



US007811421B2

(12) **United States Patent**  
**Chistyakov**

(10) **Patent No.:** **US 7,811,421 B2**  
(45) **Date of Patent:** **\*Oct. 12, 2010**

- (54) **HIGH DEPOSITION RATE SPUTTERING**
- (75) Inventor: **Roman Chistyakov**, Andover, MA (US)
- (73) Assignee: **Zond, Inc.**, Mansfield, MA (US)
- (\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 896 days.

5,733,418 A	3/1998	Hershcovitch et al.
6,024,844 A	2/2000	Drummond et al.
6,057,244 A	5/2000	Hausmann et al.
6,083,361 A	7/2000	Kobayashi et al.
6,086,730 A	7/2000	Liu et al.
6,217,717 B1	4/2001	Drummond et al.

(Continued)

**FOREIGN PATENT DOCUMENTS**

DE 3210351 A1 9/1983

(Continued)

**OTHER PUBLICATIONS**

Booth, et al., The Transition From Symmetric To Asymmetric Discharges In Pulsed 13.56 MHz Capacitively Coupled Plasmas, J. Appl. Phys., Jul. 15, 1997, pp. 552-560, vol. 82(2), American Institute of Physics.

(Continued)

*Primary Examiner*—Rodney G McDonald  
(74) *Attorney, Agent, or Firm*—Kurt Rauschenbach; Rauschenbach Patent Law Group, L.L.P

(57) **ABSTRACT**

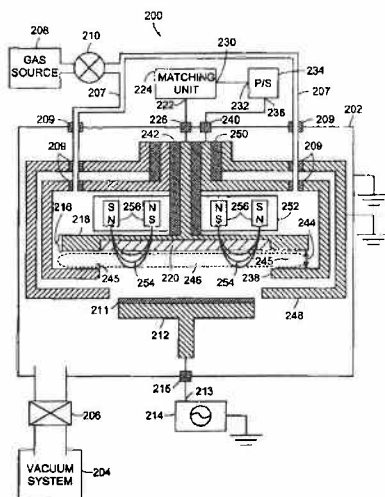
Methods and apparatus for high-deposition sputtering are described. A sputtering source includes an anode and a cathode assembly that is positioned adjacent to the anode. The cathode assembly includes a sputtering target. An ionization source generates a weakly-ionized plasma proximate to the anode and the cathode assembly. A power supply produces an electric field between the anode and the cathode assembly that creates a strongly-ionized plasma from the weakly-ionized plasma. The strongly-ionized plasma includes a first plurality of ions that impact the sputtering target to generate sufficient thermal energy in the sputtering target to cause a sputtering yield of the sputtering target to be non-linearly related to a temperature of the sputtering target.

**48 Claims, 13 Drawing Sheets**

- (21) Appl. No.: **11/183,463**
- (22) Filed: **Jul. 18, 2005**
- (65) **Prior Publication Data**  
US 2005/0252763 A1 Nov. 17, 2005
- Related U.S. Application Data**
- (63) Continuation of application No. 11/091,814, filed on Mar. 28, 2005, now abandoned.
- (51) **Int. Cl.**  
**C23C 14/35** (2006.01)
- (52) **U.S. Cl.** ..... **204/192.12; 204/298.08; 204/298.06**
- (58) **Field of Classification Search** ..... 204/192.12, 204/298.06, 298.08  
See application file for complete search history.

(56) **References Cited**  
**U.S. PATENT DOCUMENTS**

4,588,490 A	5/1986	Cuomo et al.
5,015,493 A	5/1991	Gruen
5,083,061 A	1/1992	Koshiishi et al.
5,286,360 A	2/1994	Szczyrbowski et al.
5,576,939 A	11/1996	Drummond
5,718,813 A	2/1998	Drummond et al.
5,728,278 A	3/1998	Okamura et al.



EX 1101

## U.S. PATENT DOCUMENTS

6,238,537	B1	5/2001	Kahn et al.	
6,251,242	B1 *	6/2001	Fu et al.	204/298.19
6,296,742	B1	10/2001	Kouznetsov	
6,327,163	B1	12/2001	Petr	
6,361,667	B1	3/2002	Kobayashi et al.	
6,413,382	B1	7/2002	Wang et al.	
6,413,383	B1	7/2002	Chiang et al.	
6,436,251	B2	8/2002	Gopalraja et al.	
6,521,099	B1	2/2003	Drummond et al.	
6,808,607	B2	10/2004	Christie	
6,896,773	B2 *	5/2005	Chistyakov	204/192.12
7,095,179	B2 *	8/2006	Chistyakov	315/111.21
7,147,759	B2 *	12/2006	Chistyakov	204/192.12
2002/0033480	A1	3/2002	Kawamata et al.	
2002/0114897	A1	8/2002	Sumiya et al.	
2005/0092596	A1	5/2005	Kouznetsov	
2005/0103620	A1	5/2005	Chistyakov	
2005/0109607	A1	5/2005	Ehiasarian et al.	
2005/0184669	A1	8/2005	Chistyakov	
2009/0263966	A1	10/2009	Weichart et al.	

## FOREIGN PATENT DOCUMENTS

EP	0788139	A1	8/1997
GB	1339910		12/1973
GB	2401116	A	3/2004
JP	57194254		11/1982
JP	62-216637		9/1987
JP	08-067981		3/1996
JP	08-293470		11/1996
JP	2004-010979	*	1/2004
JP	2004 010979	A	1/2004
RU	2 029 411	C1	5/1995
RU	2 058 429	C1	4/1996
RU	2058429		4/1996
WO	WO 98/40532		9/1998
WO	WO 01/98553	A1	12/2001
WO	WO 02/103078	*	12/2002

## OTHER PUBLICATIONS

Bunshah, et al., Deposition Technologies For Films And Coatings, Materials Science Series, pp. 176-183, Noyes Publications, Park Ridge, New Jersey.

Daugherty, et al., Attachment-Dominated Electron-Beam-Ionized Discharges, Applied Science Letters, May 15, 1976, vol. 28, No. 10, American Institute of Physics.

Goto, et al., Dual Excitation Reactive Ion Etcher For Low Energy Plasma Processing, J. Vac. Sci. Technol. A., Sep./Oct. 1992, pp. 3048-3054, vol. 10, No. 5, American Vacuum Society.

Kouznetsov, et al., A Novel Pulsed Magnetron Sputter Technique Utilizing Very High Target Power Densities, Surface & Coatings Technology, pp. 290-293, Elsevier Sciences S. A.

Lindquist, et al., High Selectivity Plasma Etching Of Silicon Dioxide With A Dual Frequency 27/2 MHz Capacitive RF Discharge.

Macak, Reactive Sputter Deposition Process Of Al<sub>2</sub>O<sub>3</sub> And Characterization Of A Novel High Plasma Density Pulsed Magnetron Discharge, Linkoping Studies In Science And Technology, 1999, pp. 1-2: Sweden.

Macak, et al., Ionized Sputter Deposition Using An Extremely High Plasma Density Pulsed Magnetron Discharge, J. Vac. Sci. Technol. A, Jul./Aug. 2000, pp. 1533-1537, vol. 18, No. 4, American Vacuum Society.

Mozgrin, et al., High-Current Low-Pressure Quasi-Stationary Discharge In A Magnetic Field: Experimental Research, Plasma Physics Reports, 1995, pp. 400-409, vol. 21, No. 5, Mozgrin Feitsov Khodachenko.

Rosnagel, et al., Induced Drift Currents In Circular Planar Magnetrons, J. Vac. Sci. Technol. A., Jan./Feb. 1987, pp. 88-91, vol. 5, No. 1, American Vacuum Society.

Sheridan, et al., Electron Velocity Distribution Functions In A Sputtering Magnetron Discharge For The EXB Direction, J. Vac. Sci. Technol. A., Jul./Aug. 1998, pp. 2173-2176, vol. 16, No. 4, American Vacuum Society.

Streinbruchel, A Simple Formula For Low-Energy Sputtering Yields, Applied Physics A., 1985, pp. 37-42, vol. 36, Springer-Verlag.

Chistyakov, High-Power Pulsed Magnetron Sputtering, U.S. Appl. No. 10/065,277, filed Sep. 30, 2002.

Chistyakov, High-Power Pulsed Magnetically Enhanced Plasma Processing, U.S. Appl. No. 10/061,551, filed Oct. 29, 2002.

Chistyakov, Methods And Apparatus For Generating High-Density Plasma, U.S. Appl. No. 10/065,629, filed Nov. 4, 2002.

Encyclopedia Of Low Temperature Plasma, p. 119, vol. 3.

Encyclopedia Of Low Temperature Plasma, p. 123, vol. 3.

Turenko, et al., Magnetron Discharge In The Vapor Of The Cathode Material, Soviet Technical Physics Letters, Jul. 1989, pp. 519-520, vol. 15, No. 7, New York, US.

"Notification Of Transmittal Of The International Search Report Or The Declaration" For PCT/US03/34226, Jun. 23, 2004, 6 pages, The International Searching Authority/EPO, Rijswijk, The Netherlands.

Notice Of Reasons For Rejection, Japanese Patent Office, Aug. 24, 2009, 27 Pages, Japan.

"Office Action" for U.S. Appl. No. 10/065,277, Jan. 15, 2004, 12 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/065,277, Aug. 30, 2004, 14 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/065,277, May 27, 2005, 13 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/065,277, Jan. 11, 2006, 15 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/065,277, Jul. 18, 2006, 6 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/065,629, Oct. 7, 2003, 11 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/065,739, Feb. 18, 2004, 14 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/065,739, May 20, 2004, 14 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/249,202, Feb. 11, 2004, 6 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/249,595, Apr. 22, 2004, 5 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/249,774, Aug. 27, 2004, 6 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/249,844, Apr. 23, 2004, 5 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/553,893, Mar. 7, 2008, 6 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/708,281, May 18, 2005, 15 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/708,281, Dec. 20, 2005, 14 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/710,946, Nov. 16, 2007, 7 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/710,946, Feb. 21, 2008, 18 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/710,946, Apr. 10, 2009, 18 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/897,257, Mar. 27, 2008, 13 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/897,257, Jan. 14, 2009, 7 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 10/949,427, Apr. 21, 2006, 6 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 11/091,814, Jul. 14, 2008, 19 pages, The USPTO, US.

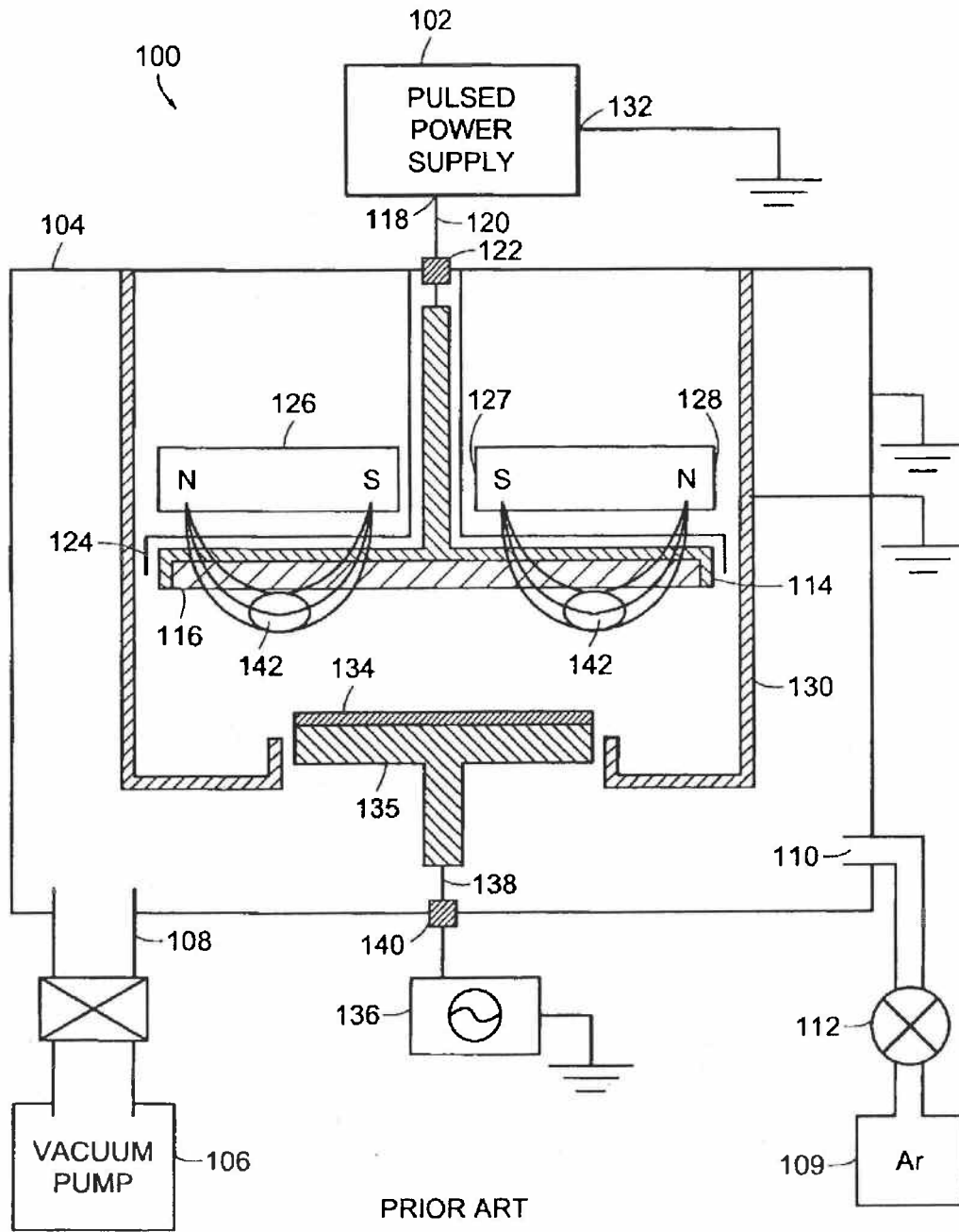
"Office Action" for U.S. Appl. No. 11/130,315, Jul. 3, 2008, 10 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 11/162,824, Apr. 28, 2008, 8 pages, The USPTO, US.

"Office Action" for U.S. Appl. No. 11/162,824, Jan. 23, 2009, 10 pages, The USPTO, US.

- "Office Action" for U.S. Appl. No. 11/162,824, May 18, 2009, 9 pages, The USPTO, US.
- "Office Action" for U.S. Appl. No. 11/376,036, Jul. 25, 2007, 7 pages, The USPTO, US.
- "Office Action" for U.S. Appl. No. 11/608,833, Mar. 11, 2009, 8 pages, The USPTO, US.
- "Office Action" for U.S. Appl. No. 12/245,193, Apr. 2, 2009, 4 pages, The USPTO, US.
- Biberman, L. M., et al., Kinetics of Nonequilibrium Low-Temperature Plasmas, 1987.
- Bugaev, S. P., et al., Investigation Of A High-Current Pulsed Magnetron Discharge Initiated In The Low-Pressure Diffuse Arc Plasma, XVIIth International Symposium On Discharges and Electrical Insulation In Vacuum, 1996, pp. 1074-1076.
- Bugaev, S. P., et al., Ion-Assisted Pulsed Magnetron Sputtering Deposition Of Ta-C Films, Thin Solid Films, 2001, pp. 16-26, vol. 389, Elsevier Science B.V., Feb. 2001.
- D' Couto, G. C., et al., In Situ Physical Vapor Deposition of Ionized Ti and TiN Thin Films Using Hollow Cathode Magnetron Plasma Source, J. Vac. Sci. Technol. B, Jan./Feb. 2001, pp. 244-249, vol. 19, No. 1, American Vacuum Society.
- Ehiasarian, A. P., et al., High Power Pulsed Magnetron Sputtered CrNx Films, Dunnschicht-/Plasmatechnik, 2003, pp. 1480-1487, Jun. 2003.
- Ehiasarian, A. P., et al., Influence Of High Power Densities On The Composition Of Pulsed Magnetron Plasmas, Vacuum, 2002, pp. 147-154, vol. 65, Elsevier Science Ltd.
- Gudmundsson, J. T. et al., Spatial and Temporal Behavior Of The Plasma Parameters In A Pulsed Magnetron Discharge, Surface and Coatings Technology, 2002, pp. 249-256, vol. 161, Elsevier Science B.V., Jul. 2002.
- Gudmundsson, J. T. et al., Evolution Of The Electron Energy Distribution And Plasma Parameters In A Pulsed Magnetron Discharge, Applied Physics Letters, May 28, 2001, pp. 3427-3429, vol. 78, No. 22, American Institute Of Physics.
- Hopwood, J., Ionized Physical Vapor Deposition Of Integrated Circuit Interconnects, Physics Of Plasmas, May 1998, pp. 1624-1631, vol. 5, No. 5, American Institute Of Physics.
- Kervallishvili, N. A., et al., Low-Pressure Discharge in Crossed Fields (E,H) In A Magnetron And Penning Cell, Sov. Phys. Tech. Phys., 1976, pp. 1591-1596, vol. 20, No. 12, American Institute Of Physics.
- Korneev, V.V., Electric Fields In A Nonequilibrium Inhomogeneous Weakly Ionized Plasma, Sov. J. Plasma Phys., Nov.-Dec. 1978, pp. 784-785, vol. 4, No. 6, American Institute of Physics.
- Lebedev, S. Ya., et al., Cathode Sputtering Under The Action Of Cesium Ions, Soviet Physics—Technical Physics, Dec. 1964, pp. 854-856, vol. 9, No. 6.
- Mesyats, G. A., et al., Pulsed Electrical Discharge In Vacuum, Springer-Verlag.
- Oks, E. M., et al., Plasma Emission Properties Of A Superdense Glow Discharge Excited In Crossed Electric And Magnetic Fields, Sov. Phys. Tech. Phys., Jun. 1991, pp. 712-714, vol. 36, No. 6, American Institute of Physics.
- Rasmussen, C. E., et al., Ionization And Current Growth In An E X B Discharge, Plasma Physics, 1969, pp. 183-195, vol. 11, Pergamon Press, Northern Ireland.
- Redhead, P. A., Instabilities In Cross-Field Discharges At Low Pressures, Vacuum, 1988, pp. 901-906, vol. 38, No. 8-10, Pergamon Press, Great Britain.
- Steinbruchel, Ch., A Simple Formula For Low-Energy Sputtering Yields, Appl. Phys. A., 1985, pp. 37-42, vol. 36, Springer-Verlag.
- Westwood, W. D., The Current-Voltage Characteristic Of Magnetron Sputtering Systems, J. Appl. Phys., Dec. 1983, pp. 6841-6846, vol. 54, No. 12, American Institute Of Physics.
- "Notification Concerning Transmittal Of Copy Of International Preliminary Report On Patentability (Chapter I Of The Patent Cooperation Treaty)" For PCT/US2008/004644, Nov. 5, 2009, 10 pgs., The International Bureau Of WIPO, Geneva, Switzerland.
- "Notification Concerning Transmittal Of Copy Of International Preliminary Report On Patentability (Chapter I Of The Patent Cooperation Treaty)" For PCT/US2008/004605, Oct. 29, 2009, 9 pgs., The International Bureau Of WIPO, Geneva, Switzerland.
- "Office Action" For European Patent Application No. 03-781-508.1-1226, Apr. 1, 2008, 5 pages, the European Patent Office.
- "Response to Office Action" For European Patent Application No. 03-781-508.1-1226, Oct. 13, 2008, 13 pages.
- "Supplement to Response to Office Action" For European Patent Application No. 03-781-508.1-1226, Oct. 23, 2008, 4 pages.
- "Office Action" For European Patent Application No. 03-781-508.1-1226, Apr. 7, 2010, 3 pages, the European Patent Office.
- "Office Action" For European Patent Application No. 03-779-387.4-1215, Oct. 10, 2007, 4 pages, the European Patent Office.
- "Response to Office Action" For European Patent Application No. 03-779-387.4-1215, Apr. 21, 2008, 15 pages.
- "Summons to Oral Proceedings" For European Patent Application No. 03-779-387.4-1215, Dec. 15, 2009, 6 pages, the European Patent Office.
- "Office Action" For European Patent Application No. 03-776-584.9-1226, Sep. 18, 2008, 6 pages, the European Patent Office.
- "Response to Office Action" For European Patent Application No. 03-776-584.9-1226, Jul. 23, 2009, 12 pages.
- "Office Action" For European Patent Application No. 04-749-844.9-2208, Jan. 28, 2009, 2 pages, the European Patent Office.
- "Office Action" For European Patent Application No. 04-750-797.5-2208, Oct. 16, 2008, 5 pages, the European Patent Office.
- "Office Action" For European Patent Application No. 04-716-928.9-2208, Dec. 15, 2006, 5 pages, the European Patent Office.
- "Response to Office Action" For European Patent Application No. 04-716-928.9-2208, Jul. 24, 2007, 20 pages.
- "Office Action" For European Patent Application No. 04-810-268.5-2208, Apr. 23, 2009, 3 pages, the European Patent Office.
- "Response to Office Action" For European Patent Application No. 04-810-268.5-2208, May 29, 2009, 2 pages.
- "Office Action" For European Patent Application No. 05-723-194.6-1226, Nov. 5, 2009, 6 pages, the European Patent Office.
- "Office Action" For European Patent Application No. 05-800-880.6-1226, Jan. 25, 2010, 3 pages, the European Patent Office.
- "Office Action" For Japanese Patent Application No. 2004-551595, Aug. 24, 2009, 2 pages, the Japanese Patent Office.
- "Response to Office Action" For Japanese Patent Application No. 2004-551595, Feb. 18, 2010, 3 pages.
- "Notice of Allowance" For US Patent No. 7,147,759, Oct. 11, 2006, 12 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 6,853,142, Mar. 29, 2004, 20 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 7,604,716, Jun. 11, 2009, 16 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 6,896,773, Jan. 7, 2005, 12 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 6,896,775, Jan. 18, 2005, 20 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 6,806,651, Jul. 12, 2004, 9 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 7,446,479, Jul. 15, 2008, 16 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 6,806,652, Jul. 2, 2004, 9 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 6,903,511, Nov. 2, 2005, 9 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 6,805,779, Jun. 29, 2004, 14 Pages, USPTO.
- "Notice of Allowance" for US Patent No. 7,095,179, May 2, 2006, 18 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 7,345,429, Nov. 30, 2007, 8 Pages, USPTO.
- "Notice of Allowance" For US Patent No. 7,663,319, Oct. 8, 2009, 50 Pages, USPTO.
- US 5,863,392, 01/1999, Drummond et al. (withdrawn)

\* cited by examiner



PRIOR ART  
FIG. 1

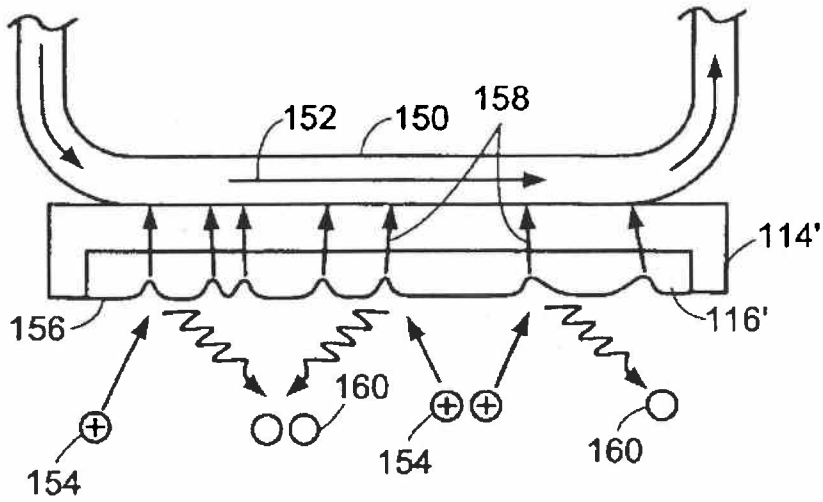


FIG. 2  
PRIOR ART

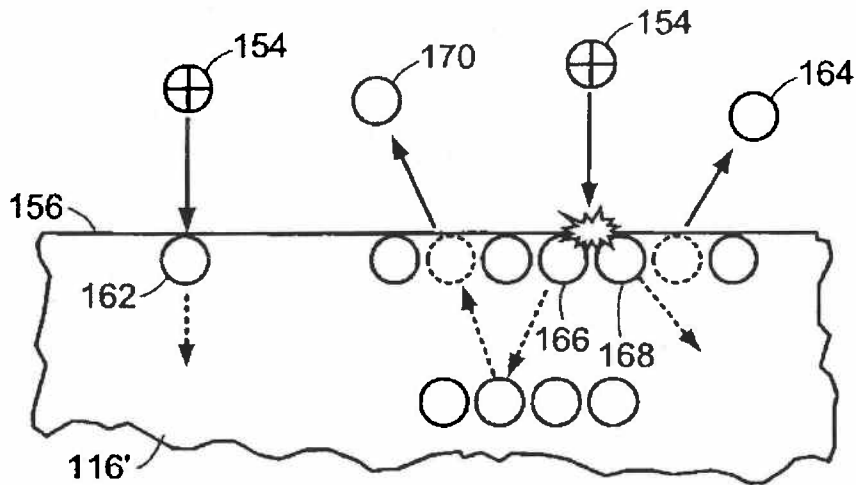


FIG. 3  
PRIOR ART

# Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

## Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

## Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

## Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

## API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

## LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

## FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

## E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.