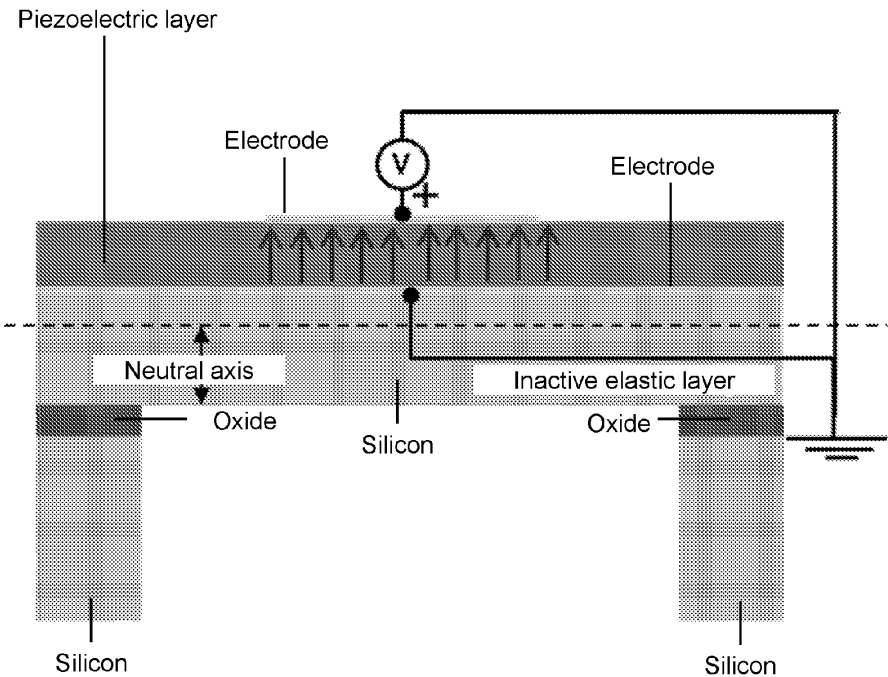
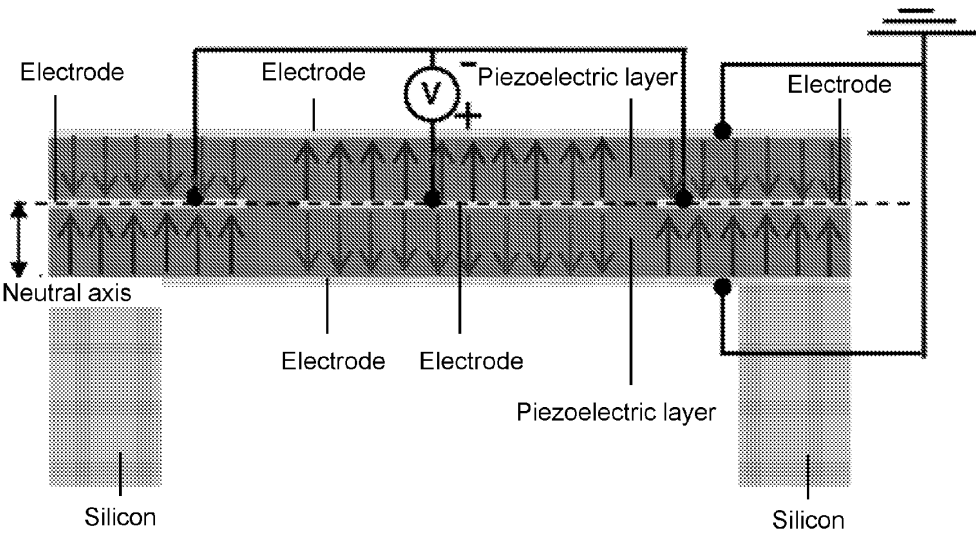


FIG. 1A



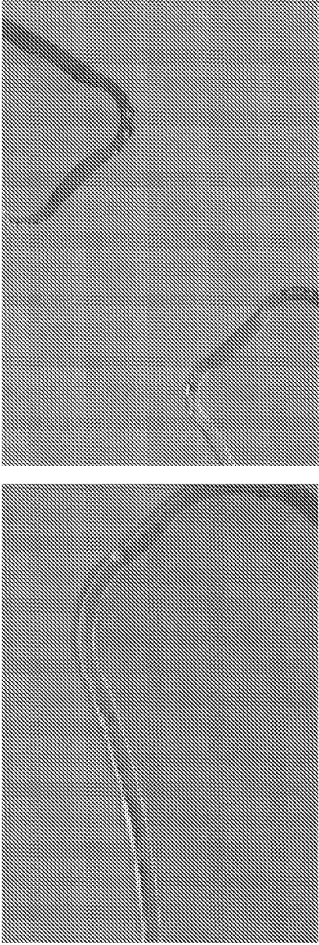
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FIG. 1B



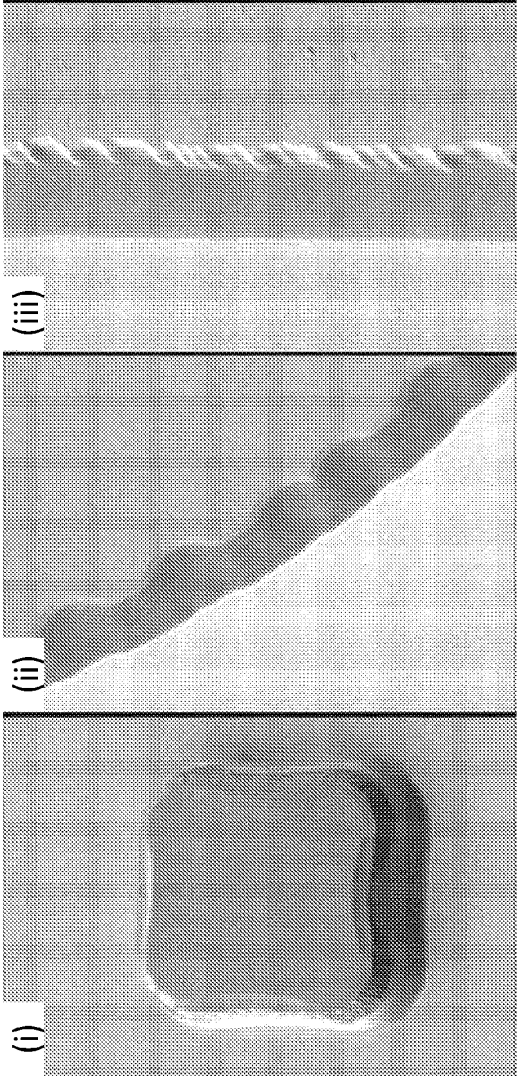
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FIG. 2A



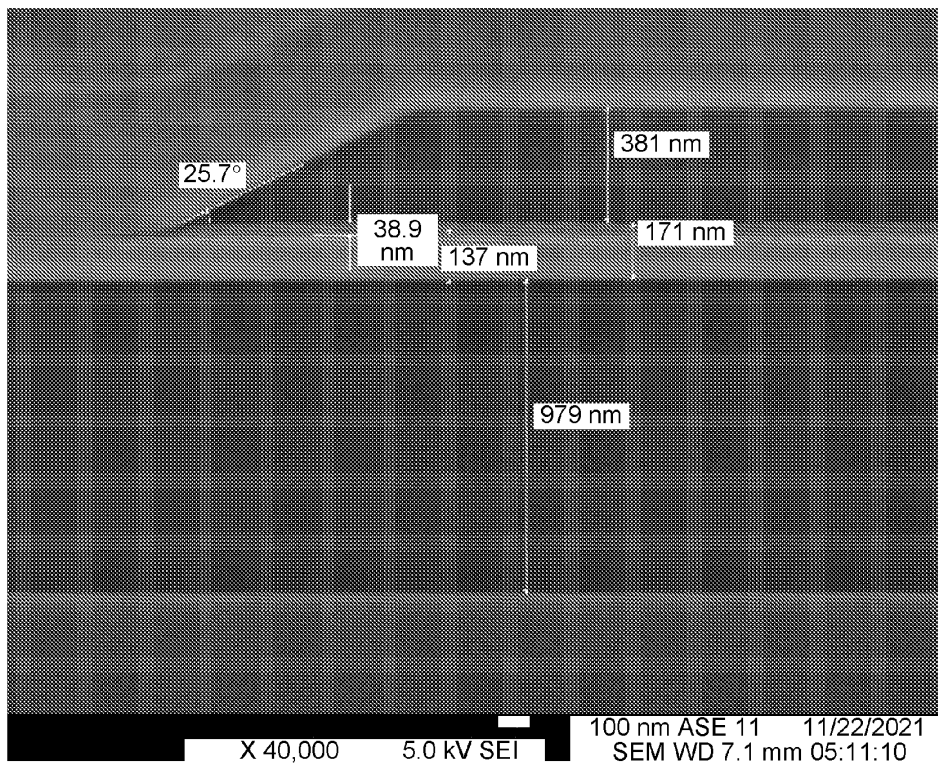
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FIG. 2B



PRIOR ART

FIG. 2C



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FIG. 3A

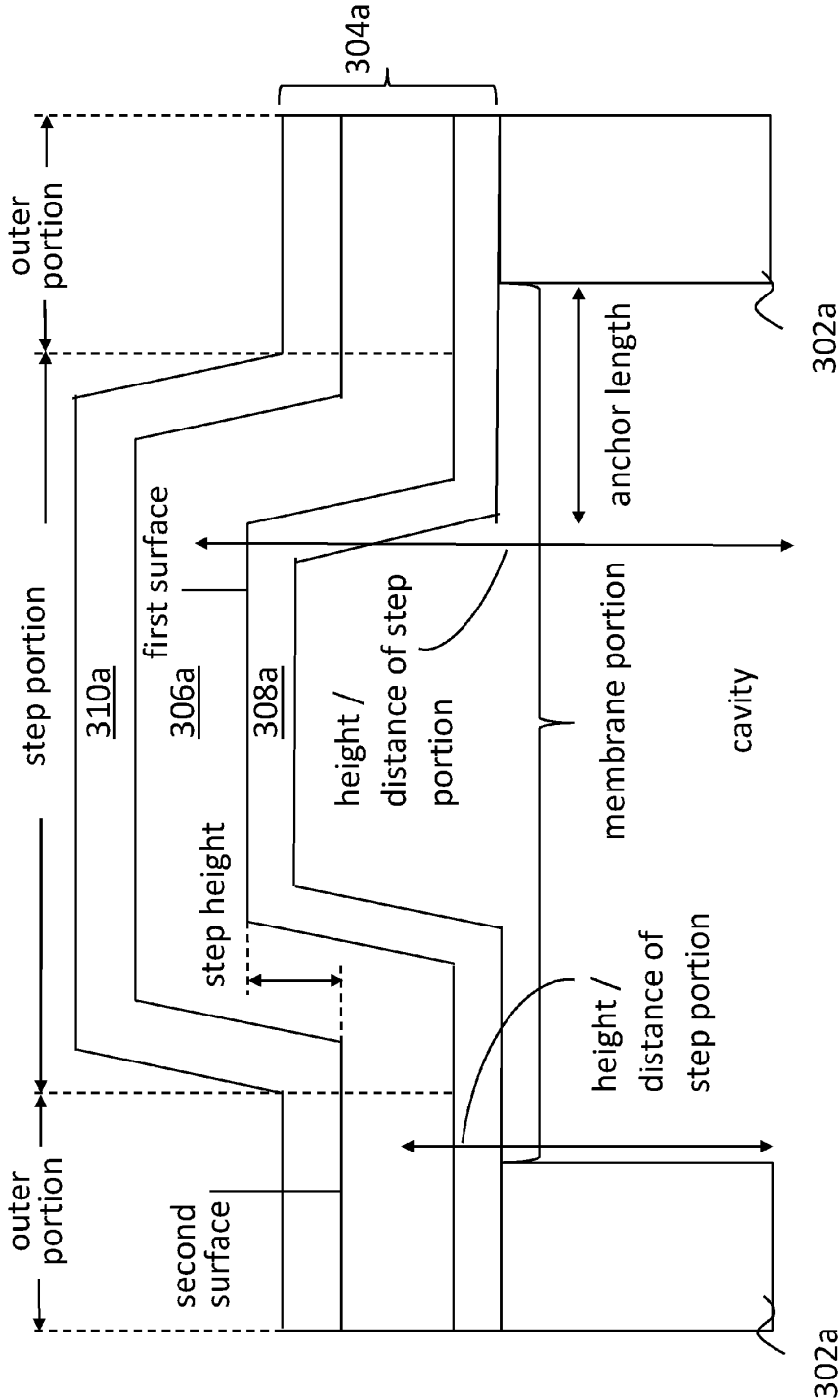
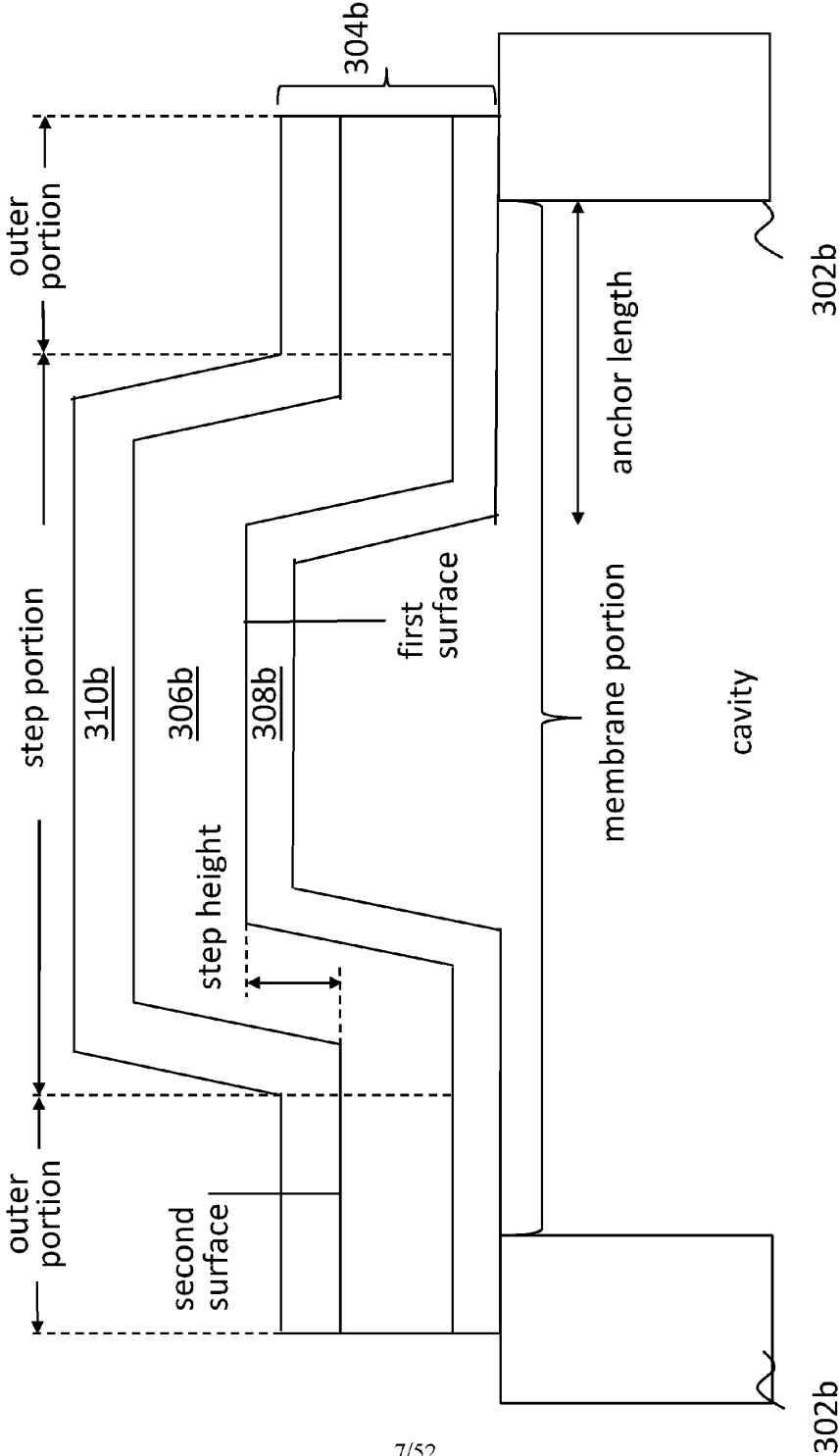
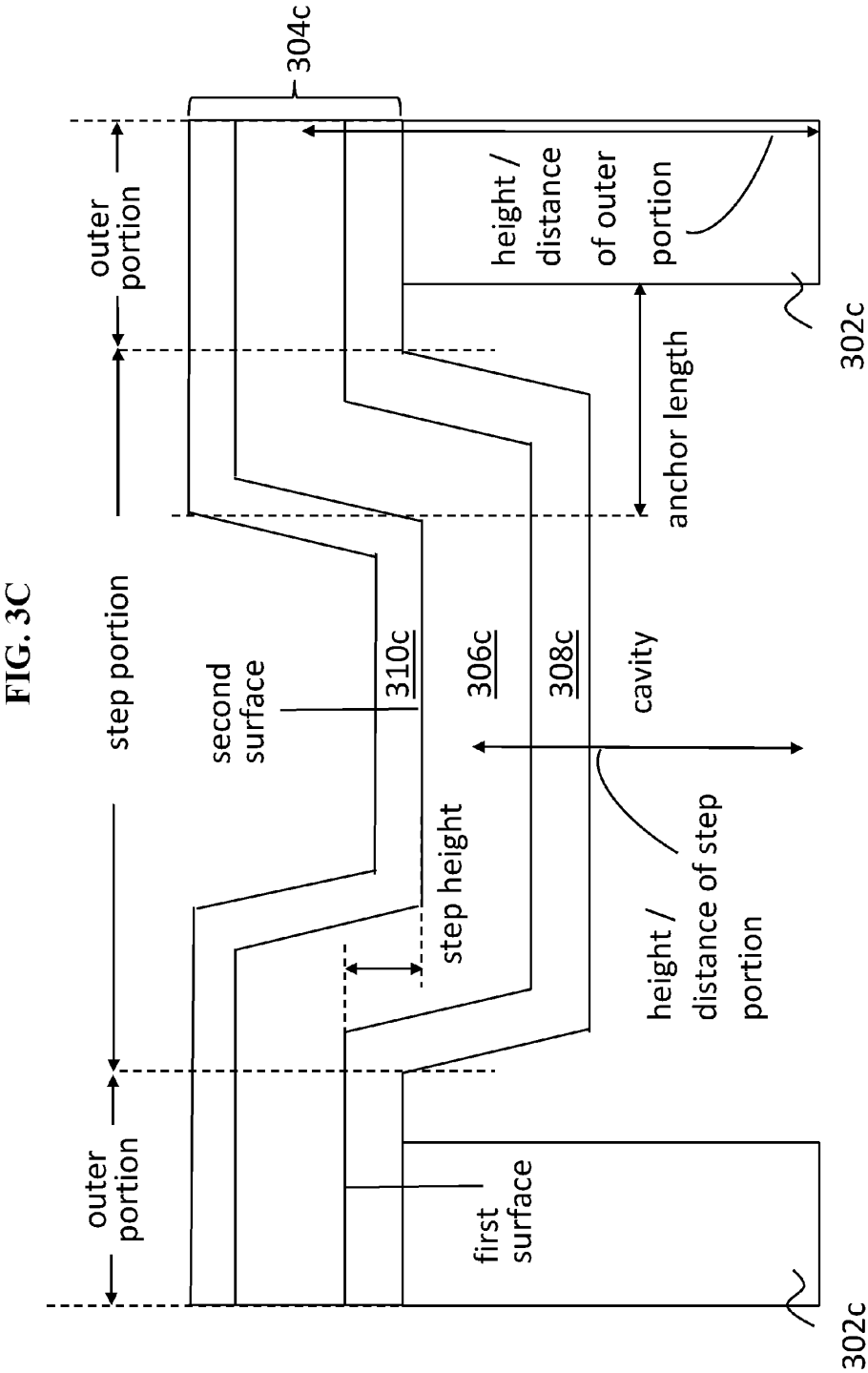


FIG. 3B





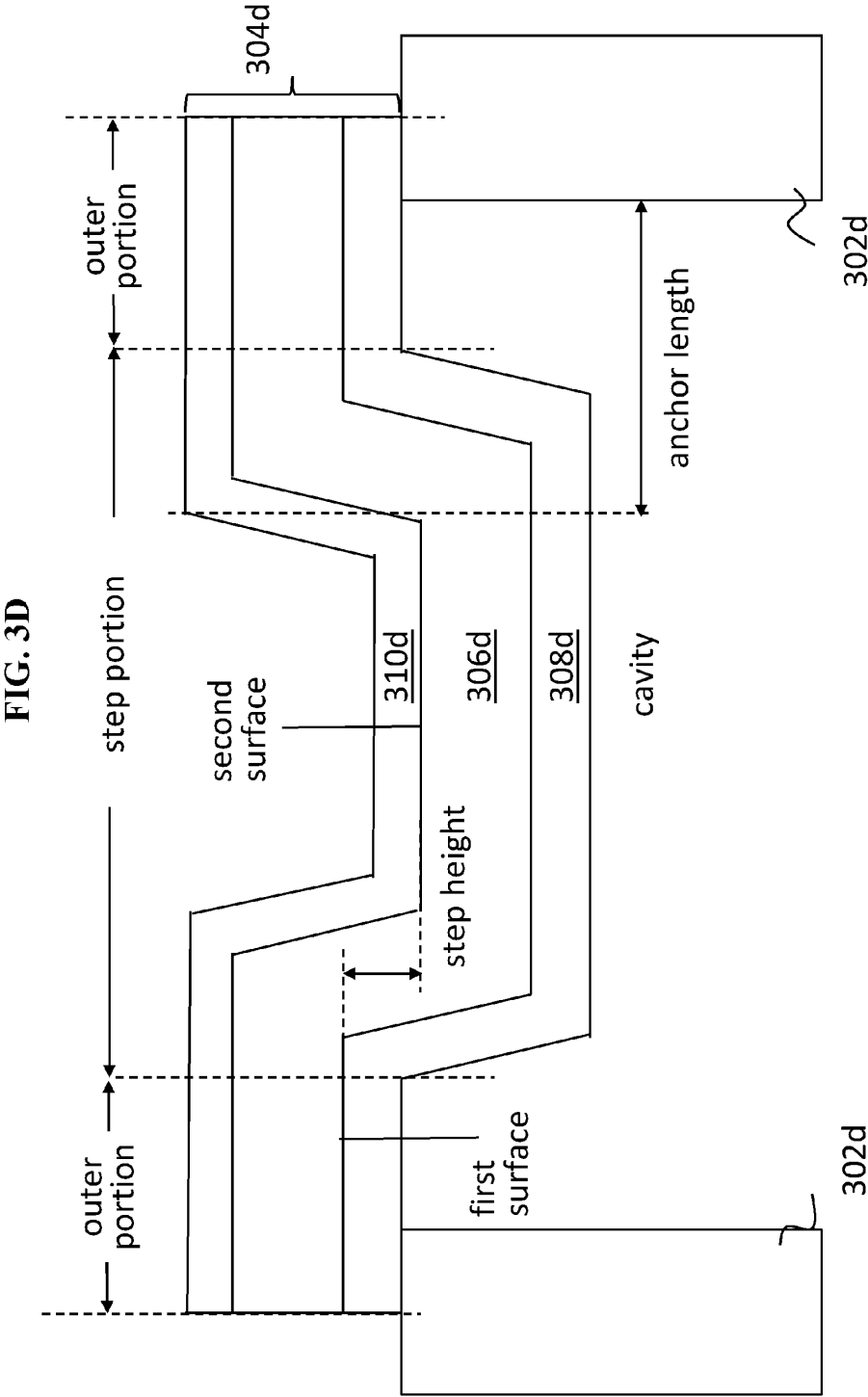


FIG. 3E

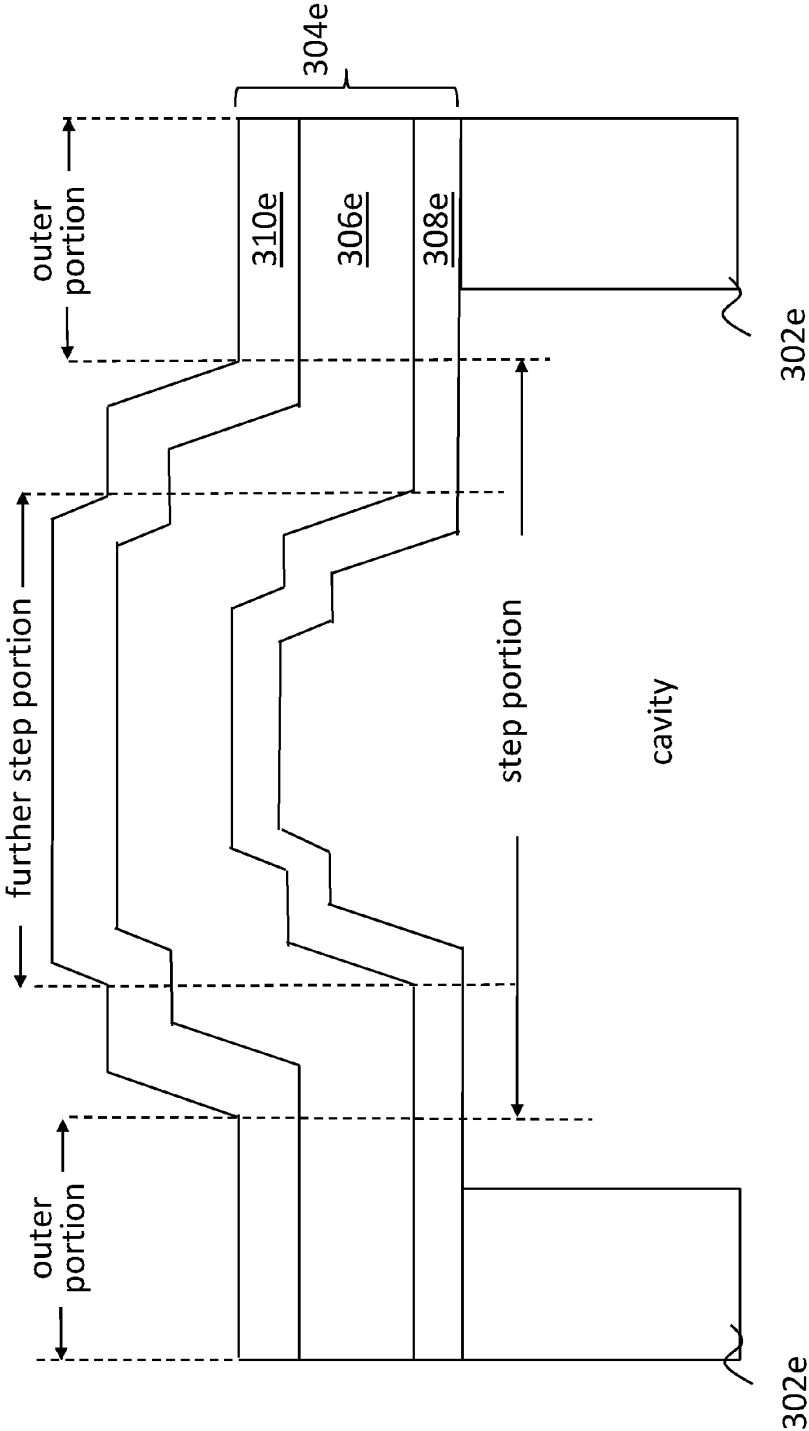


FIG. 3F

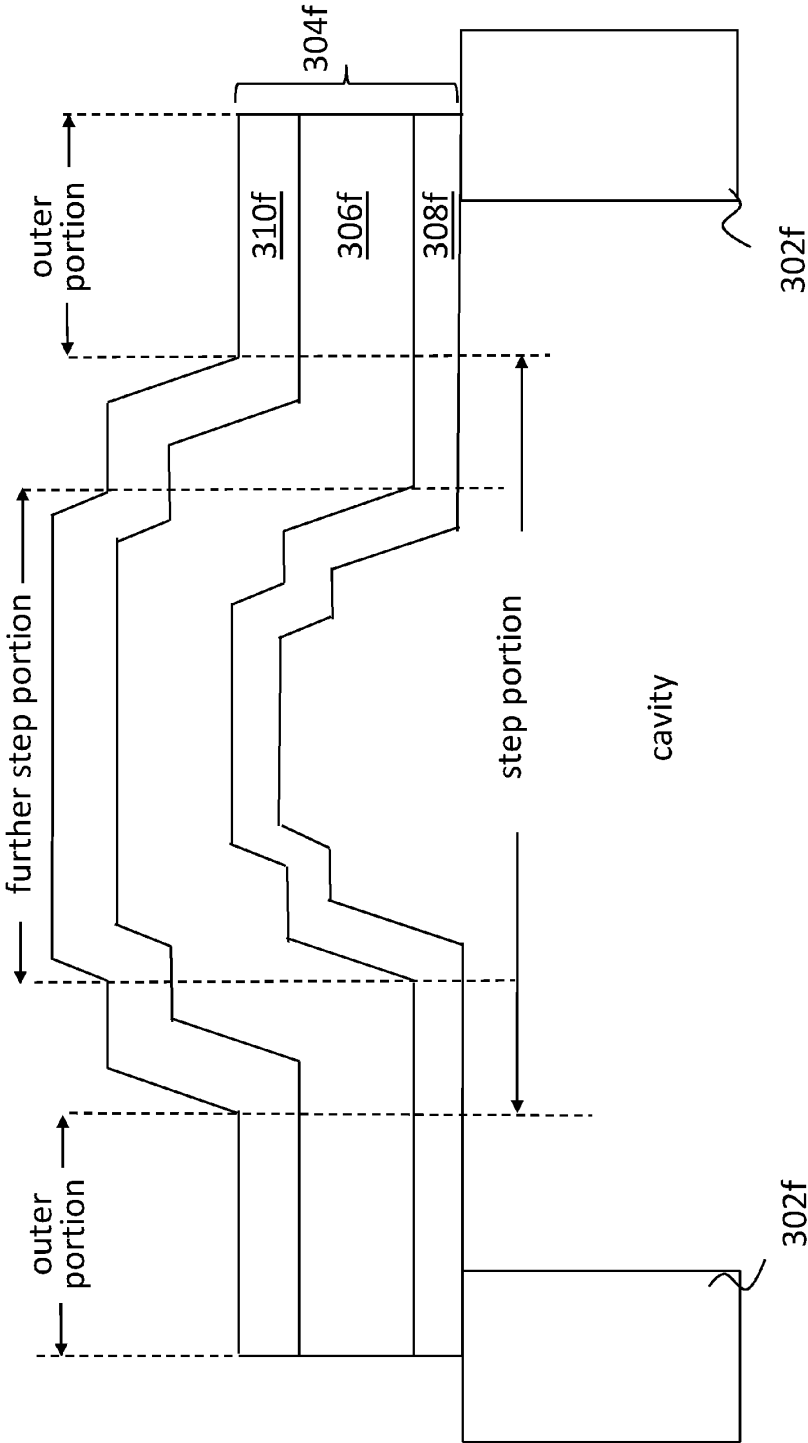


FIG. 3G

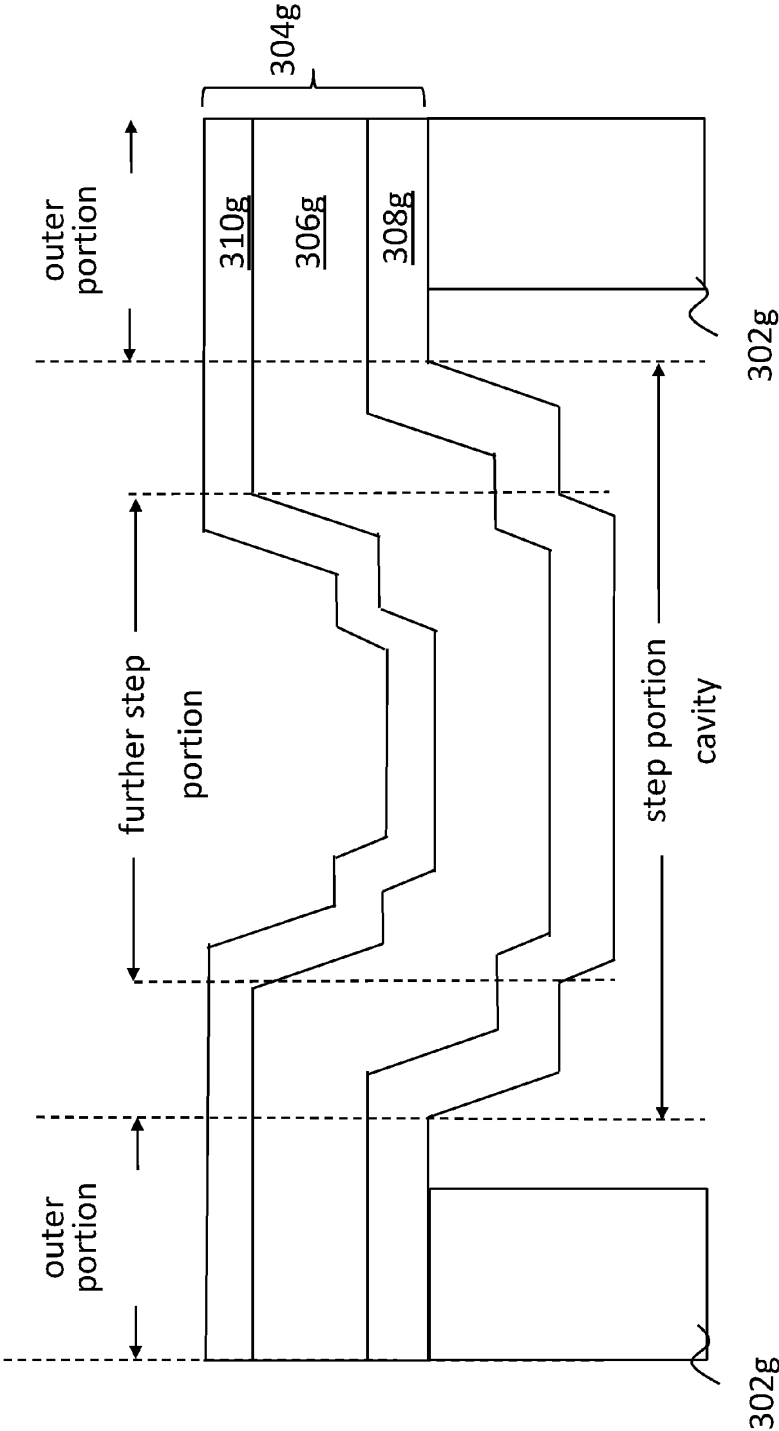
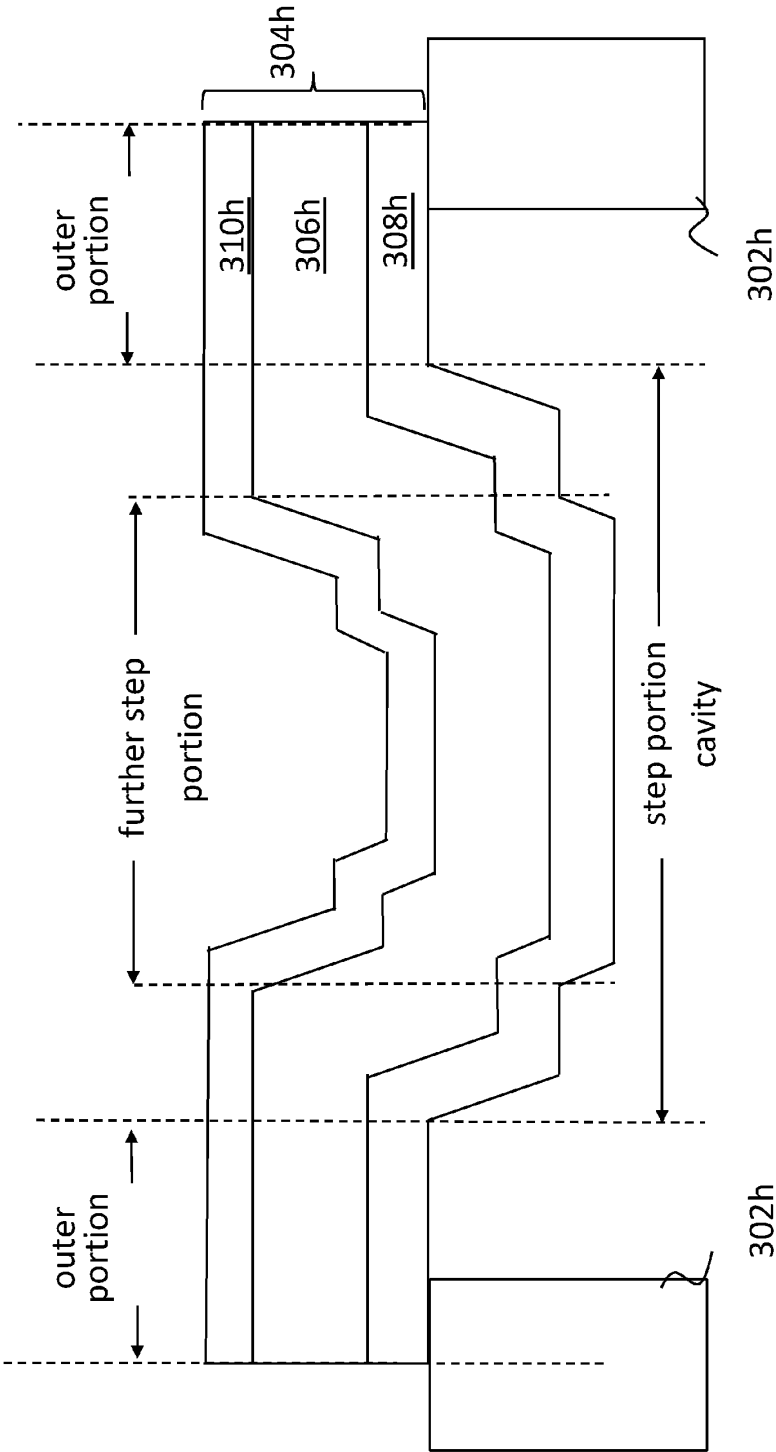
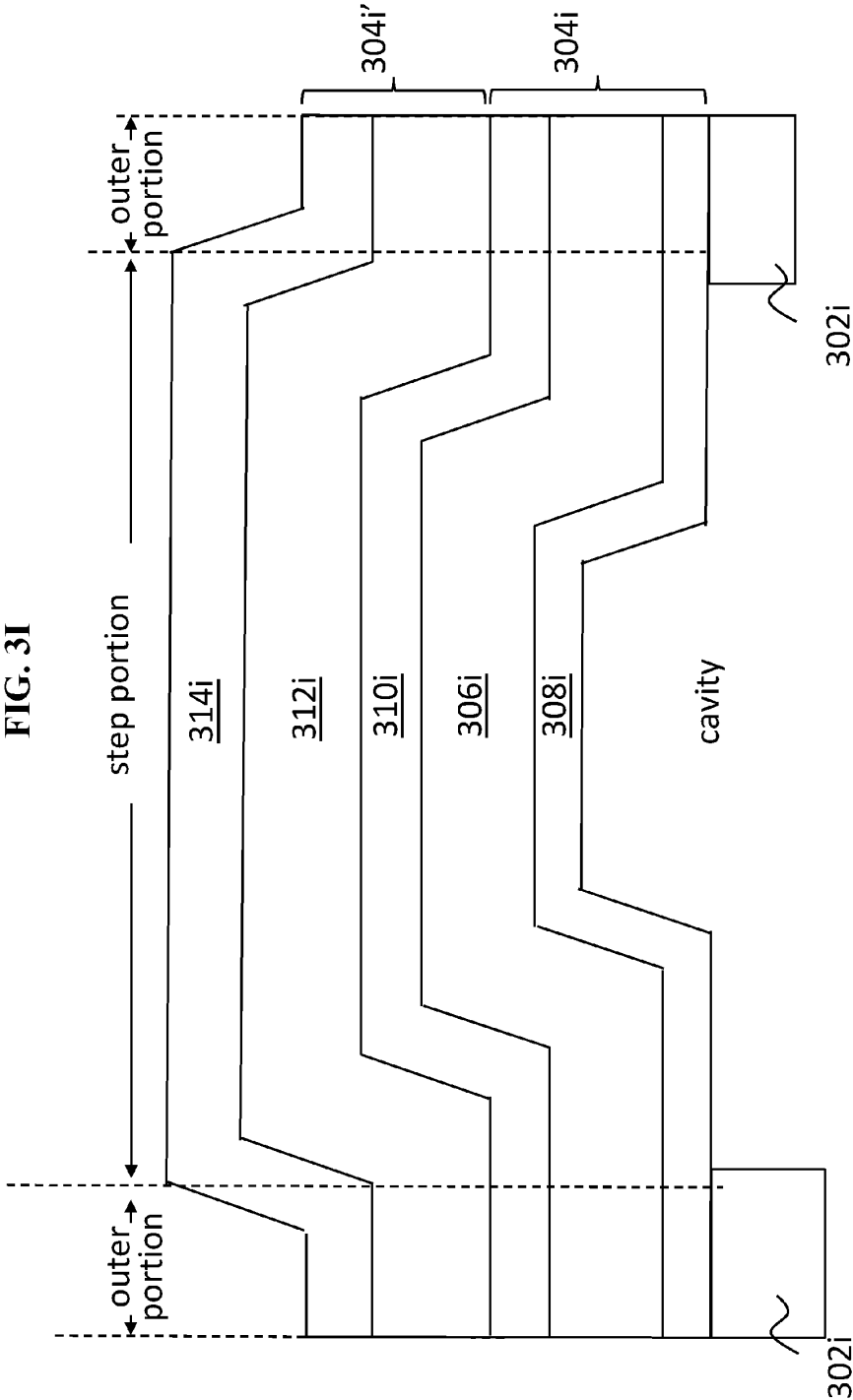


FIG. 3H





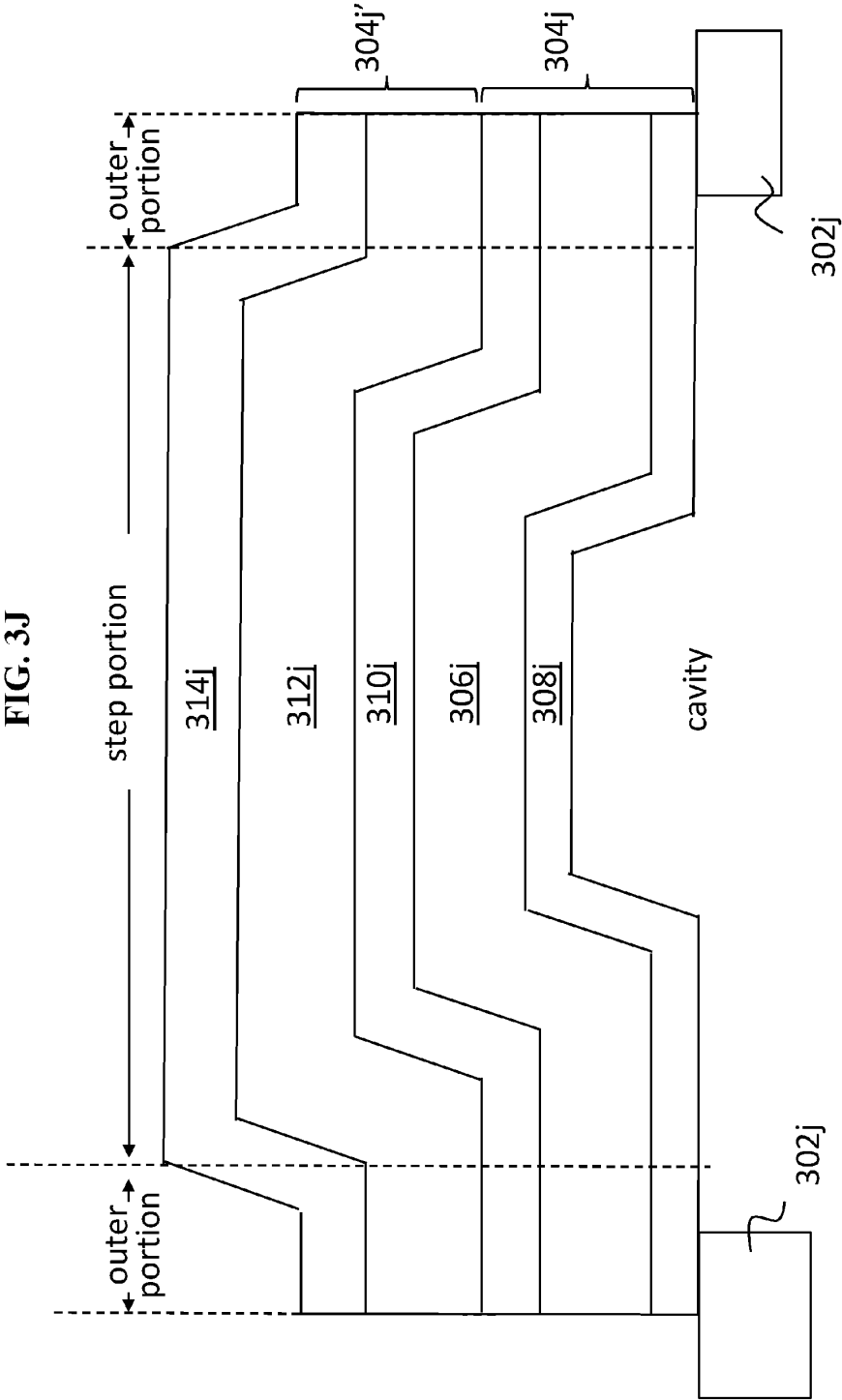


FIG. 3K

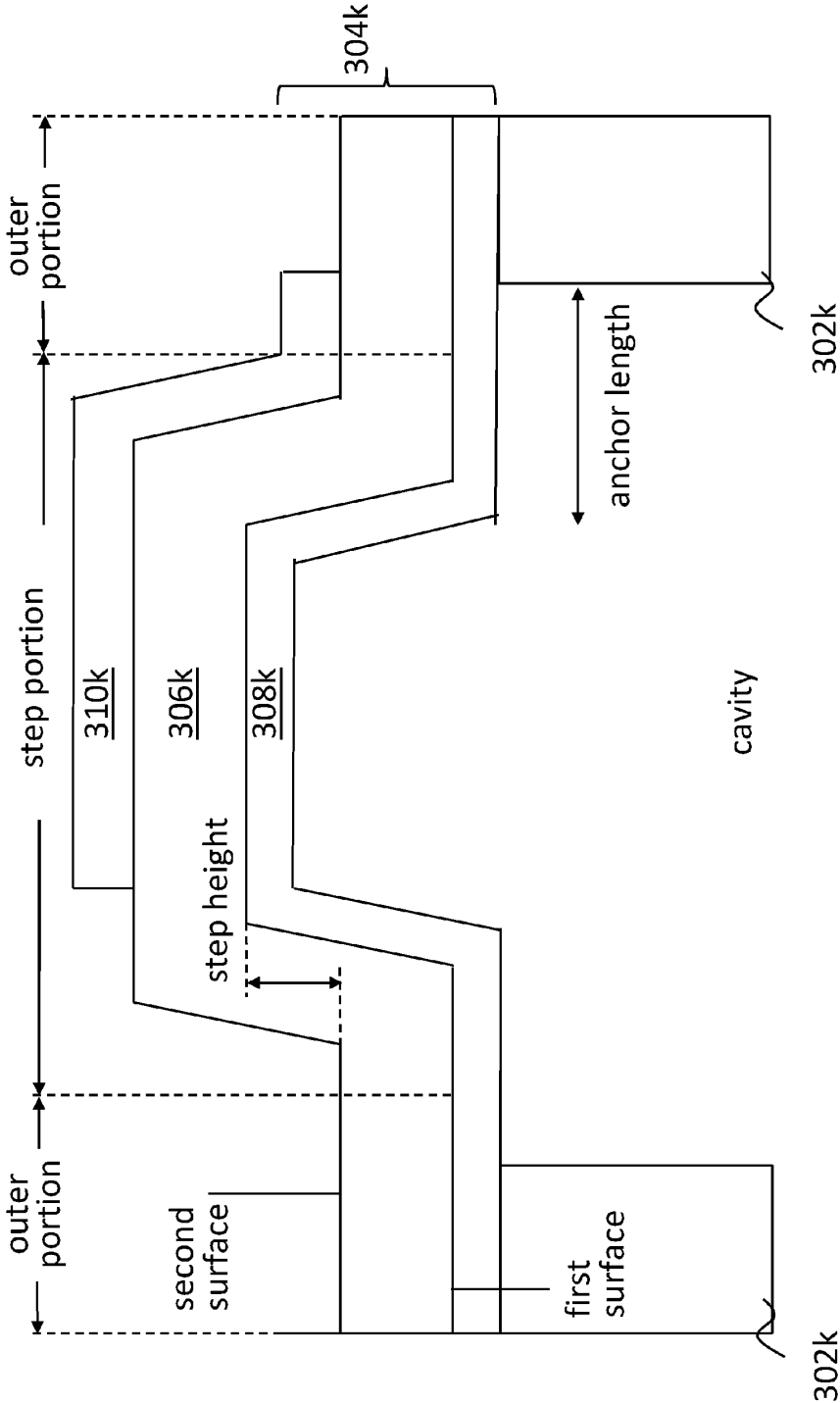


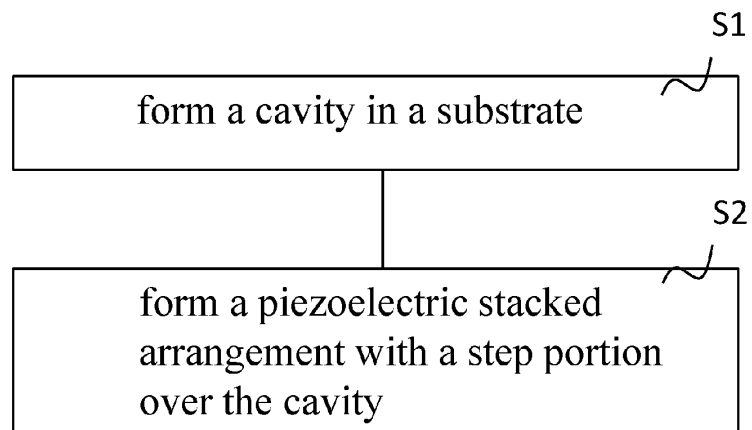
FIG. 4A

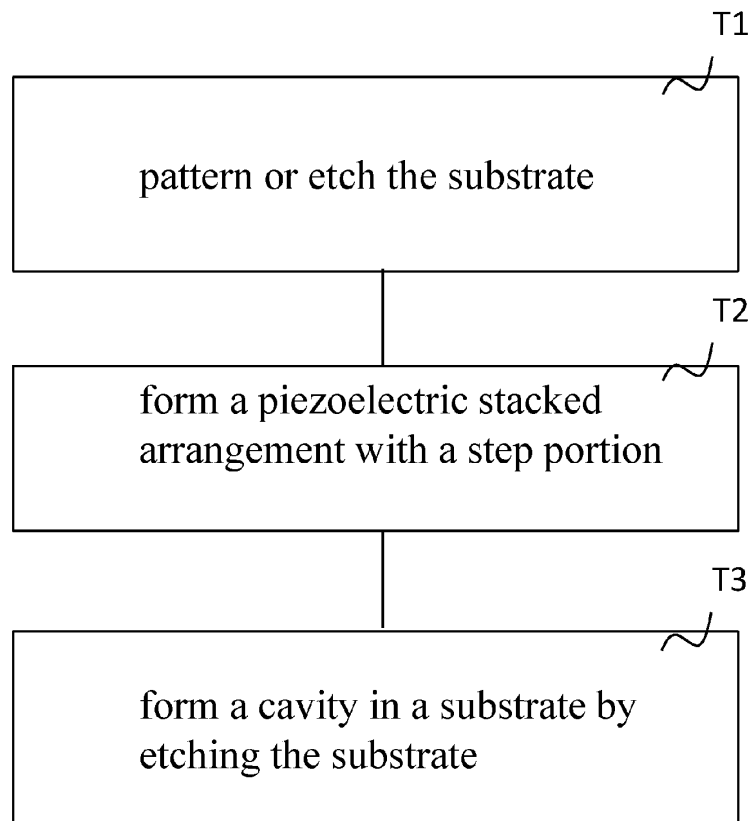
FIG. 4B

FIG. 5

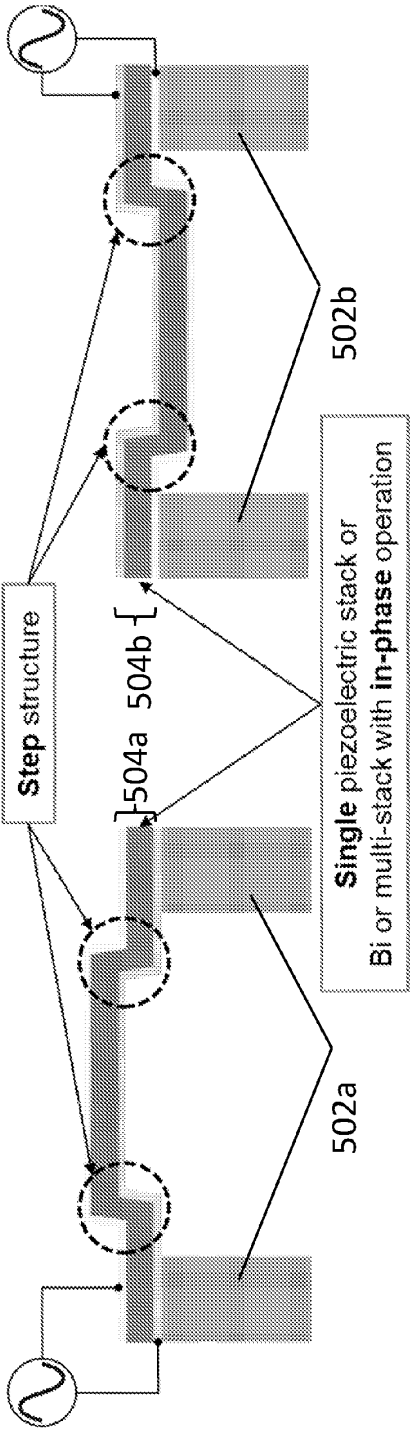


FIG. 6

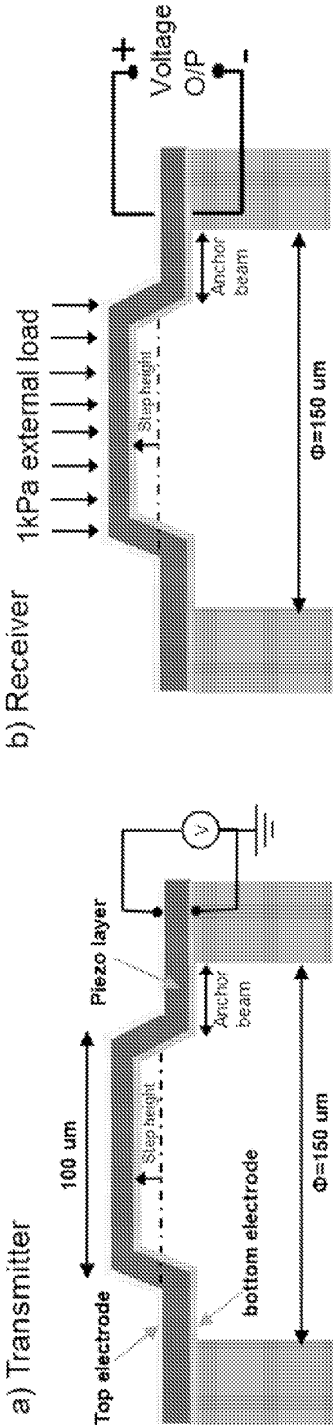


FIG. 7A

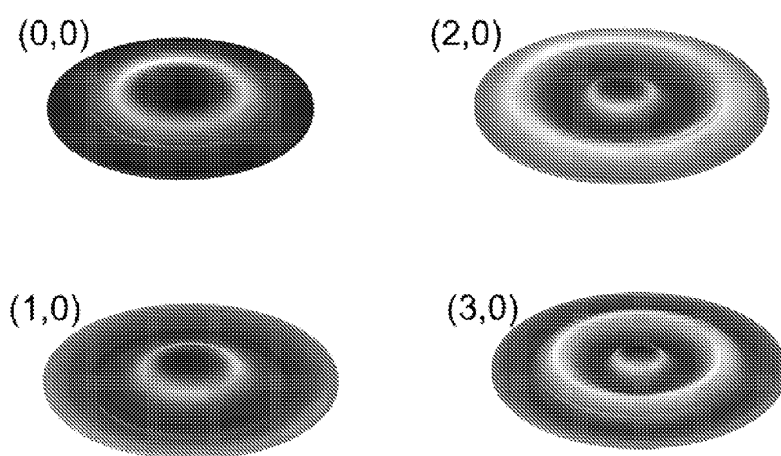


FIG. 7B

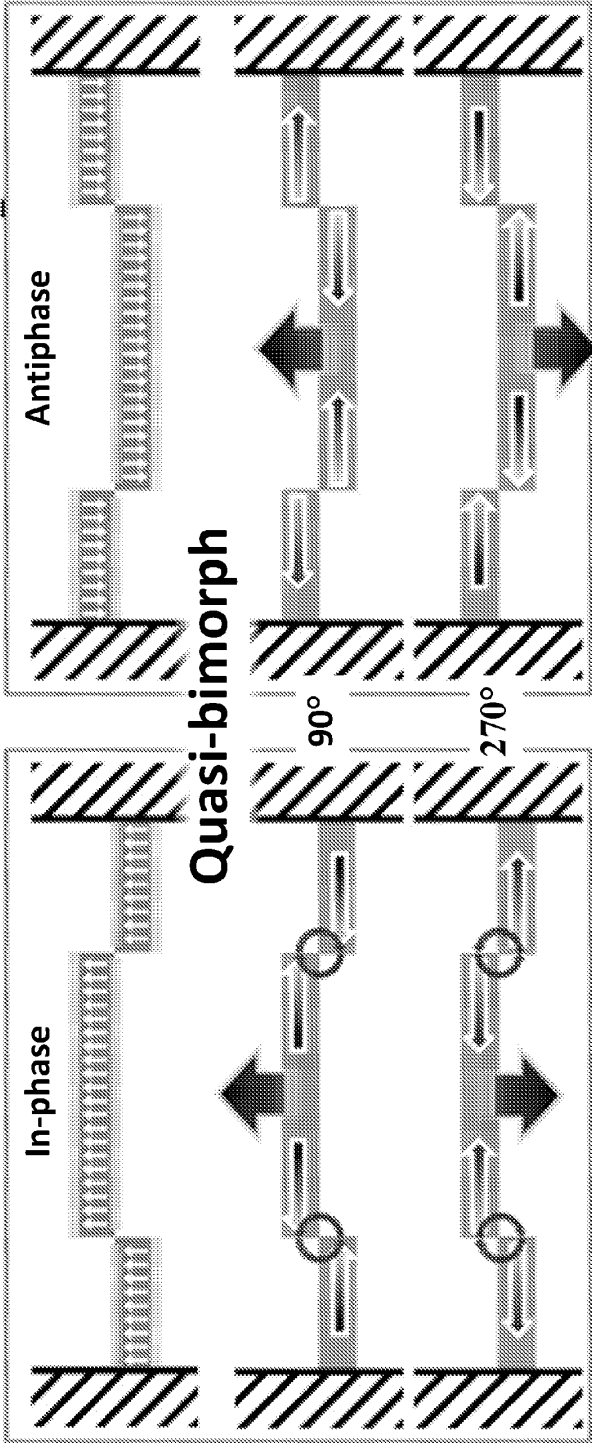
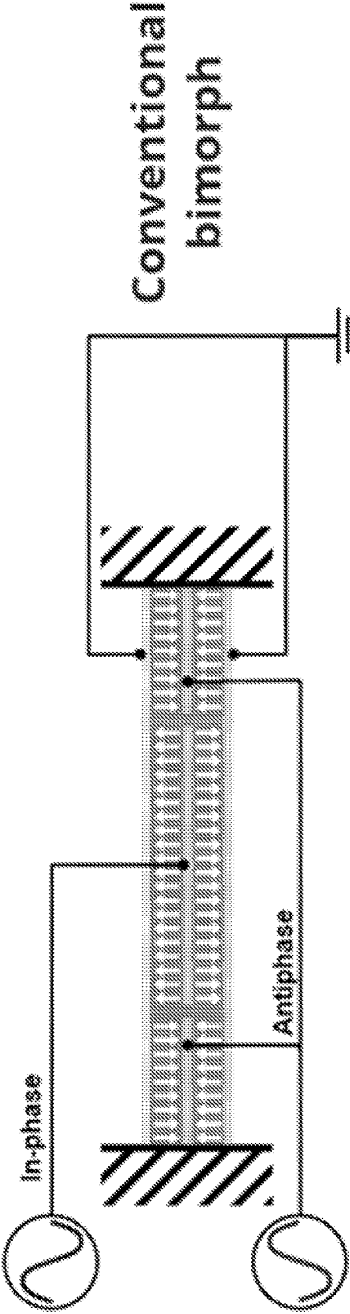


FIG. 7C



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FIG. 8A

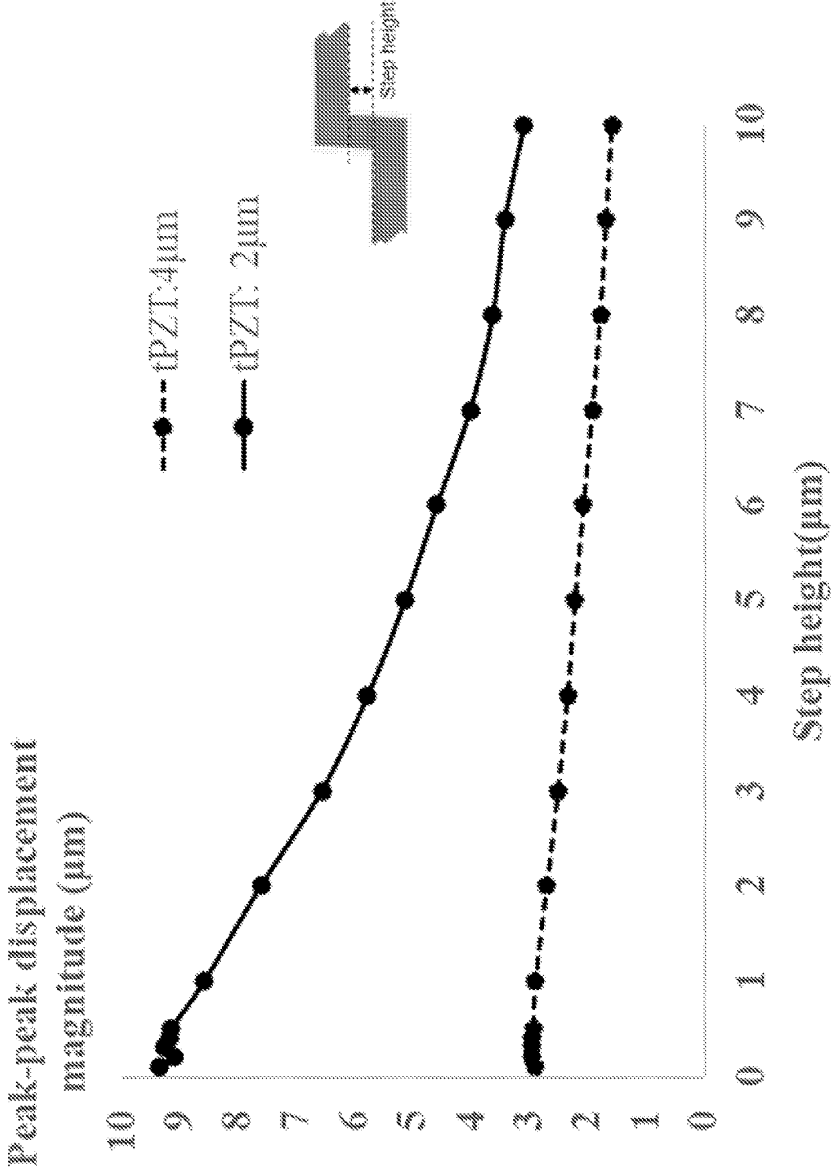


FIG. 8B

	Peak-Peak displacement at resonance (mm)	
Step height (μm)	tPZT=4 μm	tPZT=2 μm
0.1	2.91	9.35
0.2	2.97	9.09
0.3	2.96	9.28
0.4	2.96	9.18
0.5	2.93	9.15
1	2.89	8.59
2	2.70	7.62
3	2.50	6.57
4	2.34	5.78
5	2.21	5.14
6	2.07	4.59
7	1.91	4.02
8	1.78	3.63
9	1.68	3.42
10	1.58	3.09

FIG. 9A

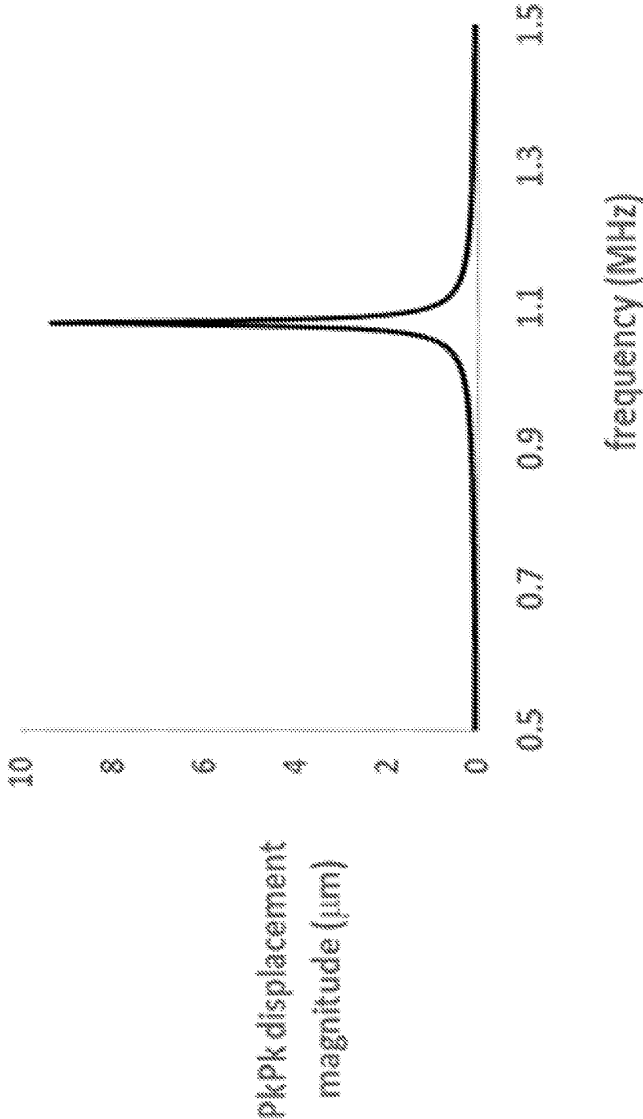


FIG. 9B

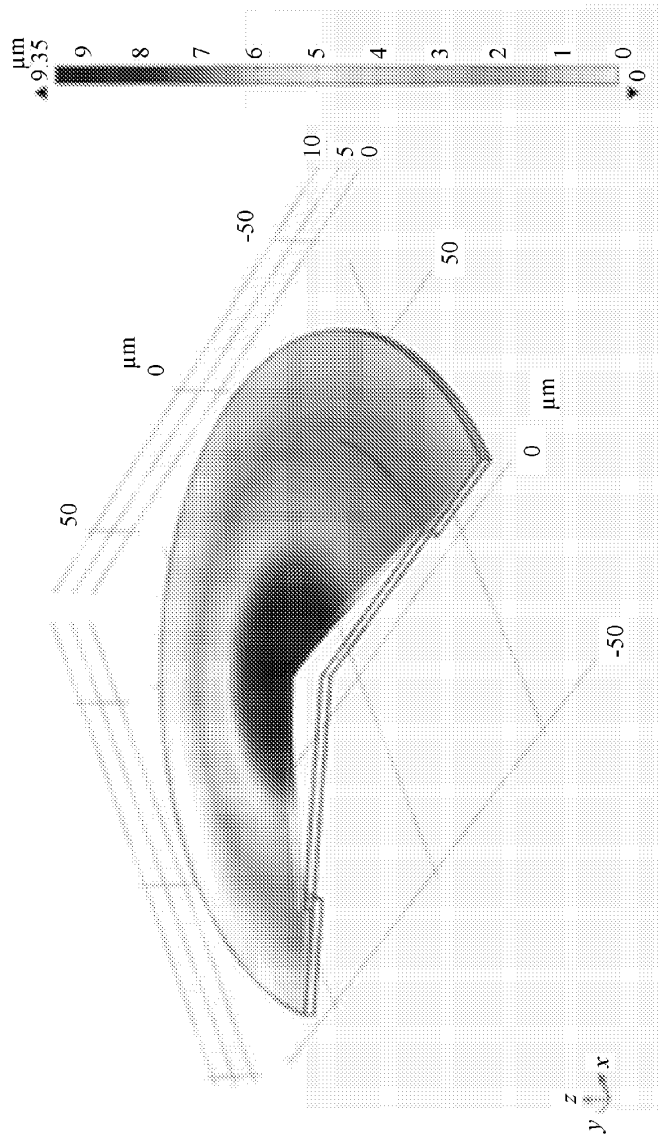


FIG. 9C

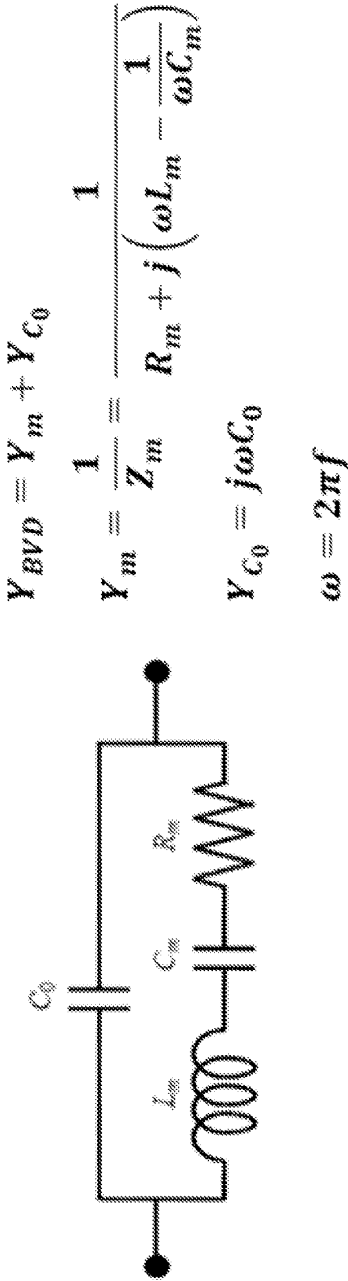


FIG. 9D

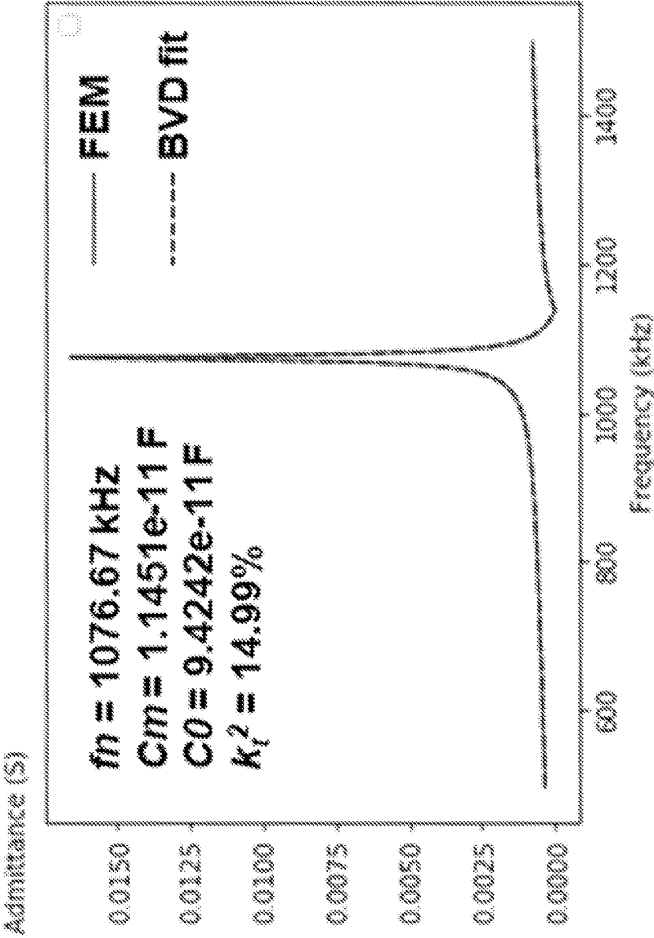


FIG. 10A

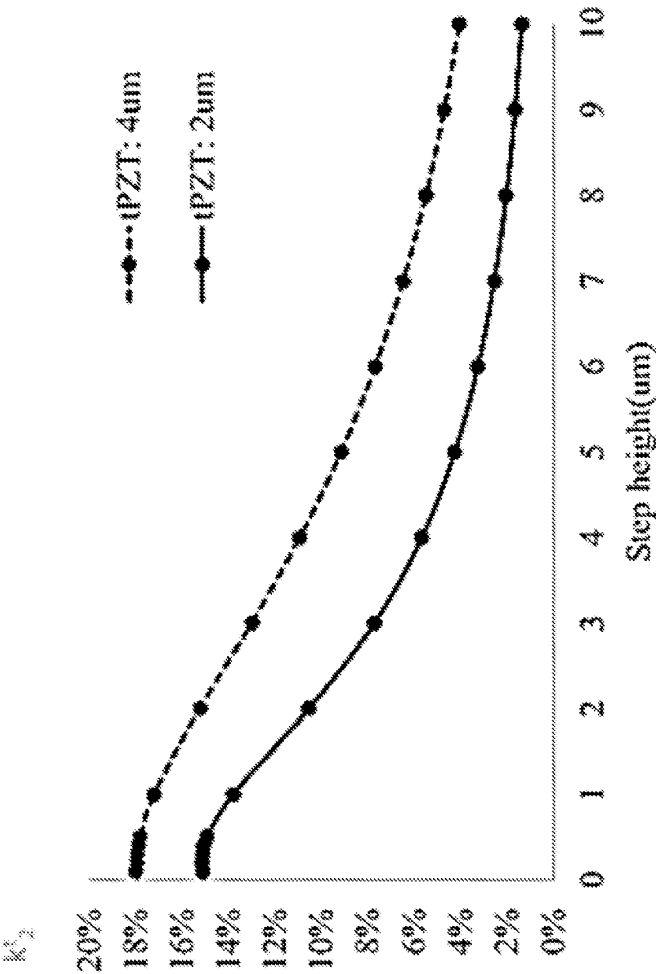


FIG. 10B

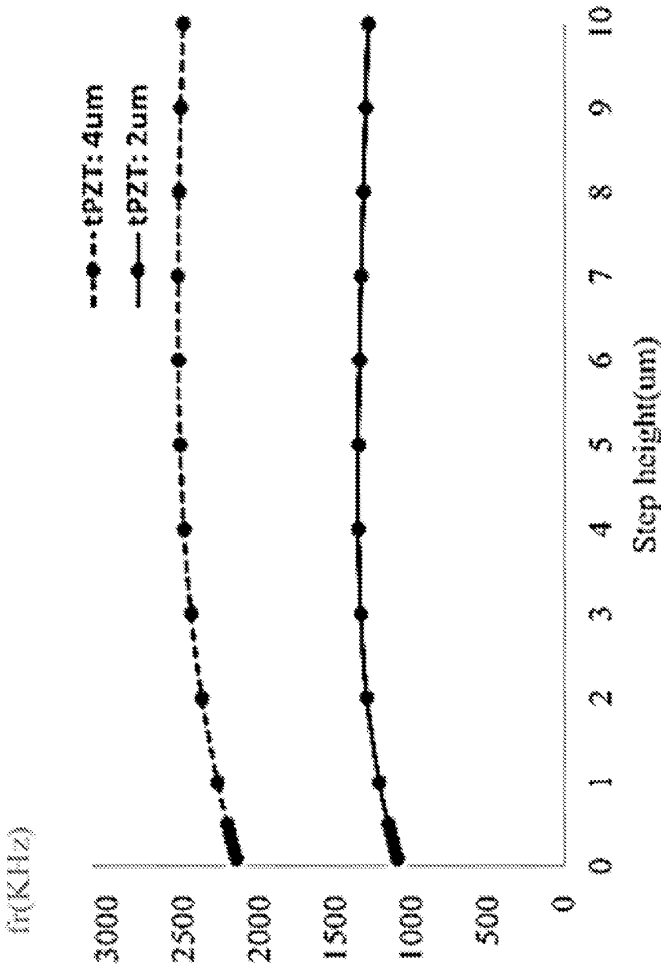


FIG. 10C

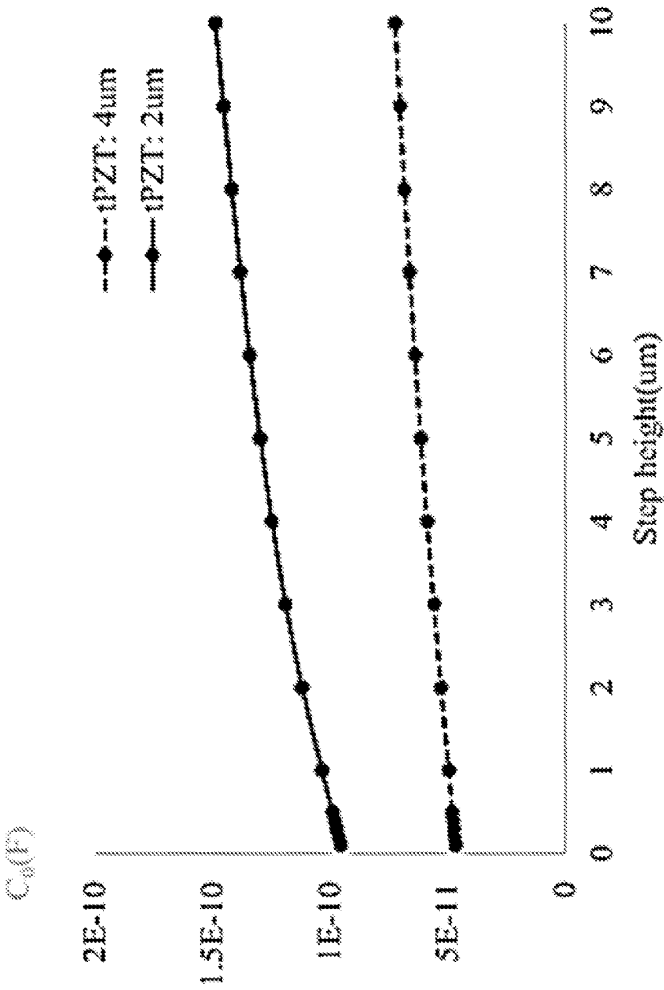


FIG. 10D

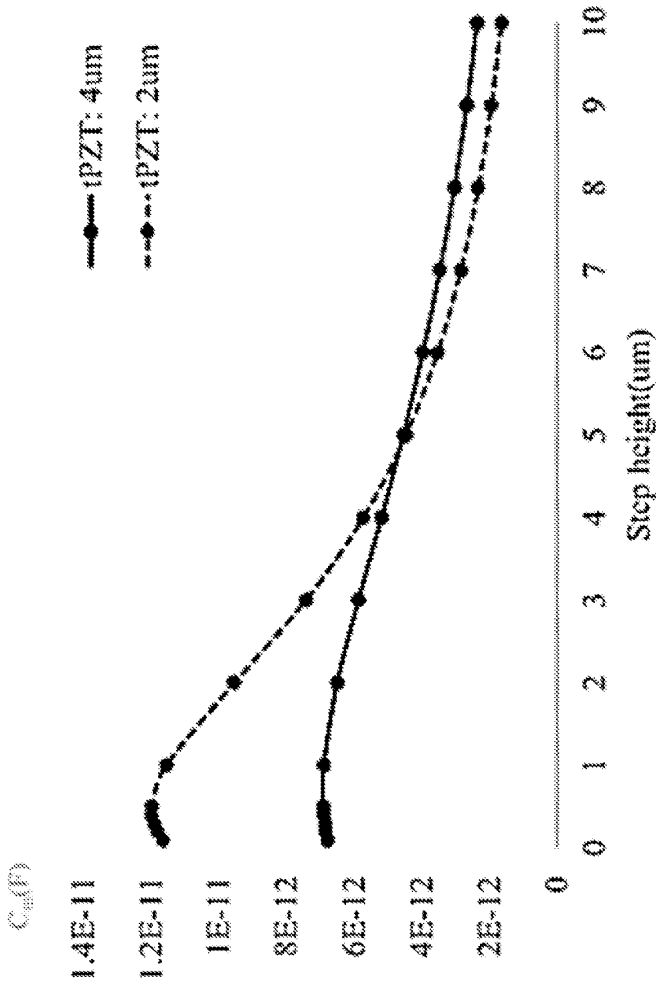


FIG. 10E

PZT thickness = 4 μm					PZT thickness = 2 μm				
Step height (μm)	k _t ² (%)	f _t (kHz)	C ₀ (F)	C _m (F)	Step height (μm)	k _t ² (%)	f _t (kHz)	C ₀ (F)	C _m (F)
0.1	17.98	2151	4.66E-11	6.80E-12	0.1	15.09	1092	9.53E-11	1.17E-11
0.2	17.98	2166	4.69E-11	6.84E-12	0.2	15.15	1108	9.62E-11	1.18E-11
0.3	17.94	2180	4.72E-11	6.87E-12	0.3	15.14	1123	9.72E-11	1.19E-11
0.4	17.89	2195	4.76E-11	6.89E-12	0.4	15.07	1137	9.81E-11	1.20E-11
0.5	17.81	2209	4.79E-11	6.91E-12	0.5	14.94	1151	9.90E-11	1.20E-11
1	17.20	2275	4.95E-11	6.90E-12	1	13.81	1212	1.03E-10	1.16E-11
2	15.24	2379	5.27E-11	6.51E-12	2	10.54	1293	1.12E-10	9.55E-12
3	13.00	2451	5.58E-11	5.88E-12	3	7.72	1333	1.19E-10	7.43E-12
4	10.92	2496	5.87E-11	5.19E-12	4	5.68	1348	1.25E-10	5.74E-12
5	9.15	2522	6.13E-11	4.55E-12	5	4.25	1349	1.30E-10	4.47E-12
6	7.68	2533	6.38E-11	3.97E-12	6	3.26	1342	1.34E-10	3.54E-12
7	6.47	2534	6.61E-11	3.47E-12	7	2.55	1330	1.38E-10	2.85E-12
8	5.50	2528	6.82E-11	3.04E-12	8	2.04	1316	1.42E-10	2.34E-12
9	4.70	2516	7.02E-11	2.68E-12	9	1.66	1301	1.45E-10	1.95E-12
10	4.05	2501	7.22E-11	2.37E-12	10	1.38	1286	1.49E-10	1.66E-12

FIG. 11

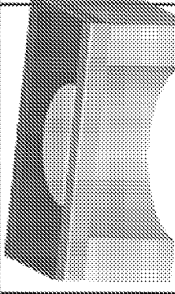
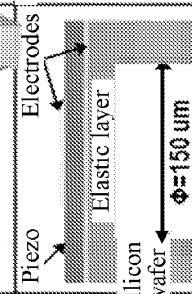
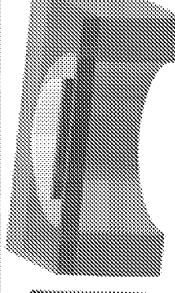
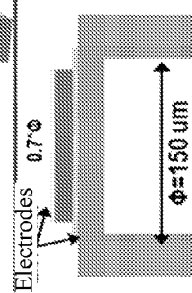
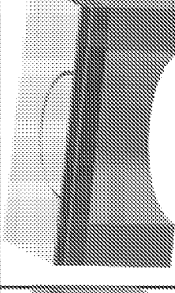
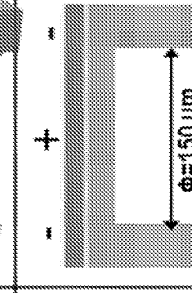
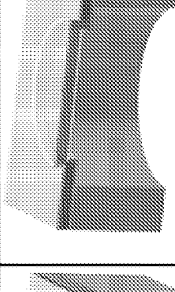
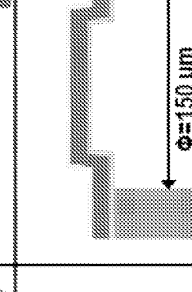
	a) One-port pMUT (Piezo not etched)	b) One-port pMUT (Piezo etched)	c) Two-port pMUT	d) Proposed Quasi-bimorph pMUT
Membrane Structure	 	 	 	 
K_t^2 [%]	6.94	11.74	19.54	15.15

FIG. 12A

Elastic later thickness (μm)	k_f^2		
	a) One-port PMUT (Piezo not etched)	a) One-port PMUT (Piezo etched)	a) Two-port PMUT
1	4.21%	6.90%	6.45%
2	6.29%	17.55%	10.94%
3	6.94%	19.54%	12.53%
4	6.91%	18.35%	12.68%
5	6.62%	16.33%	12.20%
6	6.23%	14.37%	11.48%
10	4.69%	8.99%	8.51%

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FIG. 12B

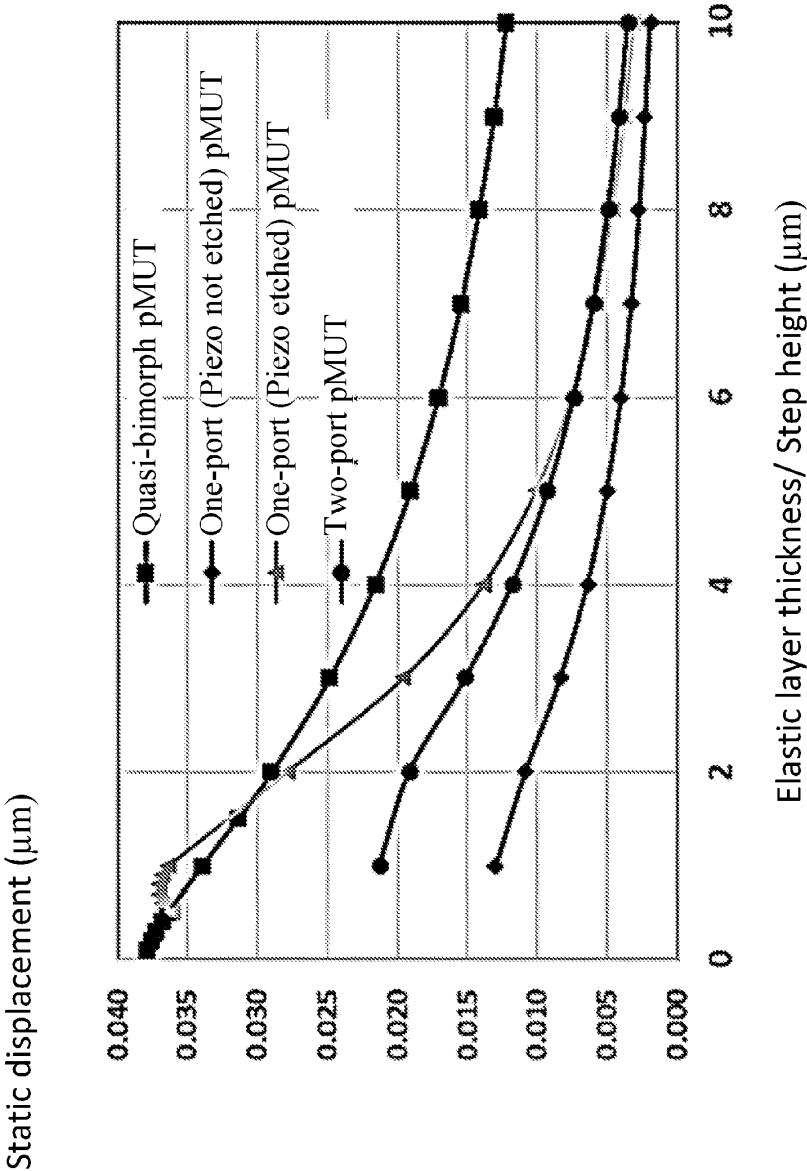


FIG. 13A

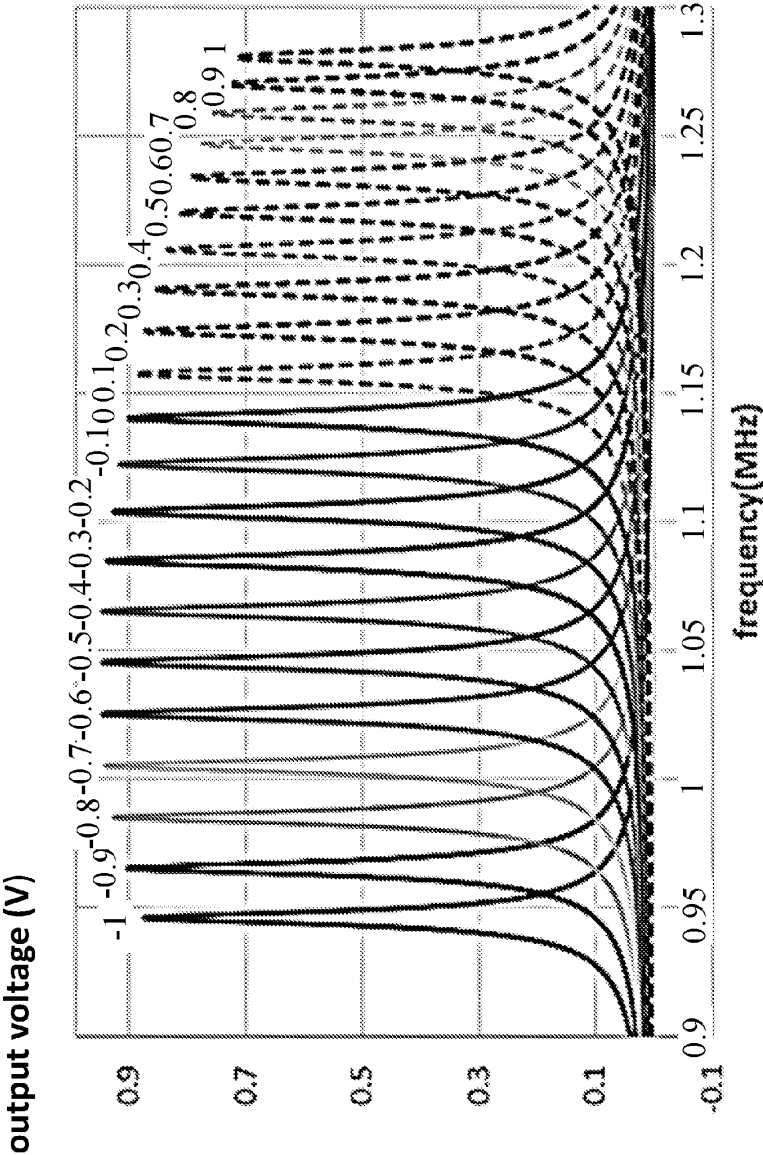


FIG. 13B

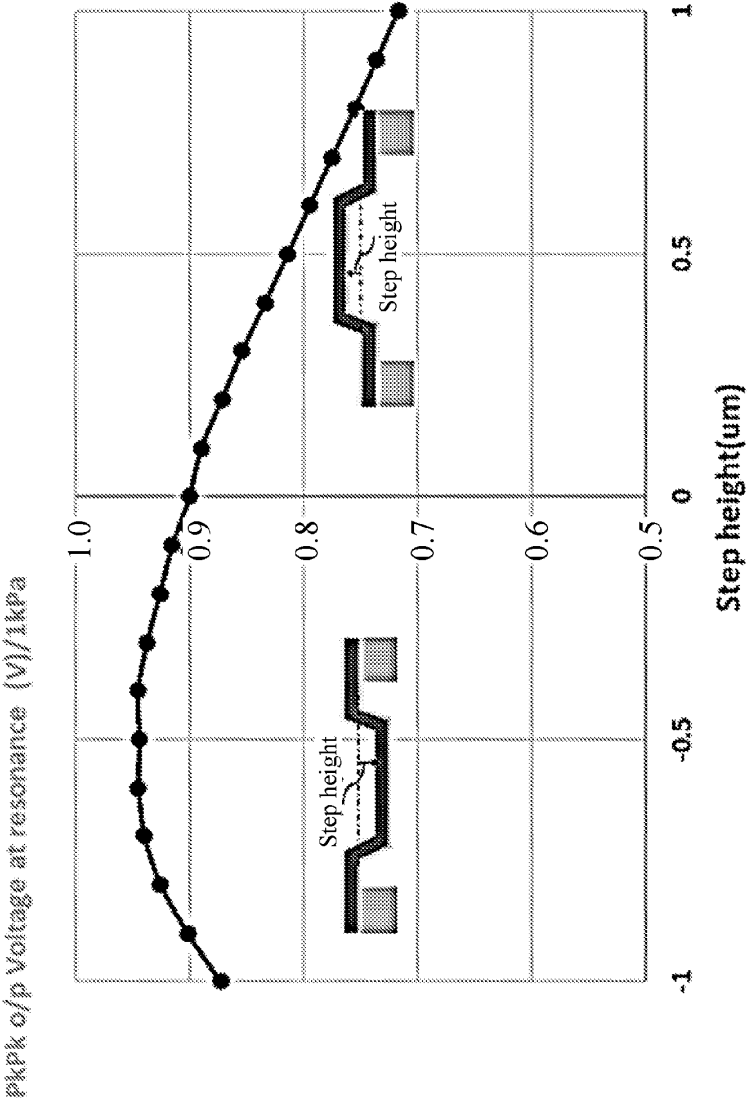


FIG. 13C

Step height (μm)	Fn (MHz)	PkPk Vout (V)/kPa
-1	0.946	0.873
-0.9	0.965	0.902
-0.8	0.985	0.926
-0.7	1.005	0.940
-0.6	1.025	0.945
-0.5	1.045	0.945
-0.4	1.065	0.945
-0.3	1.084	0.938
-0.2	1.104	0.926
-0.1	1.122	0.916
0	1.14	0.901
0.1	1.15	0.890
0.2	1.17	0.872
0.3	1.19	0.854
0.4	1.20	0.834
0.5	1.22	0.814
0.6	1.23	0.795
0.7	1.24	0.775
0.8	1.25	0.755
0.9	1.27	0.736
1	1.28	0.717

FIG. 14

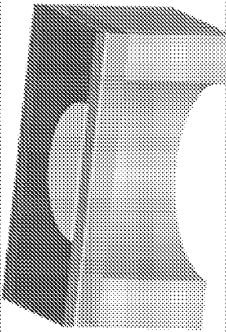
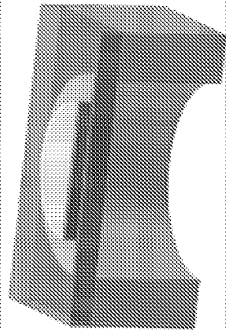
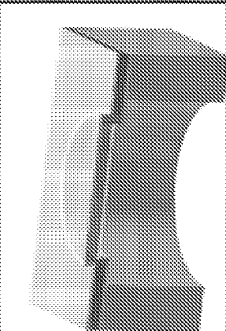
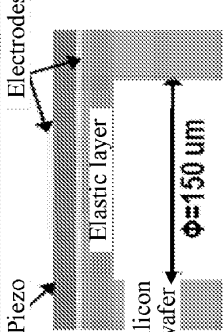
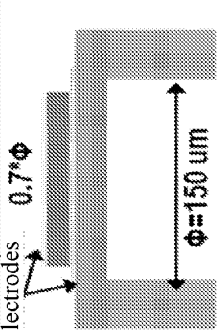
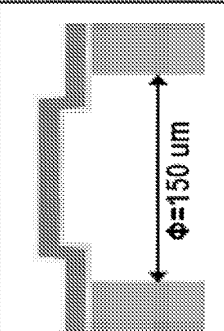
	a) One-port pMUT (Piezo not etched)	b) One-port pMUT (Piezo etched)	c) Proposed Quasi-bimorph pMUT
Membrane Structure			
			
Rx sensitivity	0.31 V/kPa	0.64 V/kPa	0.95 V/kPa

FIG. 15A

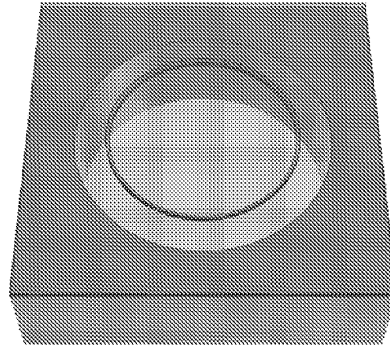


FIG. 15B

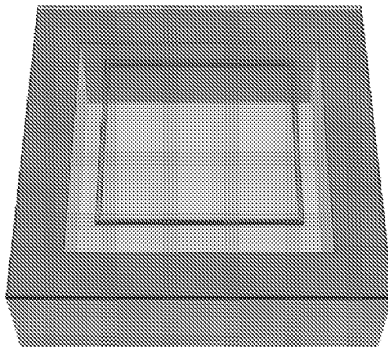


FIG. 15C

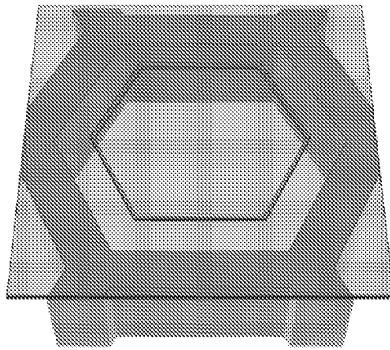


FIG. 15D

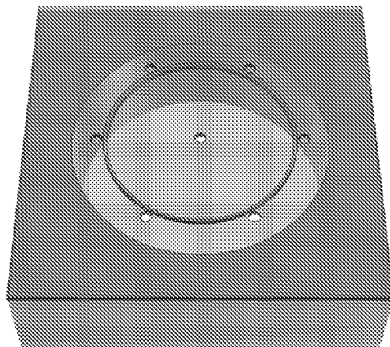


FIG. 15E

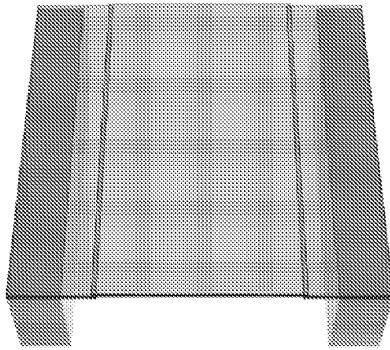


FIG. 15F

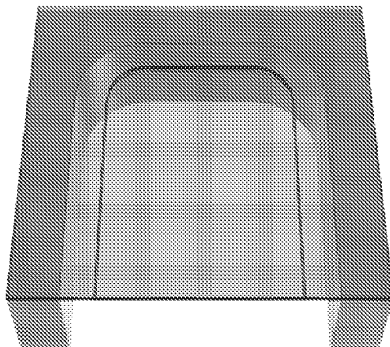


FIG. 16A

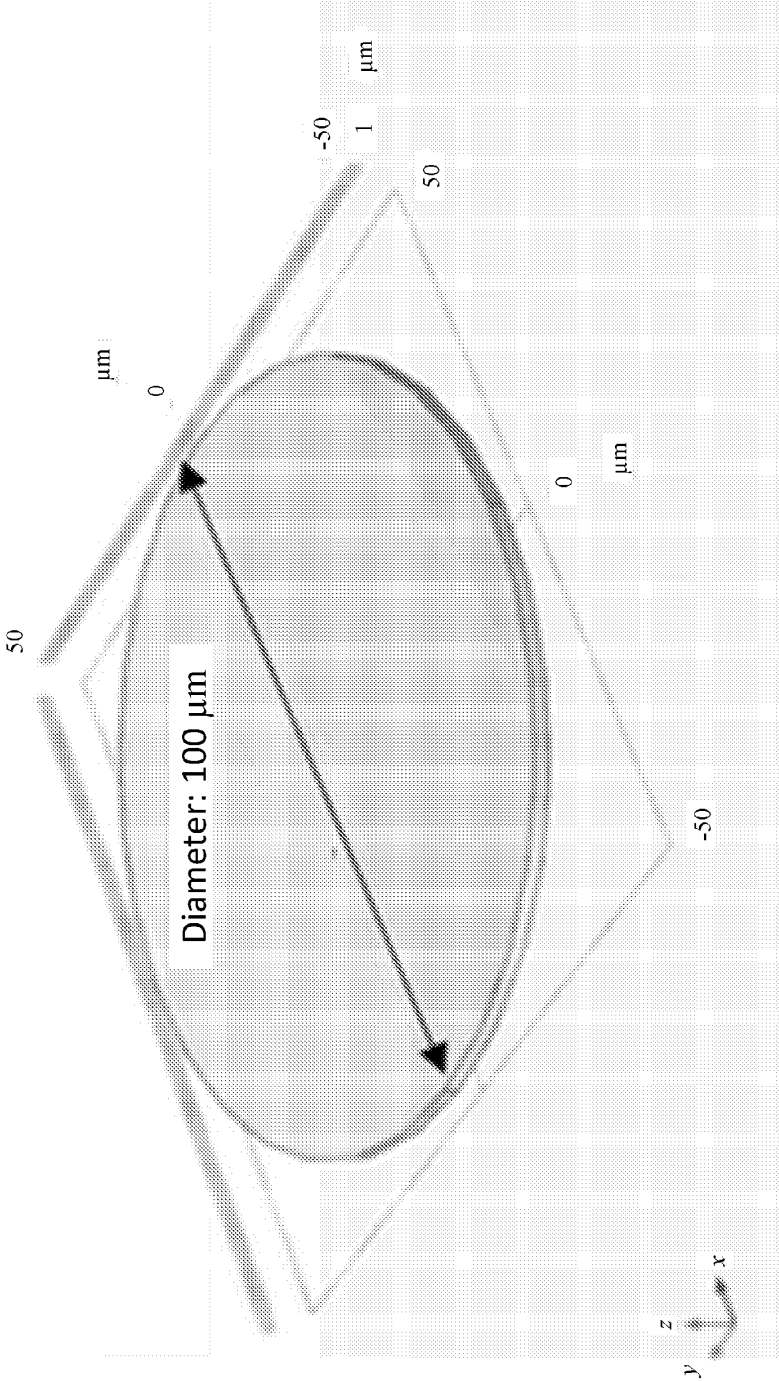


FIG. 16B

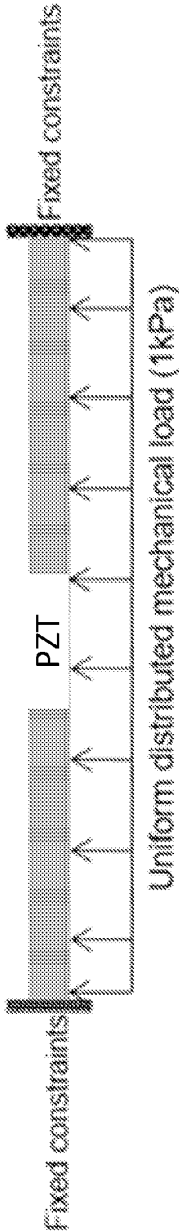


FIG. 16C

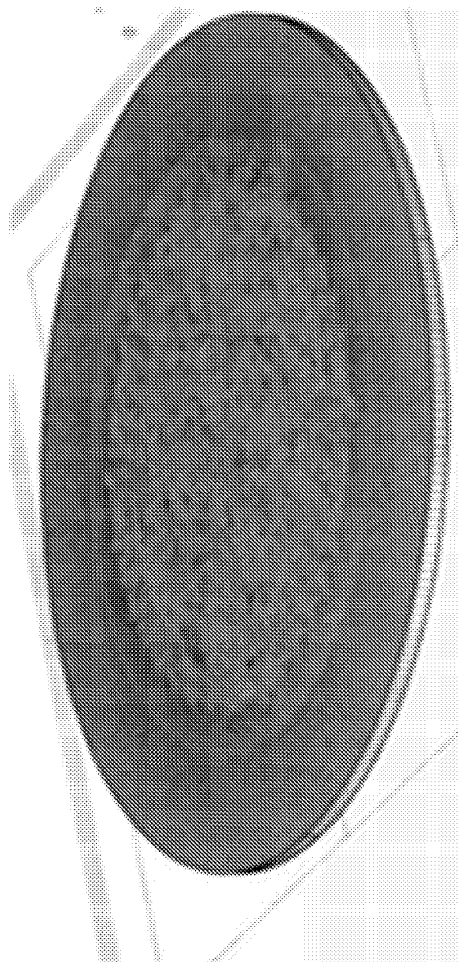


FIG. 16D

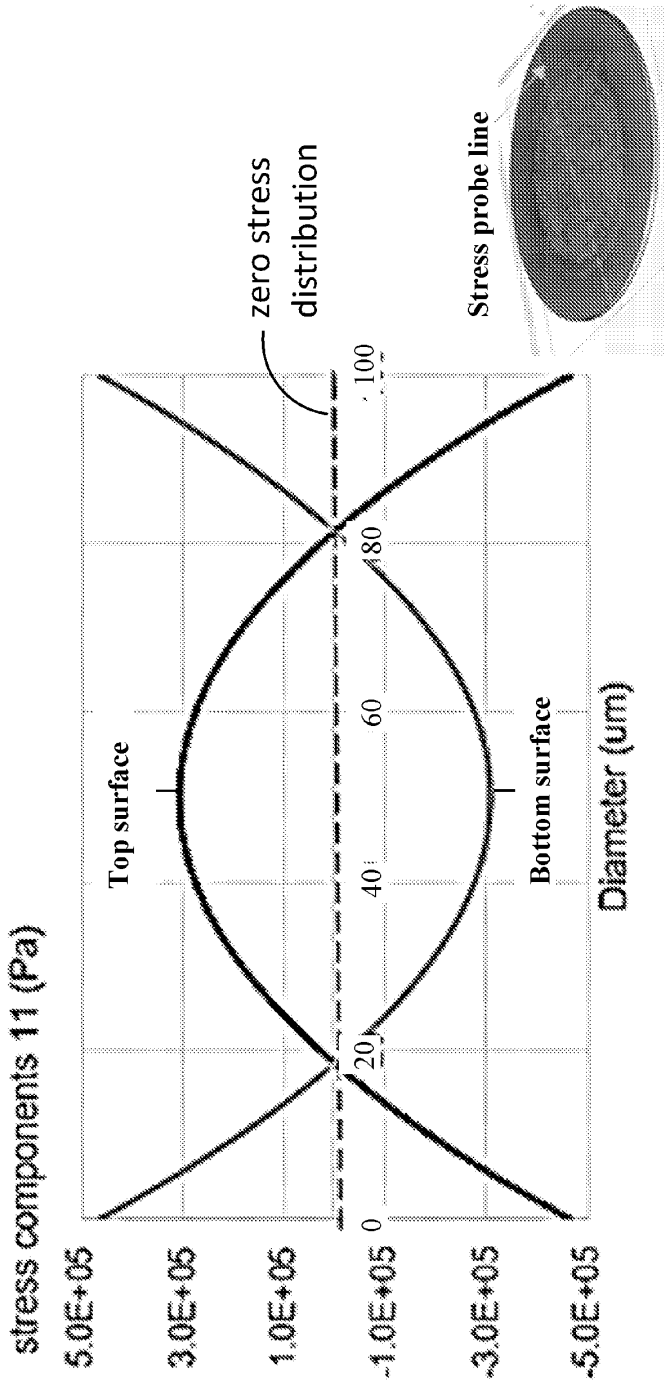


FIG. 16E

Top surface

Bottom surface

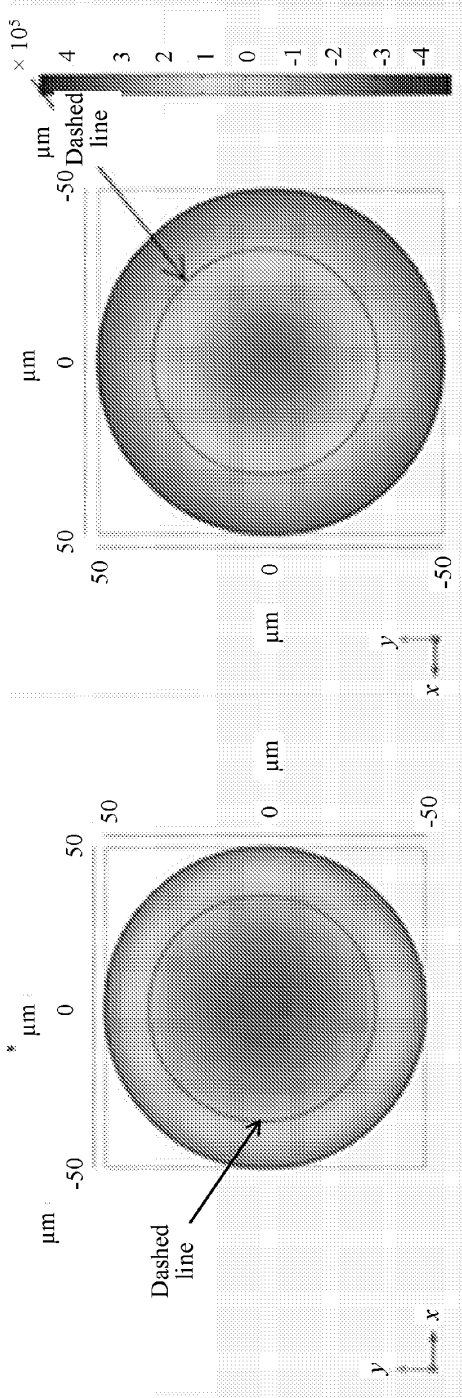


FIG. 17A

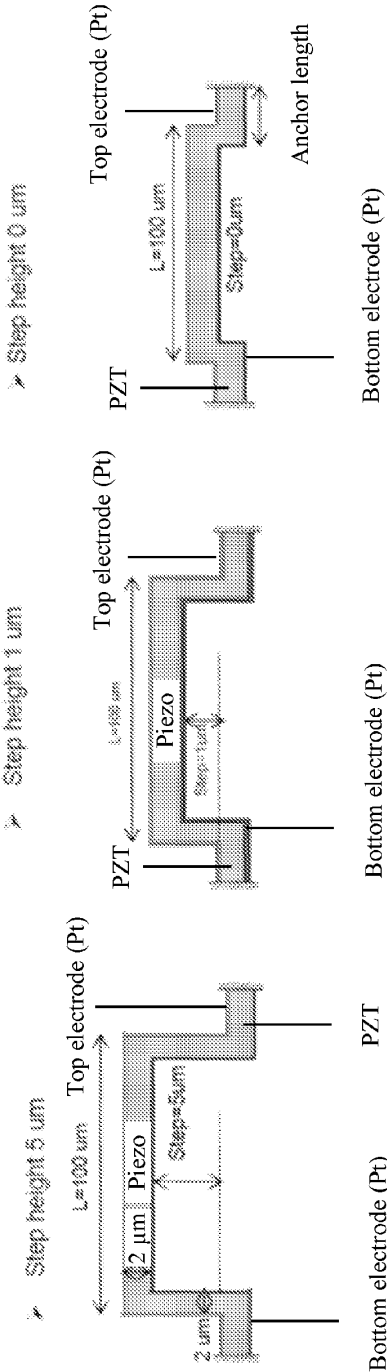


FIG. 17B

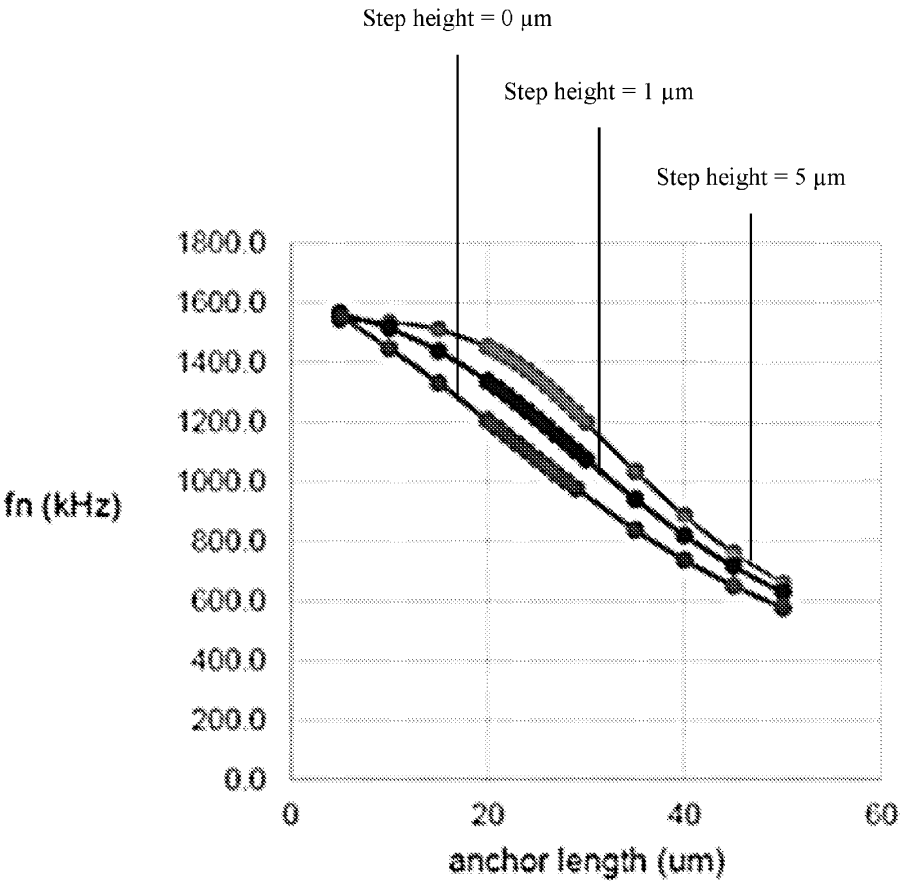


FIG. 17C

