



US00RE42119E

(19) **United States**
(12) **Reissued Patent**
Chui et al.

(10) **Patent Number:** **US RE42,119 E**
(45) **Date of Reissued Patent:** **Feb. 8, 2011**

(54) **MICROELECTROCHEMICAL SYSTEMS
DEVICE AND METHOD FOR FABRICATING
SAME**

EP	0 310 176 A2	4/1989
EP	0 361 981	4/1990
EP	0 667 548 A1	8/1995
EP	0 788 005	8/1997
EP	1484635	12/2004
JP	62 082454	4/1987
JP	2000-75224	3/1990

(75) Inventors: **Clarence Chui**, San Jose, CA (US);
Mark W. Miles, Atlanta, GA (US)

(73) Assignee: **QUALCOMM MEMS Technologies,
Inc.**, San Diego, CA (US)

(Continued)

OTHER PUBLICATIONS

(21) Appl. No.: **11/144,210**

(22) Filed: **Jun. 2, 2005**

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **6,574,033**
Issued: **Jun. 3, 2003**
Appl. No.: **10/084,893**
Filed: **Feb. 27, 2002**

(51) **Int. Cl.**
G02B 26/00 (2006.01)
G02F 1/07 (2006.01)

(52) **U.S. Cl.** **359/291**; 359/247

(58) **Field of Classification Search** 359/230,
359/231, 247, 290, 291, 302

See application file for complete search history.

Pape et al., Characteristics of the deformable mirror device for optical information processing, *Optical Engineering*, 22(6):676-681, Nov.-Dec. 1983.

Notice of Grounds for Rejection in Korean App. No. 2004-7013279, dated Sep. 30, 2008.

Office Action for Japanese Patent App. No. 2003-571782 dated Aug. 20, 2007.

ISR and WO for PCT/US02/013462 filed Apr. 29, 2002.

IPER for PCT/US02/013462 filed Apr. 29, 2002.

Akasaka, "Three-Dimensional IC Trends", *Proceedings of IEEE*, vol. 74, No. 12, pp. 1703-1714, (Dec. 1986).

(Continued)

Primary Examiner—William C Choi

(74) *Attorney, Agent, or Firm*—Knobb Martens Olson & Bear LLP

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,534,846 A	12/1950	Ambrose et al.
3,037,189 A	5/1962	Barrett et al.
3,210,757 A	10/1965	Jacob
3,439,973 A	4/1969	Paul et al.
3,443,854 A	5/1969	Weiss
3,653,741 A	4/1972	Marks
3,656,836 A	4/1972	de Cremoux et al.
3,725,868 A	4/1973	Malmer, Jr. et al.

(Continued)

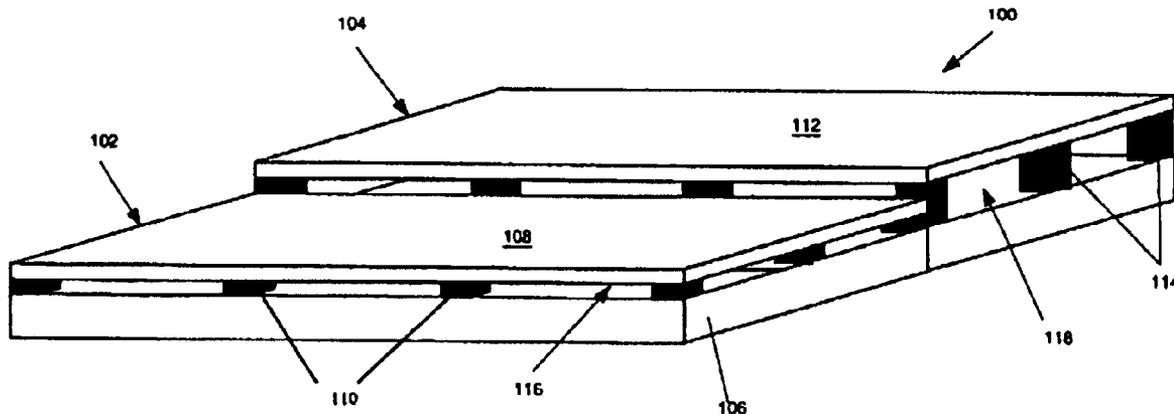
FOREIGN PATENT DOCUMENTS

DE 4108966 A1 9/1992

(57) **ABSTRACT**

One aspect of the invention provides a method for fabricating a microelectromechanical systems device. The method comprises fabricating an array of first elements, each first element conforming to a first geometry; fabricating at least one array of second elements, each second element conforming to a second geometry; wherein fabricating the arrays comprises selecting a defining aspect of each of the first and second geometries based on a defining characteristic of each of the first and second elements; and normalizing differences in an actuation voltage required to actuate each of the first and second elements, wherein the differences are as a result of the selected defining aspect, the defining characteristic of each of the elements being unchanged.

73 Claims, 10 Drawing Sheets



U.S. PATENT DOCUMENTS							
3,813,265	A	5/1974	Marks	5,231,532	A	7/1993	Magel et al.
3,955,190	A	5/1976	Teraishi	5,233,385	A	8/1993	Sampsell
3,955,880	A	5/1976	Lierke	5,233,456	A	8/1993	Nelson
4,099,854	A	7/1978	Decker et al.	5,233,459	A	8/1993	Bozler et al.
4,196,396	A	4/1980	Smith	5,254,980	A	10/1993	Hendrix et al.
4,228,437	A	10/1980	Shelton	5,272,473	A	12/1993	Thompson et al.
4,377,324	A	3/1983	Durand et al.	5,278,652	A	1/1994	Urbanus et al.
4,389,096	A	6/1983	Hori et al.	5,280,277	A	1/1994	Hornbeck
4,392,711	A	7/1983	Moraw et al.	5,287,096	A	2/1994	Thompson et al.
4,403,248	A	9/1983	te Velde	5,293,272	A	3/1994	Jansson et al.
4,441,791	A	4/1984	Hornbeck	5,296,950	A	3/1994	Lin et al.
4,445,050	A	4/1984	Marks	5,305,640	A	4/1994	Boysel et al.
4,459,182	A	7/1984	te Velde	5,311,360	A	5/1994	Bloom et al.
4,482,213	A	11/1984	Piliavin et al.	5,312,513	A	5/1994	Florence et al.
4,500,171	A	2/1985	Penz et al.	5,315,370	A	5/1994	Bulow
4,519,676	A	5/1985	te Velde	5,323,002	A	6/1994	Sampsell et al.
4,531,126	A	7/1985	Sadones	5,324,683	A	6/1994	Fitch et al.
4,566,935	A	1/1986	Hornbeck	5,325,116	A	6/1994	Sampsell
4,571,603	A	2/1986	Hornbeck et al.	5,326,430	A	7/1994	Cronin et al.
4,596,992	A	6/1986	Hornbeck	5,327,286	A	7/1994	Sampsell et al.
4,615,595	A	10/1986	Hornbeck	5,331,454	A	7/1994	Hornbeck
4,662,746	A	5/1987	Hornbeck	5,339,116	A	8/1994	Urbanus et al.
4,663,083	A	5/1987	Marks	5,345,328	A	9/1994	Fritz et al.
4,666,254	A	5/1987	Itoh et al.	5,355,357	A	10/1994	Yamamori et al.
4,681,403	A	7/1987	te Velde et al.	5,358,601	A	10/1994	Cathey
4,710,732	A	12/1987	Hornbeck	5,365,283	A	11/1994	Doherty et al.
4,748,366	A	5/1988	Taylor	5,381,232	A	1/1995	Van Wijk
4,786,128	A	11/1988	Birnbach	5,381,253	A	1/1995	Sharp et al.
4,790,635	A	12/1988	Apsley	5,401,983	A	3/1995	Jokerst et al.
4,856,863	A	8/1989	Sampsell et al.	5,411,769	A	5/1995	Hornbeck
4,857,978	A	8/1989	Goldburd et al.	5,444,566	A	8/1995	Gale et al.
4,859,060	A	8/1989	Katagiri et al.	5,446,479	A	8/1995	Thompson et al.
4,900,136	A	2/1990	Goldburd et al.	5,448,314	A	9/1995	Heimbuch et al.
4,900,395	A	2/1990	Syverson et al.	5,452,024	A	9/1995	Sampsell
4,937,496	A	6/1990	Neiger et al.	5,454,906	A	10/1995	Baker et al.
4,954,789	A	9/1990	Sampsell	5,457,493	A	10/1995	Leddy et al.
4,956,619	A	9/1990	Hornbeck	5,457,566	A	10/1995	Sampsell et al.
4,965,562	A	10/1990	Verhulst	5,459,602	A	10/1995	Sampsell
4,982,184	A	1/1991	Kirkwood	5,459,610	A	10/1995	Bloom et al.
5,018,256	A	5/1991	Hornbeck	5,461,041	A	10/1995	Bergink et al.
5,022,745	A	6/1991	Zahowski et al.	5,474,865	A	12/1995	Vasudev
5,028,939	A	7/1991	Hornbeck et al.	5,489,952	A	2/1996	Gove et al.
5,037,173	A	8/1991	Sampsell et al.	5,497,172	A	3/1996	Doherty et al.
5,044,736	A	9/1991	Jaskie et al.	5,497,197	A	3/1996	Gove et al.
5,061,049	A	10/1991	Hornbeck	5,499,037	A	3/1996	Nakagawa et al.
5,075,796	A	12/1991	Schildkraut et al.	5,499,062	A	3/1996	Urbanus
5,078,479	A	1/1992	Vuilleumier	5,500,635	A	3/1996	Mott
5,079,544	A	1/1992	DeMond et al.	5,500,761	A	3/1996	Goossen et al.
5,083,857	A	1/1992	Hornbeck	5,506,597	A	4/1996	Thompson et al.
5,096,279	A	3/1992	Hornbeck et al.	5,515,076	A	5/1996	Thompson et al.
5,099,353	A	3/1992	Hornbeck	5,517,347	A	5/1996	Sampsell
5,124,834	A	6/1992	Cusano et al.	5,523,803	A	6/1996	Urbanus et al.
5,136,669	A	8/1992	Gerdt	5,526,051	A	6/1996	Gove et al.
5,142,405	A	8/1992	Hornbeck	5,526,172	A	6/1996	Kanack
5,142,414	A	8/1992	Koehler	5,526,327	A	6/1996	Cordova, Jr.
5,153,771	A	10/1992	Link et al.	5,526,688	A	6/1996	Boysel et al.
5,162,787	A	11/1992	Thompson et al.	5,535,047	A	7/1996	Hornbeck
5,168,406	A	12/1992	Nelson	5,548,301	A	8/1996	Kornher et al.
5,170,156	A	12/1992	DeMond et al.	5,551,293	A	9/1996	Boysel et al.
5,172,262	A	12/1992	Hornbeck	5,552,924	A	9/1996	Tregilgas
5,179,274	A	1/1993	Sampsell	5,552,925	A	9/1996	Worley
5,192,395	A	3/1993	Boysel et al.	5,559,358	A	9/1996	Burns et al.
5,192,946	A	3/1993	Thompson et al.	5,563,398	A	10/1996	Sampsell
5,206,629	A	4/1993	DeMond et al.	5,567,334	A	10/1996	Baker et al.
5,212,582	A	5/1993	Nelson	5,570,135	A	10/1996	Gove et al.
5,214,419	A	5/1993	DeMond et al.	5,579,149	A	11/1996	Moret et al.
5,214,420	A	5/1993	Thompson et al.	5,581,272	A	12/1996	Conner et al.
5,216,537	A	6/1993	Hornbeck	5,583,688	A	12/1996	Hornbeck
5,226,099	A	7/1993	Mignardi et al.	5,589,852	A	12/1996	Thompson et al.
5,228,013	A	7/1993	Bik	5,597,736	A	1/1997	Sampsell
				5,600,383	A	2/1997	Hornbeck

US RE42,119 E

Page 3

5,602,671 A	2/1997	Hornbeck	6,195,196 B1	2/2001	Kimura et al.
5,606,441 A	2/1997	Florence et al.	6,201,633 B1	3/2001	Peeters et al.
5,608,468 A	3/1997	Gove et al.	6,215,221 B1	4/2001	Cabuz et al.
5,610,438 A	3/1997	Wallace et al.	6,232,936 B1	5/2001	Gove et al.
5,610,624 A	3/1997	Bhuva	6,239,777 B1	5/2001	Sugahara et al.
5,610,625 A	3/1997	Sampsell	6,243,149 B1	6/2001	Swanson et al.
5,614,937 A	3/1997	Nelson	6,282,010 B1	8/2001	Sulzbach et al.
5,619,059 A	4/1997	Li et al.	6,285,424 B1	9/2001	Yoshida
5,619,365 A	4/1997	Rhoades et al.	6,288,472 B1	9/2001	Cabuz et al.
5,619,366 A	4/1997	Rhoads et al.	6,288,824 B1	9/2001	Kastalsky
5,629,790 A	5/1997	Neukermans et al.	6,295,154 B1	9/2001	Laor et al.
5,633,652 A	5/1997	Kanbe et al.	6,323,982 B1	11/2001	Hornbeck
5,636,052 A	6/1997	Arney et al.	6,327,071 B1	12/2001	Kimura
5,636,185 A	6/1997	Brewer et al.	6,331,909 B1	12/2001	Dunfield
5,638,084 A	6/1997	Kalt	6,335,831 B2	1/2002	Kowarz et al.
5,638,946 A	6/1997	Zavracky	6,356,254 B1	3/2002	Kimura
5,641,391 A	6/1997	Hunter et al.	6,356,378 B1	3/2002	Huibers
5,646,768 A	7/1997	Kaeiyama	6,358,021 B1	3/2002	Cabuz
5,650,881 A	7/1997	Hornbeck	6,376,787 B1	4/2002	Martin et al.
5,654,741 A	8/1997	Sampsell et al.	6,407,851 B1	6/2002	Islam et al.
5,657,099 A	8/1997	Doherty et al.	6,417,868 B1	7/2002	Bock et al.
5,659,374 A	8/1997	Gale, Jr. et al.	6,433,917 B1	8/2002	Mei et al.
5,661,591 A	8/1997	Lin et al.	6,438,282 B1	8/2002	Takeda et al.
5,665,997 A	9/1997	Weaver et al.	6,447,126 B1	9/2002	Hornbeck
5,673,139 A	9/1997	Johnson	6,449,084 B1	9/2002	Guo
5,683,591 A	11/1997	Offenberg	6,456,420 B1	9/2002	Goodwin-Johansson
5,703,710 A	12/1997	Brinkman et al.	6,465,355 B1	10/2002	Horsley
5,710,656 A	1/1998	Goossen	6,466,190 B1	10/2002	Evoy
5,726,480 A	3/1998	Pister	6,466,354 B1	10/2002	Gudeman
5,739,945 A	4/1998	Tayeabati	6,466,358 B2	10/2002	Tew
5,740,150 A	4/1998	Uchimaru et al.	6,473,072 B1	10/2002	Comiskey et al.
5,745,193 A	4/1998	Urbanus et al.	6,473,274 B1	10/2002	Maimone et al.
5,745,281 A	4/1998	Yi et al.	6,480,177 B2	11/2002	Doherty et al.
5,751,469 A	5/1998	Arney et al.	6,496,122 B2	12/2002	Sampsell
5,771,116 A	6/1998	Miller et al.	6,545,335 B1	4/2003	Chua et al.
5,784,190 A	7/1998	Worley	6,548,908 B2	4/2003	Chua et al.
5,784,212 A	7/1998	Hornbeck	6,549,338 B1	4/2003	Wolverton et al.
5,786,927 A	7/1998	Greywall et al.	6,552,840 B2	4/2003	Knipe
5,793,504 A	8/1998	Stoll	6,574,033 B1	6/2003	Chui et al.
5,808,780 A	9/1998	McDonald	6,589,625 B1	7/2003	Kothari et al.
5,808,781 A	9/1998	Arney et al.	6,600,201 B2	7/2003	Hartwell et al.
5,818,095 A	10/1998	Sampsell	6,606,175 B1	8/2003	Sampsell et al.
5,825,528 A	10/1998	Goossen	6,608,268 B1	8/2003	Goldsmith
5,835,255 A	11/1998	Miles	6,624,944 B1	9/2003	Wallace et al.
5,838,484 A	11/1998	Goossen	6,625,047 B2	9/2003	Coleman, Jr.
5,842,088 A	11/1998	Thompson	6,630,786 B2	10/2003	Cummings et al.
5,905,482 A	5/1999	Hughes et al.	6,632,698 B2	10/2003	Ives
5,912,758 A	6/1999	Knipe et al.	6,635,919 B1	10/2003	Melendez et al.
5,943,158 A	8/1999	Ford et al.	6,643,069 B2	11/2003	Dewald
5,959,763 A	9/1999	Bozler et al.	6,650,455 B2	11/2003	Miles
5,986,796 A	11/1999	Miles	6,657,832 B2	12/2003	Williams et al.
5,994,174 A	11/1999	Carey et al.	6,660,656 B2	12/2003	Cheung et al.
6,028,690 A	2/2000	Carter et al.	6,674,090 B1	1/2004	Chua et al.
6,038,056 A	3/2000	Florence et al.	6,674,562 B1	1/2004	Miles
6,040,937 A	3/2000	Miles	6,680,792 B2	1/2004	Miles
6,046,840 A	4/2000	Huibers	6,710,908 B2	3/2004	Miles et al.
6,049,317 A	4/2000	Thompson et al.	6,741,383 B2	5/2004	Huibers et al.
6,055,090 A	4/2000	Miles	6,775,174 B2	8/2004	Huffman et al.
6,056,406 A	5/2000	Park	6,778,155 B2	8/2004	Doherty et al.
6,061,075 A	5/2000	Nelson et al.	6,794,119 B2	9/2004	Miles
6,097,145 A	8/2000	Kastalsky et al.	6,809,788 B2	10/2004	Yamada et al.
6,099,132 A	8/2000	Kaeriyama	6,853,129 B1	2/2005	Cummings et al.
6,100,861 A	8/2000	Cohen et al.	6,859,218 B1	2/2005	Luman et al.
6,100,872 A	8/2000	Aratani et al.	6,862,029 B1	3/2005	D'Souza et al.
6,113,239 A	9/2000	Sampsell et al.	6,867,896 B2	3/2005	Miles
6,147,790 A	11/2000	Meier et al.	6,891,658 B2	5/2005	Whitehead et al.
6,158,156 A	12/2000	Patrick	6,947,200 B2	9/2005	Huibers
6,160,833 A	12/2000	Floyd et al.	7,008,812 B1	3/2006	Carley
6,171,945 B1	1/2001	Mandal et al.	7,053,737 B2	5/2006	Schwartz et al.
6,172,797 B1	1/2001	Huibers	7,075,700 B2	7/2006	Muenter
6,180,428 B1	1/2001	Peeters et al.	7,123,216 B1	10/2006	Miles

7,161,728	B2	1/2007	Sampsel et al.
7,205,722	B2	4/2007	Koshio et al.
2001/0003487	A1	6/2001	Miles
2001/0028503	A1	10/2001	Flanders et al.
2002/0014579	A1	2/2002	Dunfield
2002/0015215	A1	2/2002	Miles
2002/0021485	A1	2/2002	Pilossof
2002/0024711	A1	2/2002	Miles
2002/0054424	A1	5/2002	Miles
2002/0070931	A1	6/2002	Ishikawa
2002/0075555	A1	6/2002	Miles
2002/0114558	A1	8/2002	Nemirovsky
2002/0126364	A1	9/2002	Miles
2002/0139981	A1	10/2002	Young
2002/0149828	A1	10/2002	Miles
2002/0149850	A1	10/2002	Heffner et al.
2002/0167072	A1	11/2002	Andosca
2002/0167730	A1	11/2002	Needham et al.
2003/0015936	A1	1/2003	Yoon et al.
2003/0016428	A1	1/2003	Kato et al.
2003/0035196	A1	2/2003	Walker
2003/0053078	A1	3/2003	Missey et al.
2003/0156315	A1	8/2003	Li et al.
2003/0210851	A1	11/2003	Fu et al.
2004/0027701	A1	2/2004	Ishikawa
2004/0051929	A1	3/2004	Sampsel et al.
2004/0056742	A1	3/2004	Dabbaj
2004/0100677	A1	5/2004	Huibers et al.
2005/0195467	A1	9/2005	Kothari et al.
2005/0249966	A1	11/2005	Tung et al.
2006/0044654	A1	3/2006	Vandorpe et al.
2006/0066599	A1	3/2006	Chui
2006/0066640	A1	3/2006	Kothari et al.
2006/0066935	A1	3/2006	Cummings et al.
2006/0067643	A1	3/2006	Chui
2006/0077152	A1	4/2006	Chui et al.
2006/0077507	A1	4/2006	Chui et al.
2006/0077508	A1	4/2006	Chui et al.
2006/0077515	A1	4/2006	Cummings et al.
2006/0077516	A1	4/2006	Kothari
2006/0079048	A1	4/2006	Sampsel
2006/0139723	A9	6/2006	Miles
2007/0229936	A1	10/2007	Miles
2008/0037093	A1	2/2008	Miles
2008/0088904	A1	4/2008	Miles
2008/0088911	A1	4/2008	Miles
2008/0088912	A1	4/2008	Miles
2008/0106782	A1	5/2008	Miles

FOREIGN PATENT DOCUMENTS

JP	05275401	A1	10/1993
JP	9-127439		5/1997
JP	11211999		8/1999
JP	2000306515	A	11/2000
JP	2002-062490		2/2002
JP	2003-195201		7/2003
WO	157313		5/1991
WO	WO 95/30924		11/1995
WO	WO 97/17628		5/1997
WO	WO 99/52006	A2	10/1999
WO	WO 99/52006	A3	10/1999
WO	WO 02/079853		10/2002
WO	WO 03/007049	A1	1/2003
WO	WO 03/014789	A2	2/2003
WO	WO 03/054925		7/2003
WO	WO 03/069404		8/2003
WO	WO 03/069413	A1	8/2003
WO	WO 03/073151	A1	9/2003
WO	WO 2005/010566		2/2005

OTHER PUBLICATIONS

- Aratani et al., "Process and Design Considerations for Surface Micromachined Beams for a Tuneable Interferometer Array in Silicon," Proc. IEEE Microelectromechanical Workshop, Fort Lauderdale, FL, pp. 230-235 (Feb. 1993).
- Aratani K., et al., "Surface micromachined tuneable interferometer array," Sensors and Actuators, pp. 17-23, (1994).
- Bass, "Handbook of Optics, vol. I, Fundamentals, Techniques, and Design, Second Edition," McGraw-Hill, Inc. New York, pp. 2.29-2.36 (1995).
- Butler et al., "An Embedded Overlay Concept for Microsystems Packaging," IEEE Transactions on Advanced Packaging IEEE USA, vol. 23, No. 4, pp. 617-622, XP002379648 (2000).
- Chiou et al., "A Novel Capacitance Control Design of Tunable Capacitor Using Multiple Electrostatic Driving Electrodes," IEEE NANO 2001, M 3.1, Nanoelectronics and Giga-Scale Systems (Special Session), Oct. 29, 2001, pp. 319-324.
- ChunJun Wang et al., "Flexible circuit-based RF MEMS Switches," MEMS. XP002379649 pp. 757-762, (Nov. 2001).
- Conner, "Hybrid Color Display Using Optical Interference Filter Array," SID Digest, pp. 577-580 (1993).
- Fan et al., "Channel Drop Filters in Photonic Crystals," Optics Express, vol. 3, No. 1, 1998.
- Giles et al., "A Silicon MEMS Optical Switch Attenuator and Its Use in Lightwave Subsystems," IEEE Journal of Selected Topics in Quantum Electronics, vol. 5, No. 1, pp. 18-25, (Jan./Feb. 1999).
- Goossen et al., "Possible Display Applications of the Silicon Mechanical Anti-Reflection Switch," Society for Information Display (1994).
- Goossen et al., "Silicon Modulator Based on Mechanically-Active Anti-Reflection Layer with 1Mbit/sec Capability for Fiber-in-the-Loop Applications," IEEE Photonics Technology Letters, pp. 1119-1121 (Sep. 1994).
- Goossen, "MEMS-based variable optical interference devices," Optical MEMS, 2000 IEEE/LEDS Int'l. Conf. on Aug. 21-24, 2000, Piscataway, NJ, Aug. 21, 2000, pp. 17-18.
- Gosh, "West Germany Grabs the Lead in X-Ray Lithography," Electronics pp. 78-80 (Feb. 5, 1987).
- Howard et al., "Nanometer-Scale Fabrication Techniques", VLSI Electronics: Microstructure Science, vol. 5, pp. 145-153 and pp. 166-173 (1982).
- Ibbotson et al., "Comparison of XeF₂ and F-atom reactions with Si and SiO₂," Applied Physics Letters, vol. 44, No. 12, pp. 1129-1131 (Jun. 1984).
- Jackson "Classical Electrodynamics", John Wiley & Sons Inc., pp. 568-573. (date unknown).
- Jerman et al., "A Miniature Fabry-Perot Interferometer with a Corrugated Silicon Diaphragm Support", (1988).
- Jerman et al., "Miniature Fabry-Perot Interferometers Micromachined in Silicon for Use in Optical Fiber WDM Systems," Transducers, San Francisco, Jun. 24-27, 1991, Proceedings on the Int'l. Conf. on Solid State Sensors and Actuators, vol. Conf. 6, Jun. 24, 1991, pp. 372-375.
- Joannopoulos et al., "Molding the Flow of Light," Photonic Crystals. 1995.
- Johnson "Optical Scanners", Microwave Scanning Antennas, vol. 1, p. 251-261, (1964).

- Kim et al., "Control of Optical Transmission Through metals Perforated With Subwave-Length Hole Arrays," *Optic Letters*, vol. 24, No. 4, Feb. 15, 1999, pp. 256–257.
- Circle 36: Light over Matter, Circle No. 36 (Jun. 1993).
- Lin et al., "Free-Space Micromachined Optical Switches for Optical Networking," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 5, No. 1m Jan./Feb. 1999, pp. 4–9.
- Little et al., "Vertically Coupled Microring Resonator Channel Dropping Filter," *IEEE Photonics Technology Letters*, vol. 11, No. 2, 1999.
- Magel, "Integrated Optic Devices Using Micromachined Metal Membranes," *SPIE* vol. 2686, 0–8194–2060–3/1996.
- Miles, Mark W., "A New Reflective FPD Technology Using Interferometric Modulation", *The Proceedings of the Society for Information Display* (May 11–16, 1997).
- Nagami et al., "Plastic Cell Architecture: Towards Reconfigurable Computing for General-Purpose," *IEEE Workshop on FPGA-based Custom Computing Machines*, (1998).
- Newsbreaks, "Quantum-trench devices might operate at terahertz frequencies", *Laser Focus World* (May 1993).
- Oliner et al., "Radiating Elements and Mutual Coupling", *Microwave Scanning Antennas*, vol. 2, pp. 131–141, (1966).
- Peerlings et al., "Long Resonator Micromachined Turnable GaAs–AlAs Fabry–Perot Filter," *IEEE Photonics Technology Letters*, IEEE Service Center, Piscatawny, NJ, vol. 9, No. 9, Sep. 1997, pp. 1235–1237.
- Raley et al., "A Fabry–Perot Microinterferometer for Visible Wavelengths", *IEEE Solid–State Sensor and Actuator Workshop*, Jun. 1992, Hilton Head, SC.
- Schnakenberg, et al. TMAHW Etchants for Silicon Micromachining. 1991 International Conference on Solid State Sensors and Actuators–Digest of Technical Papers. pp. 815–818.
- Science and Technology, *The Economist*, May 22, 1999, pp. 89–90.
- Sperger et al., "High Performance Patterned All–Dielectric Interference Colour Filter for Display Application", *SID Digest*, pp. 81–83, (1994).
- Stone, "Radiation and Optics, An Introduction to the Classical Theory", McGraw–Hill, pp. 340–343, (1963).
- Walker, et al., "Electron–beam–tunable Interference Filter Spatial Light Modulator", *Optics Letters* vol. 13, No. 5, pp. 345–347, (May 1988).
- Williams, et al., Etch Rates for Micromachining Processing. *Journal of Microelectromechanical Systems*, vol. 5, No. 4, pp. 256–259, (Dec. 1996).
- Winters, et al., The etching of silicon with XeF₂ vapor. *Applied Physics Letters*, vol. 34, No. 1, pp. 70–73, (Jan. 1979).
- Winton, John M., "A novel way to capture solar energy", *Chemical Week*, (May 1985).
- Wu, "Design of a Reflective Color LCD Using Optical Interference Reflectors", *ASIA Display '95*, pp. 929–931, (Oct. 1995).
- Wu et al., "MEMS Designed for Tunable Capacitors," *Microwave Symposium Digest, 1998 IEEE MTT–S Int'l.*, Baltimore, MD, Jun. 7–12, 1998, vol. 1, pp. 127–129.
- Zhou et al., "Waveguide Panel Display Using Electromechanical Spatial Modulators," *SID Digest*, vol. XXIX, 1998.
- International Search Report and Written Opinion of the International Searching Authority for PCT/US2005/005919 dated Aug. 24, 2005.
- International Search Report Application No. PCT/US2005/026448, Dated Nov. 23, 2005.
- International Search Report Application No. PCT/US2005/029820, Dated Dec. 27, 2005.
- International Search Report Application No. PCT/US2005/030962, Dated Aug. 31, 2005.
- International Search Report Application No. PCT/US2005/034465, Dated Sep. 23, 2005.
- European Search Report Application No. 05255693.3–2217, dated May 24, 2006.
- European Search Report Application No. EP 05 25 5673 in 9 pages, dated Jan. 23, 2006.
- Austrian Search Report No. 162/2005, Dated Jul. 14, 2005.
- Austrian Search Report No. 164/2005, Dated Jul. 4, 2005.
- Austrian Search Report No. 140/2005, Dated Jul. 15, 2005.
- Austrian Search Report No. 161/2005, Dated Jul. 15, 2005.
- Austrian Search Report No. 150/2005, Dated Jul. 29, 2005.
- Austrian Search Report No. 144/2005, Dated Aug. 11, 2005.
- Austrian Search Report No. 66/2005, Dated May 9, 2005.
- Office Action mailed Jun. 27, 2002 in U.S. Appl. No. 10/084, 893.
- English translation of First Office Action dated Feb. 24, 2006 in Chinese App. No. 02828352.
- English translation of Second Office Action dated Sep. 15, 2006 in Chinese App. No. 02828352.
- English translation of Third Office Action dated Apr. 13, 2007 in Chinese App. No. 02828352.
- Fork et al., "P–67: Chip on Glass Bonding using Stressed-Metal™ Technology" *Sid 05 Digest* May 24, 2005.
- Notice of Grounds for Rejection in Korean App. No. 2004–7013279, dated Apr. 30, 2009.

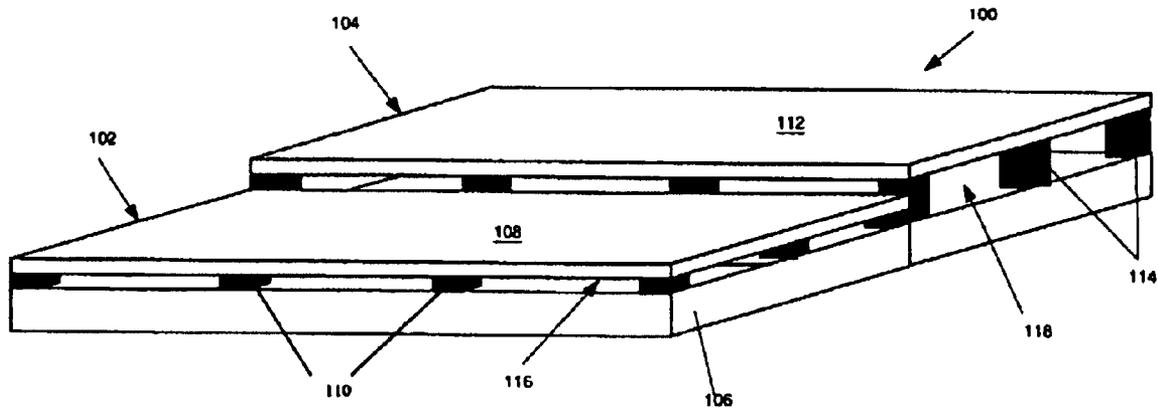


FIGURE 1

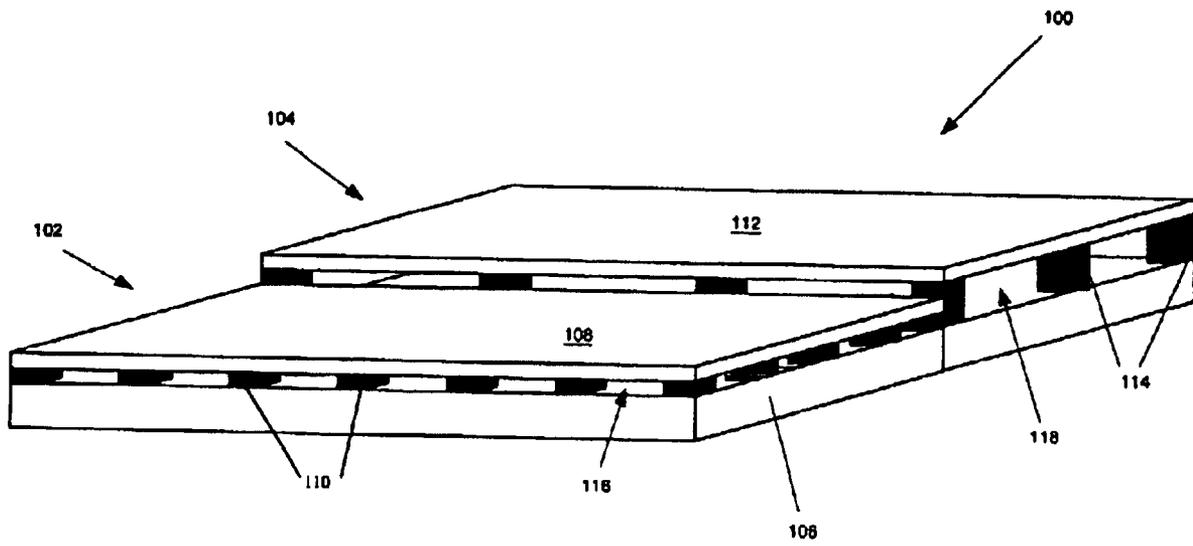


FIGURE 2

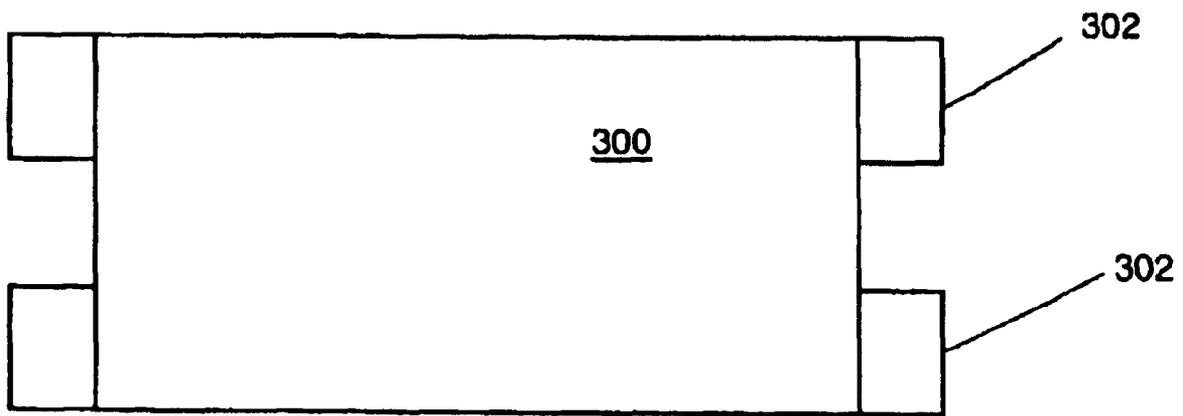


FIGURE 3A

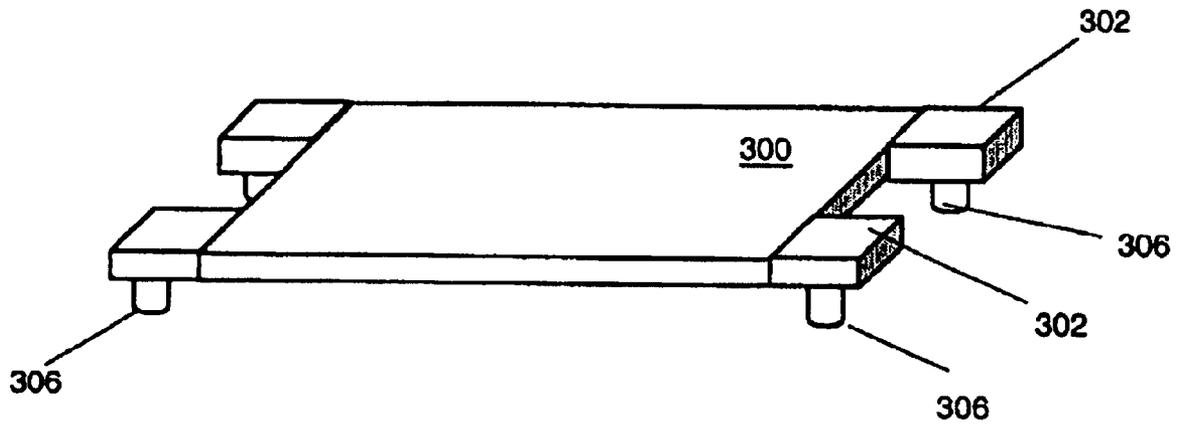


FIGURE 3B

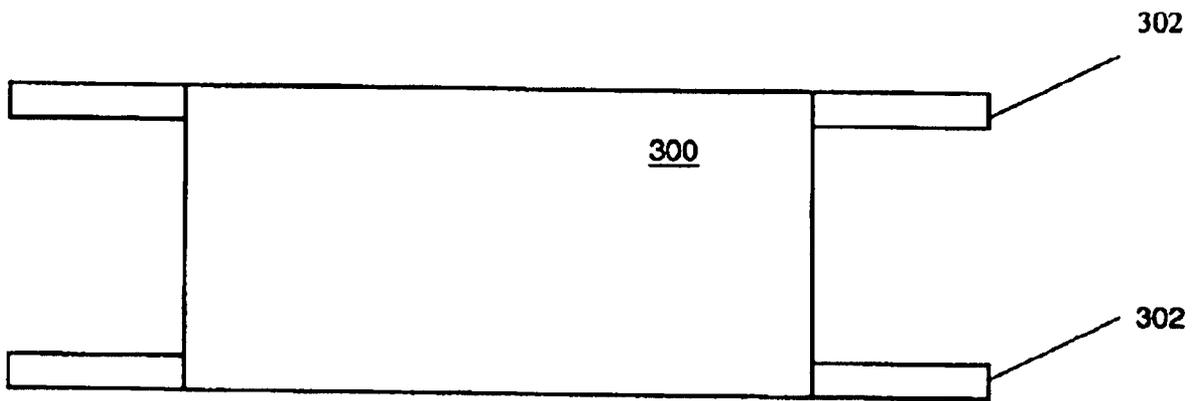


FIGURE 3C

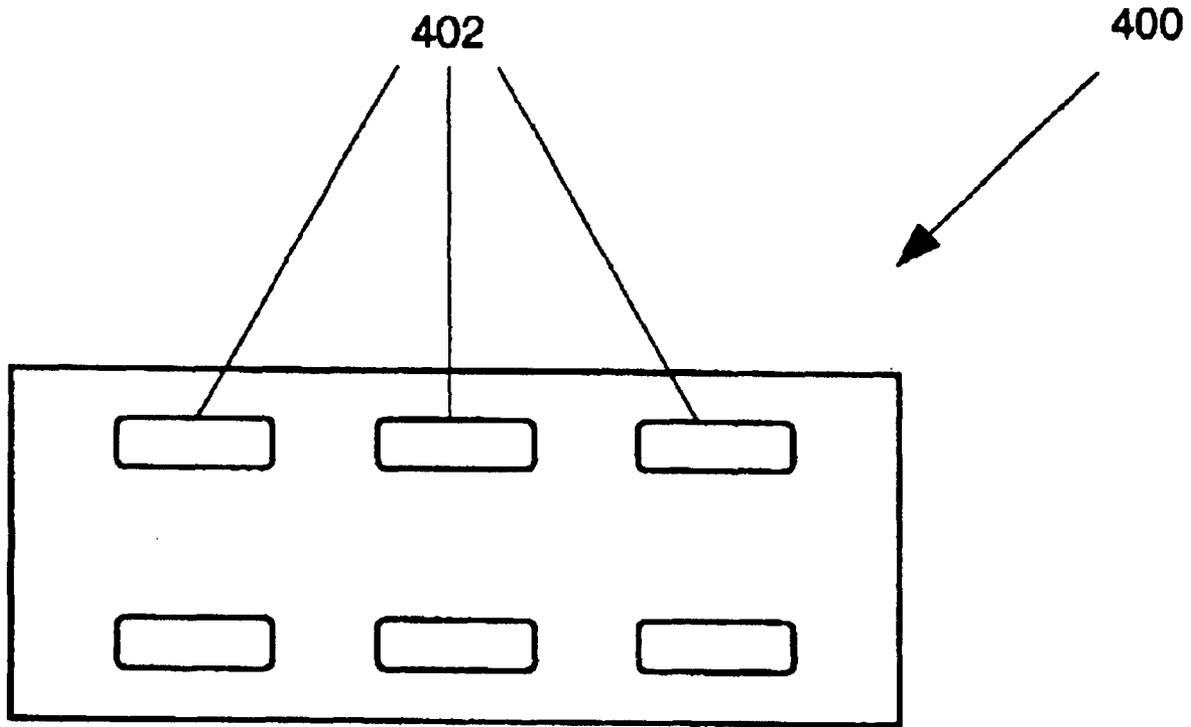


FIGURE 4

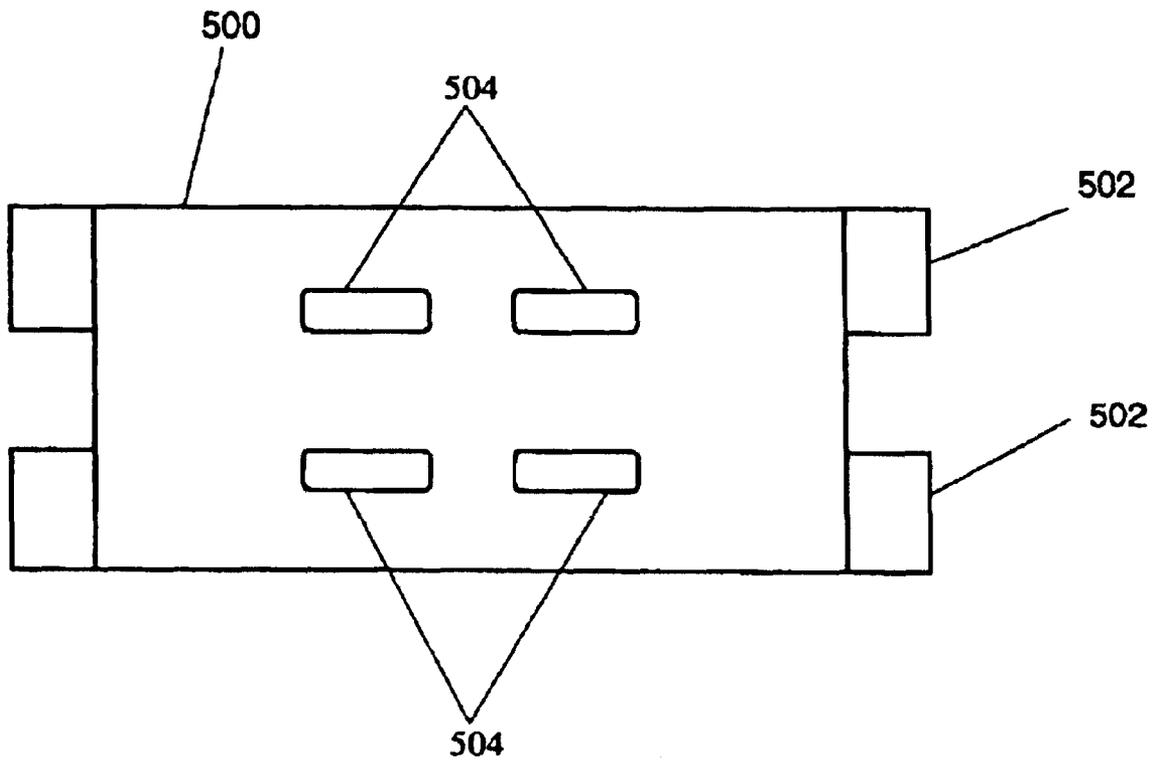


FIGURE 5

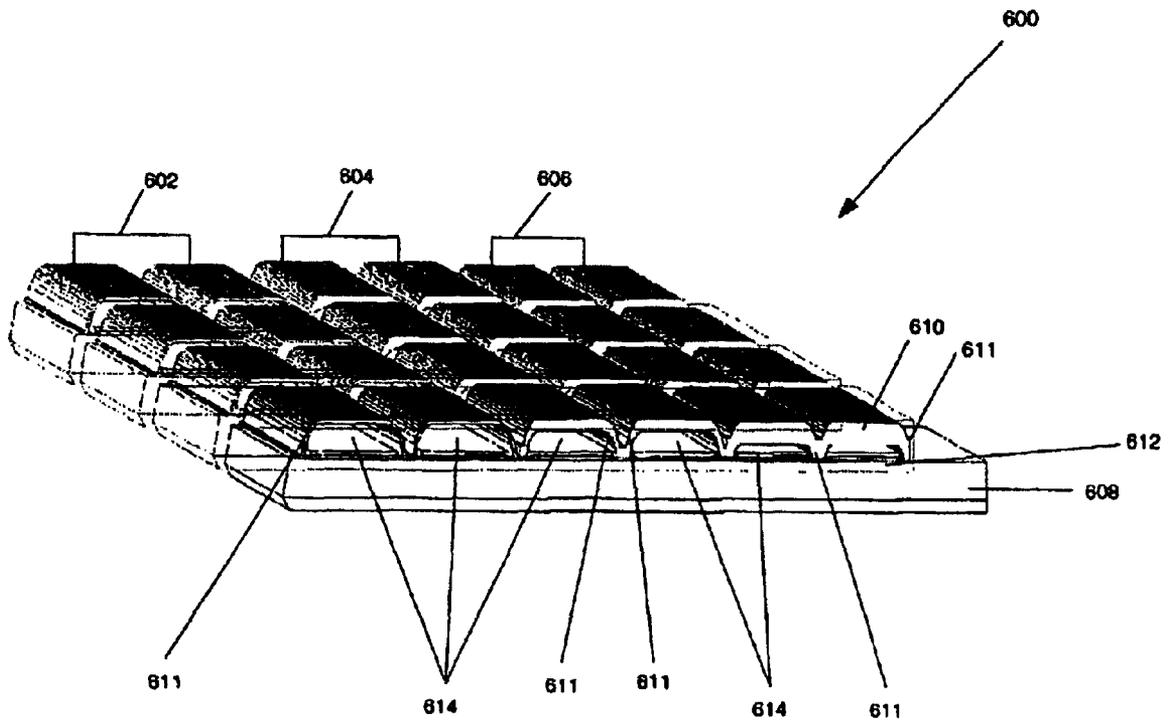


FIGURE 6

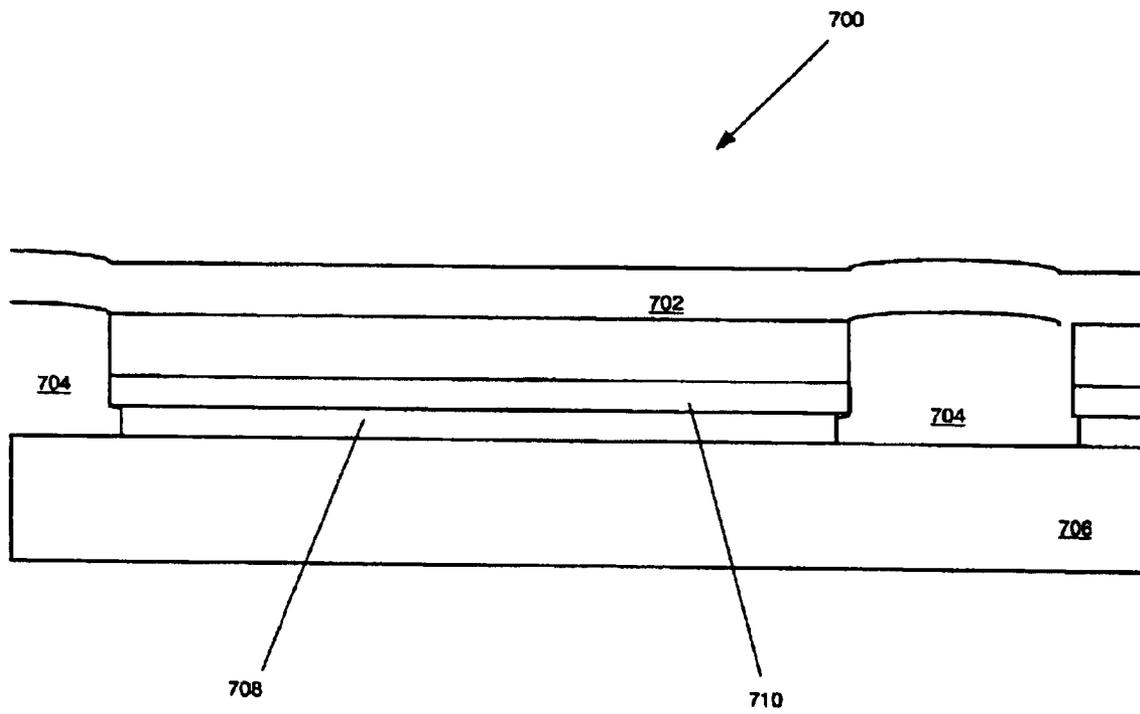


FIGURE 7

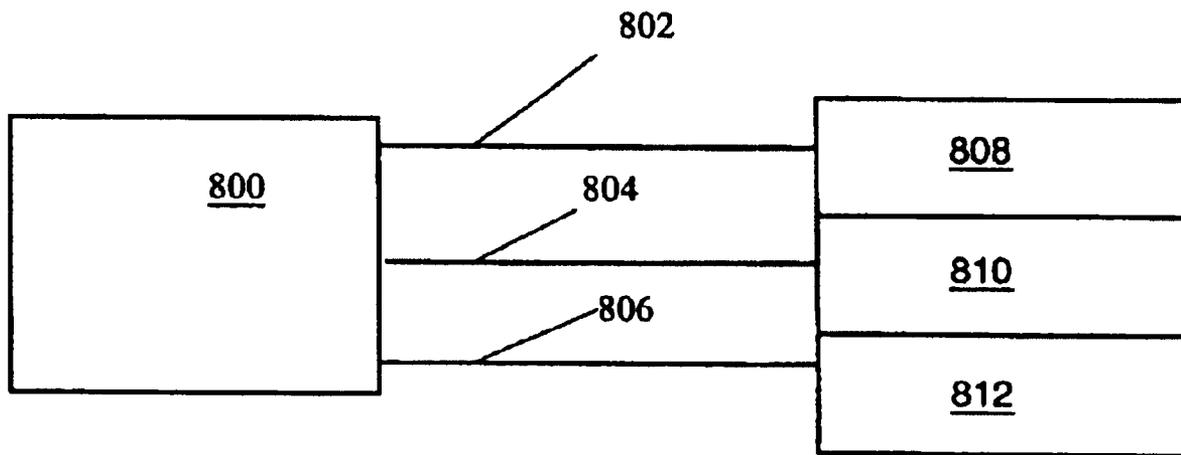


FIGURE 8

**MICROELECTROCHEMICAL SYSTEMS
DEVICE AND METHOD FOR FABRICATING
SAME**

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

FIELD OF THE INVENTION

This invention relates to the actuation of microelectromechanical systems devices. In particular, it relates to the actuation or driving of elements in an array in a microelectromechanical systems device.

BACKGROUND

Microelectromechanical systems (MEMS) devices may include arrays of elements wherein the elements are operable between one or more driven and undriven states by the application of an actuation voltage. Depending on the particular microelectromechanical systems device, the elements may include interferometric modulators (IMODs), switches, Infra Red (IR) detectors, etc.

In some microelectromechanical systems devices, it may be necessary to have multiple arrays, wherein each array comprises only elements of a particular type, and wherein each element type requires a different actuation voltage. An example of such a device is the color IMOD-based display described in U.S. Pat. No. 6,040,937, which includes three sets or arrays of IMODs designed to switch between the colors red/black, green/black and blue/black. Each array of IMODs has a different actuation voltage.

Driving the elements in these multiple arrays between their undriven and driven states present a challenge because different actuation voltages are required.

SUMMARY OF THE INVENTION

According to a first aspect of the invention there is provided a microelectromechanical systems device comprising a plurality of elements each having at least two layers disposed in a stacked relationship with a gap therebetween when the element is in an undriven state, the plurality of elements being of at least two different types, each differing in a height of its gap; and a driving mechanism to drive the plurality of elements to a driven state, wherein one of the layers of each element is electrostatically displaced relative to the other layer, and wherein a minimum voltage required to actuate the driving mechanism is substantially the same for each type of element.

According to a second aspect of the invention there is provided a method of fabricating a microelectromechanical systems device comprising constructing an array of elements, each element having a first layer, a second layer spaced from the first layer by a gap when in an undriven state, and an electrode layer to electrostatically drive the second layer to contact the first layer corresponding to a driven state when energized, the elements being of at least two different types which differ in a height of its gap, wherein said constructing includes changing a configuration of each element type to compensate for differences in a voltage required to drive each element to its driven state.

According to a further aspect of the invention, there is provided a microelectromechanical systems device comprising a plurality of elements, each having a first layer, a second layer spaced therefrom by a gap when in an undriven state,

and an electrode layer to electrostatically drive the second layer to contact the first layer corresponding to a driven state when energized, the elements being of at least two different kinds, each differing in a height of its gap; and an element driving mechanism comprising an integrated drive circuit having multilevel outputs to energize the electrode layer of each element to cause the element to change from its undriven state to its driven state.

According to yet a further aspect of the invention there is provided a method for fabricating a microelectromechanical systems device, the method comprising fabricating an array of first elements, each first element conforming to a first geometry; fabricating at least one array of second elements, each second element conforming to a second geometry; wherein fabricating the arrays comprises selecting a defining aspect of each of the first and second geometries based on a defining characteristic of each of the first and second elements; and normalizing differences in an actuation voltage required to actuate each of the first and second elements, wherein the differences are as a result of the selected defining aspect, the defining characteristics of each of the elements being unchanged.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a simplified drawing of a generic MEMS device to which aspects of the present invention apply;

FIG. 2 shows an example of how the geometry of the elements in the MEMS device of FIG. 1 may be changed, according to one embodiment of the invention, to normalize the actuation voltages of the elements;

FIG. 3A shows a different geometry for a driven layer of an element, wherein the driven layer has tabs;

FIG. 3B shows a three dimensional view of the driven layer of FIG. 3A supported on supports;

FIG. 3C shows the driven layer of FIG. 3A with a different configuration for the tabs;

FIG. 4 shows an example of how the configuration of an electrode within each element may be changed in order to achieve voltage normalization in one embodiment of the invention;

FIG. 5 shows an example of how the stiffness of the layer which is driven in each element may be varied in order to achieve voltage normalization in accordance with another embodiment of the invention;

FIG. 6 shows a simplified drawing of an IMOD-based display array wherein the thickness of the layer which is driven within each IMOD is changed in order to achieve voltage normalization, in accordance with one embodiment of the invention;

FIG. 7 shows a schematic end view of an IMOD which includes a dielectric stack; and

FIG. 8 shows a block diagram of a driver in accordance with one embodiment of the invention.

DETAILED DESCRIPTION

FIG. 1 shows, in simplified form, a generic structure of a microelectromechanical systems (MEMS) device 100 to which aspects of the present invention relate. Referring to FIG. 1, it will be seen that the MEMS device 100 comprises two elements which are designated 102 and 104 respectively. The element 102 and the element 104 each have a common lower or base layer 106. Element 102 has an upper layer 108 which is spaced from the base layer 106 by a number of supports which are in the form of posts 110.

Likewise, element **104** has an upper layer **112** which is spaced from the base layer **106** by supports in the form of posts **110**. It will be apparent that posts **114** are higher than posts **110** and so the height of a gap **116** between layer **106** and layer **108** is less than that of a gap **118** between layer **112** and layer **106**. Because of the differences in the heights of gaps **116** and **118**, an actuation voltage required to electrostatically drive layers **108** and **112** respectively from an undriven state, corresponding to the state showing FIG. 1 of the drawings, to a driven state (not shown), in which the layers **106** and **112** contact the base layer **116**, is different. Thus, any driving mechanism must take into account these differences in the actuation voltages.

As stated above, FIG. 1 is intended to be a simplified drawing of a generic MEMs device to which aspects of the present invention apply. In actual embodiments, the MEMs device **100** may include multiple arrays each array comprising elements such as the elements **102** or **108**. Thus, the elements in each array would require a different actuation voltage. An example of one such MEMs device is provided by the IMOD display described in U.S. Pat. No. 6,040,937. In this example, there are three arrays, each comprising elements in the form of IMODs designed to have a particular optical characteristic which arises from a size of an air gap in each IMOD. Each array comprises only IMODs which have a particular optical characteristic. As a result, different actuation voltages are required to drive the IMODs in each array.

Embodiments of the present invention are concerned with the problem of driving MEMs devices such as are described above, wherein different actuation voltages are required by the elements within the MEMs device. In describing specific embodiments of the invention, reference will be made to a MEMs device such as is described in U.S. Pat. No. 6,040,937. However, it must be borne in mind that the invention is applicable to any MEMs device comprising elements which each require a different actuation voltage to drive or actuate the element resulting in a geometric configuration or state of the element being changed. Such elements may include IMODs, switches, Infra Red (IR) detectors, etc., where the change in the geometric configuration comprises driving one layer of the element to contact another layer. The layer that is driven will be referred to as the driven layer to distinguish it from the undriven layer.

According to embodiments of the present invention, the actuation voltage required to actuate each of the elements is normalized. This is achieved by changing a geometry of the elements within each array. Naturally, aspects of the geometry of an element which impart a defining characteristic to the element are not changed. Thus, in the case of the IMOD displays of U.S. Pat. No. 6,040,937, the height of the air gap in each element (IMOD) imparts a defining optical characteristic to the IMOD and so the one aspect of geometry of an IMOD that is not changed is the height of the air gap.

FIG. 2 of the drawings shows an example wherein the geometry of the element **102** shown in FIG. 1 of the drawings has been changed by increasing the number of posts **110** and by decreasing the spacing therebetween. Thus the layer **108** is supported by posts **110** to a greater degree and therefore a greater actuation voltage will be required to drive layer **108** to contact layer **106**. By selecting the number of posts **110** and the spacing therebetween it will be appreciated that the actuation voltages required to drive element **102** and **108** may be normalized.

In other embodiments, the geometry of the driven layer may be changed in order to increase or decrease the degree

of support provided thereto. This is illustrated in FIGS. 3A and 3B of the drawings. Referring to FIGS. 3A and 3B, a layer **300**, which is similar to layers **108** and **112** of FIGS. 1 and 2, is shown. The layer **300** has a different geometry to that of layers **108** and **112** by virtue of tabs **302** which form tethers which themselves are supported on posts **304**. Thus, the thickness and length of the tabs may be varied to change the degree of support to the layer **300**. Assuming that an actuation voltage is required to drive layer **300** into the plane of the drawings it will be appreciated that the tabs **302** in FIG. 3A offer a greater degree of support than the tabs **302** shown in FIG. 3C of the drawings. Thus, a lesser actuation voltage will be required to drive layer **300** in FIG. 3C of the drawings than in FIG. 3A of the drawings. Embodiments of the present invention use the principles illustrated in FIGS. 3A and 3C of the drawings to normalize the actuation voltage required to actuate elements within a MEMs device wherein an operatively upper layer (driven layer) is to be driven towards an operatively lower layer across a gap. When the gap is large, the geometry of the tabs is varied in accordance with the principles shown in FIGS. 3A and 3C to reduce the degree of support provided to the driven layer. On the other hand when the gap is small then the geometry of the supports is varied to provide a greater degree of support to the driven layer. In this way, regardless of the size of the gap through which a layer must be driven, the voltage required to drive the layer can be normalized.

Although not shown in FIGS. 1 or 2 of the drawings, a driving mechanism to drive layers **108** and **112** comprises electrodes to electrostatically drive layers **108** and **112** towards base layer **106**. The electrodes are disposed on layer **106**. An example of an electrode is indicated generally by reference numeral **400** in FIG. 4 of the drawings. According to some embodiments of the present invention, in order to normalize the voltage required to drive or actuate elements within a MEMs device, the configuration of electrode **400** may be changed. Changing the configuration of the electrode may include changing the shape of the electrode or providing apertures therein, for example, such as slots **402** shown in electrode **400**. Thus, if a layer is to be driven across a small gap, the electrode may have slots such as slots **402** which serve to reduce the effective electrostatic force created by the electrode. This allows the actuation voltage to be normalized regardless of the height of the gap across which a layer has to be driven.

According to other embodiments of the present invention, changing the geometry of the elements in order to normalize the actuation voltage may include changing the stiffness of the driven layer. One way of changing the stiffness of the driven layer includes changing the Young's Modulus thereof. Thus, the layer which is required to be driven across a small air gap would be made of a material which has a higher Young's Modulus than a layer which has to be driven across a greater air gap.

Another method of changing the stiffness of the driven layer is to form apertures therein to reduce its stiffness. This is shown in FIG. 5, of the drawings where a layer **500** which includes, in addition to tabs **502** apertures or slots **504** formed therein.

Various aspects of the present invention may be applied in combination, thus in the example shown in FIG. 5, it will be seen that while layer **500** has slots formed therein, the layer itself will be supported on tabs **502** which have a thickness which is selected so that it provides a degree of support to the layer **500** to allow an actuation voltage required to actuate layer **500** to be normalized.

FIG. 6 of the drawings shows a simplified version **600** of an IMOD based display such as is described in U.S. Pat. No.

6,040,937. The display 600 includes three arrays 602, 604 and 606. Each array is fabricated on a substrate 608 and includes a 2x4 grid of IMODs. Each IMOD includes an upper layer 610 which in use is driven towards a common lower layer 612 across a gap. The layers 610 are self-supporting by virtue of having two downwardly extending limbs 611. Each IMOD has an electrode 614 which is disposed on layer 612. It will be seen that the IMODs within array 602 have the highest gap, the IMODs within array 604 have an intermediate size gap and the IMODs within array 606 have the smallest gap. This is because the IMODs in array 602, 604 and 606 are fabricated to have the defining characteristic that they each reflect red, green, and blue light, respectively, when in an undriven state. Thus, an actuation voltage required to drive the layers 610 towards the layer 612 will increase as the height of the gap through which the layer must be driven increases. Thus, the IMODs within array 602 will require a greater actuation voltage than the IMODs within array 604 or array 606. One embodiment of the present invention allows the actuation voltages to be normalized by changing the thickness of the layers 610 in inverse proportion to the size of the gap through which it must be driven. Thus, in FIG. 6, the thickness of the layers 610 have been selected to normalize the actuation voltages required by the IMODs within each array.

In another embodiment of the invention, the actuation voltages may be normalized by increasing or decreasing the tensile stress of each of the layers 610 as the height of the gap through which the layers must be driven increases or decreases, respectively. This can be accomplished by controlling deposition parameters of the film such as deposition pressure, power, and electric field bias.

FIG. 7 of the drawings shows an embodiment of a MEMS device 700 which includes an IMOD comprising a mechanical layer 702 which is supported on posts 704 which are formed on a substrate 706. Disposed on substrate 706 is an electrode 708 on which is formed a dielectric stack 710. The space between mechanical layer 702 and dielectric stack 708 defines an air gap. In use, an actuation voltage is applied to drive layer 702 to contact the dielectric stack 710. The device 700 will typically include three sets of IMODs each differing in the height of its air gap so as to reflect red, blue and green light, respectively, when in an undriven state. In order to normalize the actuation voltages required by each set of IMODs, the dielectric constant of the dielectric stack 710 is varied, in one embodiment of the invention, so that the higher the air gap, the greater the dielectric constant. Alternatively, the thickness of the dielectric stack may be varied so that the thickness of the dielectric stack is increased (or decreased) as the height of the air gap is decreased (or increased).

According to another embodiment of the invention, the problem of driving different elements within a MEMS device wherein the elements require different actuation voltages is solved by providing a driving mechanism such as the one shown in FIG. 8 of the drawings. Referring to FIG. 8, the driving mechanism comprises a driver chip 800 which includes an integrated drive circuit which has multi-level outputs 802, 804, and 806. Each of the outputs 804 to 806 delivers a different voltage and may be used, in one embodiment to drive IMODs with different sized air gaps for example IMODs 808, 810, 812 which reflect red, green, and blue light, respectively, when in an undriven state. The design and integration of components within driver chip 800 is well-known and is therefore is not further described.

Although the present invention has been described with reference to specific exemplary embodiments, it will be evi-

dent that the various modification and changes can be made to these embodiments without departing from the broader spirit of the invention as set forth in the claims. Accordingly, the specification and drawings are to be regarded in an illustrative sense rather than in a restrictive sense.

What is claimed is:

1. A microelectromechanical systems device comprising:

a plurality of elements each having at least two layers, the layers being disposed in a stacked relationship with a gap therebetween when the element is in an undriven state, the plurality of elements [being of at least two different types,] *defining at least a first region having elements only of a first type and a second region having elements only of a second type, wherein each type [differing] differs in a height of its gap, wherein the elements within the first region are substantially co-planar, and wherein the elements within the second region are substantially co-planar;* and

a driving [mechanism] *circuit configured to drive the plurality of elements to a driven state, wherein one of the layers of each element is configured to electrostatically displace[d] relative to the other layer to close the gap between the layers, and wherein a minimum voltage required to [actuate the driving mechanism] electrostatically displace the layer to a driven state is [substantially] different for each type of element.*

[2. The microelectromechanical systems device of claim 1, wherein the plurality of elements are arranged in an array structure wherein the plurality of elements are substantially co-planar.]

[3. The microelectromechanical systems device of claim 2, further comprising a plurality of said array structures each containing only elements of one type.]

4. The microelectromechanical systems device of claim 1, wherein the electrostatically displaceable layer [is self-supporting] compris[ing]es a plurality of spaced apart limbs which rest on a substrate.

5. The microelectromechanical systems device of claim [3] 1, wherein the layers of each element [in an array] are continuous, the electrostatically displaceable layer being supported by a support structure comprising a plurality of supports spaced along a first axis and extending in a direction which is transverse thereto, each support having a support surface to support the electrostatically displaceable layer above the other layer when the elements are in the undriven state.

6. The microelectromechanical systems device of claim 5, wherein the spacing between the supports along the first axis [in each array] depends on the height of the gap between the layers, the higher the gap, the greater the spacing.

7. The microelectromechanical systems device of claim 5, wherein an area of the support surface of each support [in an array] is a function of the height of the gap between the layers, the higher the gap, the smaller the area.

8. The microelectromechanical systems device of claim 1, wherein the electrostatically displaceable layer of each element has a Young's Modulus which is a function of the height of its gap, the higher the gap, the lower the Young's Modulus.

9. The microelectromechanical systems device of claim 1, wherein a thickness of the electrostatically displaceable layer of each element is a function of the height of its gap, the higher the gap, the smaller the thickness.

10. The microelectromechanical systems device of claim 1, wherein the electrostatically displaceable layer of at least those elements having the highest gap have apertures formed therein to reduce a stiffness thereof.

11. The microelectromechanical systems device of claim 1, wherein the electrostatically displaceable layer of each element is under tensile stress to a degree which increases as the height of its gap decreases.

12. The microelectromechanical systems device of claim 1, wherein the driving [mechanism] circuit comprises an electrode layer to electrostatically displace the electrostatically displaceable layer when energized, wherein the electrode layers which drive at least those elements having the smallest gap have apertures formed therein to increase the minimum voltage required to energize the electrode layers.

13. The microelectromechanical systems device of claim 1, wherein the electrostatically displaceable layer of each element is formed on a dielectric material having a dielectric constant which is a function of the height of the gap of the element, the higher the gap, the greater the dielectric constant.

14. The microelectromechanical systems device of claim 1, wherein the electrostatically displaceable layer of each element is formed on a dielectric material having a thickness which is a function of the height of the gap of the element, the higher the gap, the lower the thickness.

15. The microelectromechanical systems device of claim 1, wherein the minimum voltage is *not substantially* the same for each [kind] type of element.

16. The microelectromechanical systems device of claim 1, wherein each [of the] element[s] defines an interferometric modulator [which] configured to modulate[s] light.

17. The microelectromechanical systems device of claim 16, comprising three different [kinds] types of interferometric modulators, each differing in a height of its gap to reflect red, blue, or green light, respectively when in the undriven state.

18. A method [for] of fabricating a microelectromechanical systems device comprising:

constructing [an array] a plurality of elements, each element having a first layer, a second layer spaced from the first layer by a gap when in an undriven state, and an electrode layer configured to electrostatically drive the second layer to contact the first layer [corresponding to] when in a driven state [when energized], the elements being of at least two different types, each type differing in a height of its gap, wherein said constructing includes changing a configuration of [each] at least one element type to [compensate for] reduce a difference[s] in between a voltage required to drive [each] the at least one element type and another voltage required to drive another element type to [its] their respective driven state.

19. The method of claim 18, wherein the first and second layers of each element [in an array] are defined by continuous layers which are supported by a support structure comprising a plurality of supports spaced along a first axis and extending in a direction which is transverse thereto, each support having a support surface to support the first layer above the second layer when the elements are in the undriven state, wherein changing the configuration of each element type [then comprising] comprises changing the spacing between the supports.

20. The method of claim 19, wherein changing the configuration of each element type comprises changing an area of the support surface of each support.

21. The method of claim 18, wherein changing the configuration of each element type comprises using a material having a different Young's Modulus for the second layer of each element type.

22. The method of claim 18, wherein changing a configuration of each element type comprises changing a thickness of the second layer of each element type.

23. The method of claim 18, wherein changing a configuration of each element type comprises forming apertures in the second layers of at least those elements having the highest gap.

24. The method of claim 18, wherein changing a configuration of each element type comprises subjecting the second layer of each element to tensile stress to a degree which is inversely proportional to the height of its gap.

25. The method of claim 18, wherein changing a configuration of each element type comprises forming apertures in the electrode layer of at least those element types having the smallest gap.

26. The method of claim 18, wherein the second layer of each element is formed on a dielectric material, wherein changing a configuration of each element type [then comprising] comprises changing the dielectric constant of the dielectric material on which the second layer of each element is formed.

27. The method of claim 26, wherein changing a configuration of each element type comprises changing a thickness of the dielectric material.

28. The method of claim 18, wherein the elements are interferometric modulators [which] configured to modulate light.

29. A microelectromechanical systems device comprising:

a plurality of elements, each element having a first layer, a second layer spaced from the first layer by a gap when in an undriven state, and an electrode layer configured to electrostatically drive the second layer to contact the first layer corresponding to a driven state when the electrode layer is energized, the elements being of at least two different kinds, each kind of element differing in at least a height of its gap; and

[an element driving mechanism comprising an integrated] a drive circuit having multilevel outputs configured to energize the electrode layer of each element to cause the element to change from its undriven state to its driven state.

30. A method for fabricating a microelectromechanical systems device, the method comprising:

fabricating [an array] a plurality of first elements, each first element conforming to a first geometry;

fabricating [at least one array of] a plurality of second elements, each second element conforming to a second geometry; wherein

fabricating the [arrays] first and second elements comprises

selecting [a defining] an aspect of each of the first and second geometries [based on a defining characteristic of each of the first and second elements]; and normalizing differences in an actuation voltage required to actuate each of the first and second elements, wherein the differences in the actuation voltages are [as] a result of the selected [defining] aspect[, the defining characteristic of each of the elements being unchanged] of the first and second geometries.

31. The method of claim 30, wherein the normalizing comprises changing an other aspect[s] of the first and second geometries without changing the [defining] selected aspect[s] of the first and second geometries.

32. The method of claim [30] 31, wherein the [defining] selected aspect comprises a gap between an [operatively] upper and lower layer of each element, the upper and lower layers being separated by supports.

33. The method of claim 32, wherein each element comprises an electrode to electrostatically drive the upper layer towards the lower layer when actuated by the actuation voltage.

34. The method of claim 33, wherein changing [the] said other aspect[s] comprises at least a change[s] selected from the group comprising changing a thickness of the upper layer, and changing a distance between the supports.

35. The method of claim [31] 32, wherein the normalizing comprises changing a stiffness of the upper layer of each first and second element.

36. The method of claim 35, wherein changing the stiffness comprises changing the Young's modulus of the upper layer of each first and second element.

37. The method of claim 35, wherein changing the stiffness comprises forming apertures in the upper layer to reduce the stiffness thereof.

38. The method of claim 33, wherein the normalizing comprises changing a configuration of the electrode of each first or second element.

39. The method of claim 38, wherein changing a configuration of the electrode comprises forming apertures therein.

40. The method of claim 30, wherein the elements are formed on a dielectric material, [the normalization then comprising] wherein normalizing the differences comprises changing the dielectric properties of the dielectric material.

41. The method of claim 30, wherein the first and second elements are pixels.

42. A microelectromechanical systems device comprising:
a first element having a first element characteristic and at least two layers with a first gap between the two layers, wherein one layer of the at least two layers of the first element is configured to move relative to another layer and substantially close the first gap upon applying at least a first voltage to the first element; and

a second element having a second element characteristic and at least two layers with a second gap between the two layers, wherein one layer of the at least two layers of the second element is configured to move relative to another layer and substantially close the second gap upon applying at least a second voltage to the second element, wherein the first and second element characteristics are different, wherein a size of the first gap is different than a size of the second gap, wherein the first and second voltages comprise respective minimum sufficient voltages sufficient to substantially close the gap in the respective element, and wherein the first and second voltages are substantially the same.

43. The microelectromechanical systems device of claim 42, further comprising a circuit configured to apply the first voltage to at least the first element and the second voltage to at least the second element.

44. The microelectromechanical systems device of claim 43, wherein the driving circuit comprises an electrode layer in each of the first and second elements, and wherein the element characteristics of the first and second elements relate to the presence of at least one aperture in the electrode layer of at least one of the first and second elements.

45. The microelectromechanical systems device of claim 42, further comprising a plurality of the first and second elements arranged in a substantially co-planar array.

46. The microelectromechanical systems device of claim 45, further comprising at least two of the substantially co-planar arrays, wherein one of said at least two substantially co-planar arrays comprises only first elements and one of said at least two substantially co-planar arrays comprises only second elements.

47. The microelectromechanical systems device of claim 42, wherein the at least two layers of the respective first and second elements are continuous.

48. The microelectromechanical systems device of claim 42, wherein each movable layer is supported by a support structure comprising a plurality of supports spaced along a first axis and extending in a direction which is transverse to the first axis, and each support having a support surface to support the movable layer above the other of the at least two layers of the respective element.

49. The microelectromechanical systems device of claim 48, wherein the element characteristics of the first and second elements relate to the spacing between the supports along the first axis, wherein the spacing is a function of the size of the gap between the at least two layers of the respective element.

50. The microelectromechanical systems device of claim 48, wherein the element characteristics of the first and second elements relate to an area of the support surface of each support, and wherein the area of the support surface is a function of the height of the gap between the at least two layers.

51. The microelectromechanical systems device of claim 42, wherein the element characteristics of the first and second elements relate to a Young's Modulus of the movable layer, wherein the Young's Modulus is a function of the size of the gap of the respective element.

52. The microelectromechanical systems device of claim 42, wherein the element characteristics of the first and second elements relate to a thickness of the movable layer, wherein the thickness is a function of the size of the gap of the respective element.

53. The microelectromechanical systems device of claim 42, wherein the element characteristics of the first and second elements relate to the presence of at least an aperture formed on the movable layer of at least one of the first and second elements.

54. The microelectromechanical systems device of claim 42, wherein the element characteristics of the first and second elements relate to a tensile stress of the movable layer, wherein the tensile stress is a function of the size of the gap of the respective element.

55. The microelectromechanical systems device of claim 42, wherein the element characteristics of the first and second elements relate to a dielectric material of the first and second elements, wherein the dielectric material comprises a dielectric constant that is a function of the size of the gap of the respective element.

56. The microelectromechanical systems device of claim 42, wherein the element characteristics of the first and second elements relate to a dielectric material of the first and second elements, wherein a thickness of the dielectric material is a function of the size of the gap of the respective element.

57. The microelectromechanical systems device of claim 42, wherein the minimum voltage is the same for the first and second elements.

58. The microelectromechanical systems device of claim 42, wherein each of the first and second elements are interferometric modulators configured to modulate light.

59. The microelectromechanical systems device of claim 58, further comprising a third element, wherein the first, second and third elements each comprise an interferometric modulators, each element differing in a height of its gap to reflect red, blue, or green light, respectively.

60. A microelectromechanical systems device comprising:
a first element comprising a first electrode and at least two layers with a first gap between the two layers, wherein

at least one of the at least two layers of the first element is configured to move relative to another layer and substantially close the first gap upon applying a first voltage to at least the first electrode; and

a second element comprising a second electrode and at least two layers with a second gap between the two layers, wherein a size of the first gap is different than a size of the second gap, wherein at least one of the at least two layers of the second element is configured to move relative to another layer and substantially close the second gap upon applying a second voltage to at least the second electrode, wherein the first and second voltages are different;

wherein a plurality of said first and second elements are arranged in a substantially co-planar array.

61. The microelectromechanical systems device of claim 60, further comprising a circuit configured to apply the first voltage to at least the first electrode and the second voltage to at least the second electrode.

62. The microelectromechanical systems device of claim 60, wherein the first electrode is located over one of the at least two layers of the first element, and the second electrode is located over one of the at least two layers of the second element.

63. The microelectromechanical systems device of claim 60, further comprising at least two of the substantially co-planar arrays, wherein one of said at least two substantially co-planar arrays comprises only first elements and one of said at least two substantially co-planar arrays comprises only second elements.

64. The microelectromechanical systems device of claim 60, wherein the at least two layers of the respective first and second elements are continuous.

65. The microelectromechanical systems device of claim 60, wherein in each of the first and second elements the layer configured to move relative to another layer is supported by a support structure comprising a plurality of supports spaced along a first axis and extending in a direction which is transverse to the first axis.

66. The microelectromechanical systems device of claim 65, wherein the spacing between the supports along the first axis is a function of the size of the gap between the at least two layers of the respective element.

67. The microelectromechanical systems device of claim 65, wherein an area of the support surface of each support is a function of the height of the gap between the at least two layers of the respective element.

68. The microelectromechanical systems device of claim 60, wherein in each of the first and second elements the layer configured to move relative to another layer is characterized by a Young's Modulus, wherein the Young's Modulus is a function of the size of the gap of the respective element.

69. The microelectromechanical systems device of claim 60, wherein in each of the first and second elements the layer configured to move relative to another layer has a thickness that is a function of the size of the gap of the respective element.

70. The microelectromechanical systems device of claim 60, wherein at least the element having the largest gap size has at least one aperture formed in the layer configured to move relative to another layer.

71. The microelectromechanical systems device of claim 60, wherein in each of the first and second elements the layer configured to move relative to another layer is subject to a tensile stress that is a function of the size of the gap of the respective element.

72. The microelectromechanical systems device of claim 60, wherein the element having the smallest gap size has at least one aperture formed in its electrode layer.

73. The microelectromechanical systems device of claim 60, wherein each of the first and second elements further comprises a dielectric material located between the at least two layers, wherein the dielectric material is characterized by a dielectric constant that is a function of the size of the gap of the respective element.

74. The microelectromechanical systems device of claim 60, wherein each of the elements is an interferometric modulator configured to modulate light.

75. The microelectromechanical systems device of claim 74, further comprising a third element, wherein the first, second and third elements each comprise an interferometric modulators, each of the elements differing in a height of its gap to reflect one of red, blue, and green light.

* * * * *