. and a resistivity of between 75000 ohm-cm and 300000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 75 ohm-cm and 110 ohm-cm at 50° C. and a resistivity of between 90 ohm-cm and 110 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 125000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 75 ohm-cm and 150 ohm-cm at 50° C. and a resistivity of between 90 ohm-cm and 150 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 150000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 75 ohm-cm and 200 ohm-cm at 50° C. and a resistivity of between 90 ohm-cm and 200 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 175000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 75 ohm-cm and 300 ohm-cm at 50° C. and a resistivity of between 90 ohm-cm and 300 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 200000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 75 ohm-cm and 400 ohm-cm at 50° C. and a resistivity of between 90 ohm-cm and 400 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 250000 ohm-cm at 260° C. In implementations, the PTCR heating element has a resistivity of between 75 ohm-cm and 500 ohm-cm at 50° C. and a resistivity of between 90 ohm-cm and 500 ohm-cm at 100° C. and a resistivity of between 100000 ohm-cm and 300000 ohm-cm at 260° C.

**[0099]** FIG. **11** illustrates another example PTCR resistivity versus temperature curve. In this example, the PTCR material has a density of 5700 kg/m3, a heat capacity of 520 J/kg K, and a thermal conductivity of 2.1 W/m K. The coefficient of resistivity begins to initially increase at a temperature after about 440 K and then sharply increases between 503 K and 518 K. At 298 K, the resistivity of the PTCR material forming the PTCR heating element is 0.168 ohm-m, and at 373 K the resistivity of the PTCR material forming the PTCR heating element is 0.105 ohm-m, and at 518 K the resistivity of the PTCR material forming the PTCR heating element is 3.669 ohm-m. In some example implementations, the PTCR material has a density between 5000 kg/m3 and 7000 kg/m3, a heat capacity between 450 J/kg K and 600 J/kg K, and a thermal conductivity between 1.5 W/m K and 3.0 W/m K.

**[0100]** FIG. **12**A is a diagram illustrating an example PTCR heating element **50** that can enable improved vaporizer heating. A thin section of nonlinear PTCR material **10** is shown in FIG. **12**A, where nonlinear PTCR material **10** is sandwiched between electrically conductive layers **20**, which in turn are attached to conductive leads **30** such that conductive leads **30** may have differential voltage applied. FIG. **9**B is a cross section of the example PTCR heating element **50** illustrated in FIG. **12**A.

**[0101]** In some example implementations, which can be effective in a vaporizer device using, for example, a fluid combination including propylene glycol and glycerol, a PTCR heater **50** includes the geometry illustrated in FIG. **12**A with nonlinear PTCR material thickness of 0.5 mm (height) and 5.0 mm (length and width) in the other dimensions. The nonlinear PTCR material electrical characteristics includes these values: $T_1$ value between 150° C. and 300° C., such as between 220° C. and 280° C.; resistivity at temperatures below $T_1$ between 0.01 Ohm-m and 100 Ohm-m, such as between 0.1 Ohm-m and 1 Ohm-m; resistivity change between $T_1$ and $T_2$ having an increase of a factor exceeding 10 such as exceeding 100; and temperature difference between $T_1$ and $T_2$ less than 200° C. such as less than 50° C.

**[0102]** FIG. **13**A-FIG. **13**E illustrate modeled temperatures of the example PTCR heater **50**. In the illustrated example, the nonlinear PTCR material **10** included a plate geometry with dimensions of 5 mm×5 mm×0.5 mm; the conductive layers **20** were formed of silver (Ag) with dimensions of 5 mm×5 mm×0.025 mm; and the conductive leads **30** were formed of copper (CU) with dimensions of 12 mm×2 mm×0.2 mm. The nonlinear PTCR material **10** included a PTCR resistivity versus temperature curve as illustrated in FIG. **32**, with a nonlinear transition zone of about 240° C. to about 300° C. A voltage of 3 to 6 volts was applied across the conductive leads **30** of the example PTCR heater **50**. Under these circumstances, the example PTCR heater **50** in open air with free convective airflow will increase in temperature as shown in the modeled sequence of FIG. **13**A-FIG. **13**E, which illustrate respectively 0.0, 0.2, 0.5, 1.0, and 2.0 seconds after application of the voltage differential. As illustrated, the temperature beyond 1.0 second is relatively uniform and the peak temperatures at the surface of conductive layers **20** is less than 270° C.

**[0103]** FIG. **14**A-FIG. **14**F illustrate modeled temperatures of another example of a PTCR heater **50**. A gradient temperature scale is shown on the left side of each figure with red representing the hottest temperature of about 255° C. and continues through the colors of the visible light spectrum in order (i.e. red, orange, yellow, green, blue, and violet) to the coolest temperature of about 23° C. In each of the illustrated examples, the nonlinear PTCR material **10** includes a plate geometry with dimensions of about 5 mm×5 mm×0.5 mm; the conductive layers **20** were formed of silver (Ag) with dimensions of about 5 mm×5 mm×0.025 mm; and the conductive leads **30** were formed of copper (CU) with dimensions of about 12 mm×2 mm×0.2 mm. The plate geometry can include two parallel sides including conductive layers **20** with conductive leads **30** attached thereto. The conductive leads **30** are centrally attached to conductive layers **20** on each side of the PTCR heating element **50** with a connection **40**. In implementations, the connection **40** is a clamp, a clip, a conductive paste, a high-temperature, lead-free solder, and/or combinations thereof.

**[0104]** FIG. **14**A illustrates the temperature 1.0 second after activation by applying a current to the PTCR heating element **50**. The violet colored conductive leads **30** are still about 25° C. The majority of the PTCR material **10** and conductive layer **20** has increased in temperature to about 120° C., with the area including connection **40** in the center being slightly cooler at a temperature around 80° C.

**[0105]** FIG. **14**B illustrates the temperature 2.0 seconds after activation by applying a current to the PTCR heating element **50**. The blue/green colored conductive leads **30** have increased in temperature to about 90° C. The majority of the PTCR material **10** and conductive layer **20** has increased in temperature to about 210° C., with the area including connection **40** in the center being cooler at a temperature around 160° C.

**[0106]** FIG. **14**C illustrates the temperature 3.0 seconds after activation by applying a current to the PTCR heating element **50**. The green colored conductive leads **30** have increased in temperature to about 140° C. The majority of the PTCR material **10** and conductive layer **20** has increased in temperature to about 250° C., with the area including connection **40** in the center being cooler at a temperature around 200° C.

**[0107]** FIG. **14**D illustrates the temperature 4.0 seconds after activation by applying a current to the PTCR heating element **50**. The green colored conductive leads **30** have increased in temperature to about 160° C. The majority of the PTCR material **10** and conductive layer **20** remains at temperature to about 250° C., with the area including connection **40** in the center being cooler at a temperature around 215° C.

**[0108]** FIG. **14**E illustrates the temperature 5.0 seconds after activation by applying a current to the PTCR heater **50**. The green/yellow colored conductive leads **30** have increased in temperature to about 180° C. The majority of the PTCR material **10** and conductive layer **20** remains at temperature to about 250° C., with the area including connection **40** in the center being slightly cooler at a temperature around 225° C.

**[0109]** FIG. **14**F illustrates the temperature 6.0 seconds after activation by applying a current to the PTCR heating element **50**. The yellow colored conductive leads **30** have increased in temperature to about 200° C. The majority of the PTCR material **10** and conductive layer **20** remains at temperature to about 250° C., with the area including connection **40** in the center being just slightly cooler at a temperature around 235° C. FIG. **15** illustrates modeled temperatures of an example heater 6.0 seconds after application of a voltage in a free convective state.

**[0110]** FIG. **16**A illustrates a modeled surface temperature as a function of time for an example PTCR heating element. In the model, the surface temperature of the PTCR heater starts at 25° C. (i.e. room temperature) at time zero. After an electrical current is applied, the surface temperature increases linearly for about 2 seconds to a temperature of about 225° C. After about 2 seconds, the rate of the temperature increase tapers off to a steady-state operating temperature of about 250° C. that is achieve about 3 seconds after activation. In the model, it was assumed that the nonlinear PTCR material is in a non-contact, free convective state, and the emitted radiation was measured from a distance. In implementations, the PTCR heating element is heated to an operating temperature between 240° C. and 280° C. In implementations, the PTCR heating element is heated to an operating temperature between 245° C. and 255° C. In implementations, the PTCR heating element is heated to an operating temperature about 250° C.

**[0111]** FIG. **16**B illustrates a modeled and measured maximum surface temperatures as a function of time for an example PTCR heater. Four measurements were repeated using an infrared camera to measure the maximum surface temperatures of the PTCR heater as a function of time, which were then plotted against the model of the maximum surface temperature. In the model, it was assumed that the nonlinear PTCR material is in a non-contact, free convective state and the emitted radiation was measured from a distance. In each case, the maximum surface temperature of the PTCR heating element starts at about 25° C. (i.e. room temperature) at time zero. After an electrical current is applied, the maximum surface temperature increases linearly for about 2 seconds to a temperature of about 225° C. After about 2 seconds, the rate of the temperature increase tapers off to a steady-state operating temperature of about 250° C. that is achieve about 3 seconds after activation. In implementations, the PTCR heating element is heated to an operating temperature between 240° C. and 280° C. In implementations, the PTCR heating element is heated to an operating temperature between 245° C. and 255° C. In implementations, the PTCR heating element is heated to an operating temperature about 250° C.

**[0112]** FIG. **16**C illustrates a modeled and measured average surface temperatures as a function of time for an example PTCR heating element. Four measurements were repeated using an infrared camera to measure the average surface temperatures of the PTCR heating element as a function of time, which were then plotted against the model of the average surface temperature. In the model, it was assumed that the nonlinear PTCR material is in a non-contact, free convective state and the emitted radiation was measured from a distance. In each case, the average surface temperature of the PTCR heating element starts at about 25° C. (i.e. room temperature) at time zero. After an electrical current is applied, the maximum surface temperature increases linearly for about 2 seconds to a temperature of about 225° C. After about 2 seconds, the rate of the temperature increase tapers off to a steady-state operating temperature of about 250° C. that is achieve about 3 seconds after activation. In implementations, the PTCR heating element is heated to an operating temperature between 240° C. and 280° C. In implementations, the PTCR heating element is heated to an operating temperature between 245° C. and 255° C. In implementations, the PTCR heating element is heated to an operating temperature about 250° C.

**[0113]** FIG. **17** illustrates a transient current response as a function of time of an example heater, consistent with implementations of the current subject matter. In the graph, the current is measured in amps, which increases at a near linear rate, and reaches a peak draw after about 1.5 seconds from activation. Thereafter, the resistance quickly increases to reduce the current draw as the PTCR heater achieves a self-regulating operating temperature.

**[0114]** Uniform temperature can be a desirable performance attribute of PTCR heaters, providing a distinct advantage over series coil heaters, including series heaters having power input controlled by temperature sensors, electronic circuits with microprocessors, and sophisticated algorithms dedicated to the purpose of temperature control. These existing series heaters can have overall power modulated in response to temperature measurement at a point or by average temperature estimated by overall electrical resistivity in combination with TCR (temperature coefficient of resistivity) of the typical series heating element. However, in some series heaters, temperatures within the series heater can vary by 40° C. or more because local differences in the thermal mass of the surrounding medium, and local differences in losses to the sounding medium, lead to variations in the local resistivity along the series heater.

**[0115]** In some implantations, a PTCR heater **50** constructed with material having a nonlinear PTCR resistivity vs. temperature curve the same or similar to that shown in FIG. **9**, with parallel geometry such as that shown in FIGS. **12**A-**12**B, and with an adequate (e.g., 3V to 6V) differential voltage applied to conductive leads **30**, each of a given control volume within such a PTCR heater will have a temperature within a narrow range, typically less than 10° C. This can be achieved even with differential thermal loading. The less than 10° C. range can be tailored for vaporization by controlling the materials and geometric arrangement of the PTCR heating element.

**[0116]** Alternative PTCR heater designs and geometries are possible.

**[0117]** In implementations, the PTCR heater can include a heat exchanger for the purpose of preheating air entering and passing through vaporizable materials. FIG. **18** is a perspective view of an example PTCR heater assembly **395** including a PTCR heater **390** and heat exchanger elements **320** that can enable convective heating and improved uniform heating of vaporizable materials.

**[0118]** The example PTCR heater assembly **395** (also referred to as a rectangular PTCR air heater assembly) includes PTCR heater **390** including a PTCR material **300** sandwiched between electrically conductive layers **305**. In contact with the electrically conductive layers **305** are heat exchanger elements **320**, which can be made of, for example, aluminum or other thermally conductive material. Heat exchanger elements **320** can be made from a thermally conductive material extrusion or assembly. In implementations, the heat exchanger elements **320** can be a metal foam, e.g. an aluminum foam. Heat exchanger elements **320** can be made by extruding, machining, milling, casting, foaming, printing, injection molding, forging, stamping, sintering, and other metal shaping methods. Surrounding heat exchanger elements **320** is heater assembly cover **350**. In implementations, the heater assembly cover **350** comprises a non-electrically conductive material. In implementations, the heater assembly cover **350** comprises a non-thermally conductive material. In implementations, the heater assembly cover **350** comprises a metal with a non-electrically conductive coating isolating the heater assembly cover **350** from the heat exchanger elements **320**. In implementations, the heater assembly cover **350** comprises polytetrafluoroethylene (PTFE).

**[0119]** FIG. **19** is an exploded view of a PTCR vaporization assembly **398** including an exploded view of the example PTCR heater assembly **395**. In some implementations, the PTCR vaporization assembly **398** is rectangular. The PTCR vaporization assembly **398** includes the example PTCR heater assembly **395** and a product cover **380** for containing a disposable product **360**. In some implementations, the product cover **380** and disposable product **360** are each rectangular. In implementations, the disposable product **360** within a product cover **380** can include a disposable containing a solid vaporizable material. In implementations, product cover **380** is a disposable liquid cartridge (e.g., pod) configured to contain a liquid vaporizable material. In implementations, product cover **380** is a disposable liquid cartridge (e.g., pod) including a first air inlet and/or wick, and is configured to contain a liquid vaporizable material.

**[0120]** FIG. **20** is a perspective view of an assembled example PTCR vaporization assembly **398**. The product cover **380** containing the disposable product therein can be attached via an interference fit, press-fit, snap-fit coupling, magnetic coupling, adhesive, and other fastening means to the heater assembly cover **350**, the PTCR heater assembly, and/or the adjoining segment on the opposite side of the product cover **380**. The product cover **380** can be releasably attached such that it can be separated from the vaporizer device to replace the disposable product and then reassembled.

**[0121]** FIG. **21** is a perspective, transparent view of an example PTCR vaporization assembly **398** and disposable product **360**. In implementations, the disposable product **360** and product cover **380** can include a disposable containing a solid vaporizable material. In implementations, the disposable product **360** and product cover **380** can include a disposable liquid cartridge (e.g., pod) containing a liquid vaporizable material. In implementations, the disposable product **360** and product cover **380** can include a disposable liquid cartridge (e.g., pod) having a first air inlet and/or wick, and contains a liquid vaporizable material. Though a PTCR heater is not shown in FIG. **21**, the PTCR heater is inserted in the volume **304** between heat exchanger elements **320**. Heat exchanger elements **320** provides an increased surface area for heating more of the incoming air, as compared to just having a PTCR heater (without heat exchanger) to heat the incoming air. Surrounding heat exchanger elements **320** is heater assembly cover **350**. In implementations, the flow rate of the incoming air through the PTCR heater assembly **395** is about 1.4 liters per minute. The heat exchanger elements **320** can reach a steady state temperature of over 200° C. in order to rapidly heat the incoming air. The heat exchanger elements **320** can be designed to maximize the specific surface area ($mm^2/mm^3$), which provides for improved heat transfer from the PTCR heater to the heat exchanger elements **320**, and also provides for improved heat transfer from the heat exchanger elements **320** to the incoming air. As shown in FIG. **21**, heat exchanger elements **320** can be a finned design made from a thermally conductive material (e.g. metals such as aluminum, copper, steel, stainless steel, titanium).

**[0122]** FIG. **22** is a perspective, transparent view of an example PTCR vaporization assembly **398** and a disposable product **360** about 0.2 seconds after activation of the PTCR heater **390**. PTCR heater **390** heats the heat exchanger elements **320**, which transfer the heat to the air entering the PTCR heater assembly **395**. The air exiting the PTCR heater assembly **395** has been heated to a temperature of between about 110° C. and about 160° C. The heated airflow flows through disposable product **360** (e.g. a tobacco containing media) at a flow rate of about 1.4 liters per minute. The vapor and/or aerosol exiting the PTCR vaporization assembly **398** contains the vaporized material released from the disposable product **360** at a temperature of between about 50° C. and about 150° C.

**[0123]** FIG. **23** is a perspective, transparent view of an example PTCR vaporization assembly **398** and a disposable product **360** about 0.5 seconds after activation of the PTCR heater **390**. PTCR heater **390** heats the heat exchanger elements **320**, which transfer the heat to the air entering the PTCR heater assembly **395**. The air exiting the PTCR heater assembly **395** has been heated to a temperature of between about 150° C. and about 210° C. The heated airflow flows through disposable product **360** (e.g. a tobacco containing media) at a flow rate of about 1.4 liters per minute. The vapor and/or aerosol exiting the PTCR vaporization assembly **398** contains the vaporized material released from the disposable product **360** at a temperature of between about 100° C. and about 210° C.

**[0124]** FIG. **24** is a perspective, transparent view of an example PTCR vaporization assembly **398** and a disposable product **360** about 1.0 second after activation of the PTCR heater **390**. PTCR heater **390** heats the heat exchanger elements **320**, which transfer the heat to the air entering the PTCR heater assembly **395**. The air exiting the PTCR heater assembly **395** has been heated to a temperature of between about 170° C. and about 230° C. The heated airflow flows through disposable product **360** (e.g. a tobacco containing media) at a flow rate of about 1.4 liters per minute. The vapor and/or aerosol exiting the PTCR vaporization assembly **398** contains the vaporized material released from the disposable product **360** at a temperature of between about 110° C. and about 220° C.

**[0125]** FIG. **25** is a perspective, transparent view of an example PTCR vaporization assembly **398** and a disposable product **360** about 2.0 seconds after activation of the PTCR heater **390**. PTCR heater **390** heats the heat exchanger elements **320**, which transfer the heat to the air entering the PTCR heater assembly **395**. The air exiting the PTCR heater assembly **395** has been heated to a temperature of between about 180° C. and about 240° C. The heated airflow flows through disposable product **360** (e.g. a tobacco containing media) at a flow rate of about 1.4 liters per minute. The vapor and/or aerosol exiting the PTCR vaporization assembly **398** contains the vaporized material released from the disposable product **360** at a temperature of between about 120° C. and about 230° C.

**[0126]** FIG. **26** is a perspective, transparent view of an example PTCR vaporization assembly **398** and a disposable product **360** about 3.0 seconds after activation of the PTCR heater **390**. PTCR heater **390** heats the heat exchanger elements **320**, which transfer the heat to the air entering the PTCR heater assembly **395**. The air exiting the PTCR heater assembly **395** has been heated to a temperature of between about 180° C. and about 240° C. The heated airflow flows through disposable product **360** (e.g. a tobacco containing media) at a flow rate of about 1.4 liters per minute. The vapor and/or aerosol exiting the PTCR vaporization assembly **398** contains the vaporized material released from the disposable product **360** at a temperature of between about 120° C. and about 230° C.

**[0127]** The current subject matter is not limited to rectangular geometries. In implementations, the PTCR heater is a polygon that is not a rectangle. For example, alternative designs of a PTCR heater may depart from planar geometry in many possible configurations produced by extrusion or injection molding. For example, FIG. **27** is a perspective view of an example PTCR heater **290** with cylindrical geometry. In this example, PTCR heater **290** includes PTCR material **200** with surface conductive layers **205**, each of which is cylindrical.

**[0128]** FIG. **28** is an exploded view illustrating an example PTCR heater assembly **295**, which includes the example PTCR heater **290**, external heat exchanger **210**, internal heat exchanger **220**, flow diverter **230**, and Heater assembly cover **250**, each of which is cylindrical. FIG. **29** is a perspective view of the example PTCR heater assembly **295**. FIG. **30** is a perspective view of the example PTCR vaporization assembly **298** with external covers and flow diverter **230** removed, thereby showing orientation of PTCR heater **290**, external heat exchanger **210** and internal heat exchanger **220** aligned with disposable product **260**.

**[0129]** FIG. **31** is a perspective view of the example PTCR vaporization assembly **298** including the PTCR heater **290**, external heat exchanger **210**, internal heat exchanger **220**, flow diverter **230**, Heater assembly cover **250**, and product cover **280** (which, in FIG. **18**, obscures disposable product **260**).

**[0130]** FIG. **32** is a plot of the logarithm of resistivity of an example vaporization device with PTCR heater as a function of temperature. The performance illustrated in FIG. **32** is according to example calculations characterizing a performance of an example implementation of a cylindrical PTCR vaporization assembly **298**. The example PTCR vaporization assembly **298** is a HNB device, with solid vaporizable material (e.g. HNB product) as the disposal product **260**, treated in the calculation as a porous medium, with specific area by mass $S_m \cong 10000\ cm^2/g$, density $\rho \cong 300\ kg/m^3$. Convective heat transfer constant $h \cong 2.0\ W/m^2K$. Surface area by volume can be calculated as $S_{vol} = S_m \times \rho = 10000\ cm^2/g \times 1000\ g/kg \times m^2/10000\ cm^2$, and $S_{vol} \cong 1000\ m^2/kg$ from which volumetric heat exchange coefficient $\nu\gamma = h\ \rho\ (S_{vol}) \cong 6.0\ E5\ W/m^3K$.

**[0131]** For the calculations, ambient conditions were 20.05° C. at standard pressure of 1 atmosphere. Input airflow rate was constant at 1.4 l/m, applied voltage was constant 3.7 volts across opposing electrically conductive layers **205**. No electric current restrictions were applied beyond PTCR behavior shown in FIG. **32**.

**[0132]** The calculated vaporization device with PTCR heater included electrically conductive layers **205** that were silver, a cylindrical external heat exchanger **210** and a cylindrical internal heat exchanger **220** that were aluminum extrusions, flow diverter **230** and Heater assembly cover **250** were made from PTFE, and product cover **280** was made from paper.

**[0133]** FIG. **33** is a cross sectional plot showing temperature simulations of the example implementation of the PTCR vaporization assembly **298** that is also described above with respect to FIG. **32**. The PTCR vaporization assembly **298** includes a PTCR heater assembly **295** for heating of a disposal product (e.g. a solid vaporizable material) **260**. FIGS. **34**A-**34**G are cut plots showing transient response of temperature as color for the example implementation of the PTCR vaporization assembly **298** with PTCR heater assembly **295**. FIGS. **34**A-**34**G demonstrate that temperatures everywhere never exceed 280° C., well below combustion temperature of disposable product **260**. It can also be seen in FIGS. **34**A-**34**G that heating of disposal product (e.g. a solid vaporizable material) **260** proceeds in a wave from upstream to downstream such that cross-sectional hot spots and resulting differential porosity voids are eliminated.

**[0134]** In the descriptions above and in the claims, phrases such as "at least one of" or "one or more of" may occur followed by a conjunctive list of elements or features. The term "and/or" may also occur in a list of two or more elements or features. Unless otherwise implicitly or explicitly contradicted by the context in which it is used, such a phrase is intended to mean any of the listed elements or features individually or any of the recited elements or features in combination with any of the other recited elements or features. For example, the phrases "at least one of A and B;" "one or more of A and B;" and "A and/or B" are each intended to mean "A alone, B alone, or A and B together." A similar interpretation is also intended for lists including three or more items. For example, the phrases "at least one of A, B, and C;" "one or more of A, B, and C;" and "A, B, and/or C" are each intended to mean "A alone, B alone, C alone, A and B together, A and C together, B and C together, or A and B and C together." In addition, use of the term "based on," above and in the claims is intended to mean, "based at least in part on," such that an unrecited feature or element is also permissible.

**[0135]** The subject matter described herein can be embodied in systems, apparatus, methods, and/or articles depending on the desired configuration. The implementations set forth in the foregoing description do not represent all implementations consistent with the subject matter described herein. Instead, they are merely some examples consistent with aspects related to the described subject matter. Although a few variations have been described in detail above, other modifications or additions are possible. In particular, further features and/or variations can be provided in addition to those set forth herein. For example, the implementations described above can be directed to various combinations and subcombinations of the disclosed features and/or combinations and subcombinations of several further features disclosed above. In addition, the logic flows depicted in the accompanying figures and/or described herein do not necessarily require the particular order shown, or sequential order, to achieve desirable results. Other implementations may be within the scope of the following claims.

**1-105**. (canceled)

**106**. A PTCR heater assembly for heating an airflow of a vaporizer device, comprising:

a heater assembly cover;

a heat exchanger disposed within the heater assembly cover, the heat exchanger configured to transfer heat to the airflow to vaporize a solid vaporizable material; and

a positive temperature coefficient of resistivity (PTCR) heating element thermally coupled to the heat exchanger, the PTCR heating element configured to electrically couple to the power source to receive the current flow and heat the airflow, the PTCR heating element comprising a PTCR material having an electrical resistivity that varies based on temperature, the electrical resistivity including an electrical resistivity transition zone in which the electrical resistivity increases over a temperature range, such that when the PTCR heating element is heated above a first temperature within the transition zone, current flow from the power source is reduced to a level that limits further temperature increases of the PTCR heating element.

**107**. The PTCR heater assembly of claim **106**, wherein the heat exchanger includes a first heat exchanger thermally coupled to a first side of the heating element, the heat exchanger including a second heat exchanger thermally coupled to a second side of the heating element.

**108**. The PTCR heater assembly of claim **106**, wherein the heat exchanger includes a plurality of fin features.

**109**. The PTCR heater assembly of claim **106**, wherein the heat exchanger is made from aluminum, copper, steel, stainless steel, or titanium.

**110**. The PTCR heater assembly of claim **106**, wherein the heat exchanger is made from a thermally conductive material extrusion.

**111**. The PTCR heater assembly of claim **106**, wherein the heat exchanger is made from a metal foam.

**112**. The PTCR heater assembly of claim **111**, wherein the metal foam is an aluminum foam.

**113**. The PTCR heater assembly of claim **106**, wherein the electrical resistivity transition zone begins at the first temperature of between 150° C. and 350° C.

**114**. The PTCR heater assembly of claim **106**, wherein the PTCR heating element is heated to an operating temperature between 240° C. and 280° C.

**115**. The PTCR heater assembly of claim **106**, wherein the increase in the electrical resistivity over the temperature range of the electrical resistivity transition zone includes an increase factor of at least 100, the increase factor characterizing a relative change in electrical resistivity between electrical resistivity at the first temperature associated with a start of the electrical resistivity transition zone and electrical resistivity at a second temperature associated with an end of the electrical resistivity transition zone.

**116**. The PTCR heater assembly of claim **106**, wherein the increase in the electrical resistivity over the temperature range of the electrical resistivity transition zone includes an increase factor of at least 1000, the increase factor characterizing a relative change in electrical resistivity between electrical resistivity at the first temperature associated with a start of the electrical resistivity transition zone and electrical resistivity at a second temperature associated with an end of the electrical resistivity transition zone.

**117**. The PTCR heater assembly of claim **106**, wherein the electrical resistivity transition zone begins at the first temperature and ends at a second temperature, a difference between the first temperature and the second temperature being 500° C. or less.

**118**. The PTCR heater assembly of claim **106**, wherein the electrical resistivity transition zone begins at the first temperature and the electrical resistivity of the PTCR heating element at temperatures below the first temperature is between 20 ohm-cm and 200 ohm-cm.

**119**. The PTCR heater assembly of claim **106**, wherein the electrical resistivity transition zone begins at the first temperature and the electrical resistivity of the PTCR heating element at temperatures below the first temperature is between 2.0 ohm-cm and 20 ohm-cm.

**120**. The PTCR heater assembly of claim **106**, wherein the electrical resistivity transition zone begins at the first temperature and the electrical resistivity of the PTCR heating element at temperatures below the first temperature is between 0.2 ohm-cm and 2.0 ohm-cm.

**121**. The PTCR heater assembly of claim **106**, wherein the electrical resistivity transition zone begins at the first temperature and the electrical resistivity of the PTCR heating element at temperatures below the first temperature is between 0.1 ohm-cm and 100 ohm-cm.

**122**. The PTCR heater assembly of claim **106**, wherein the heater assembly cover comprises a non-electrically conductive material.

**123**. The PTCR heater assembly of claim **106**, wherein the heater assembly cover comprises a non-thermally conductive material.

**124**. The PTCR heater assembly of claim **106**, wherein the heater assembly cover comprises a metal with a non-electrically conductive coating isolating the heater assembly cover from the heat exchanger.

**125**. The PTCR heater assembly of claim **106**, wherein the heater assembly cover comprises polytetrafluoroethylene (PTFE).

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