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(12) **United States Patent**
Chistyakov

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(54) **METHODS AND APPARATUS FOR GENERATING HIGH-DENSITY PLASMA**

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(51) **Int. Cl.**⁷ **C23C 16/452**

(52) **U.S. Cl.** **315/111.41; 156/345.33; 118/723.1**

(58) **Field of Search** 315/111.01-111.91; 156/345.21, 345.29, 345.33, 345.42, 345.44, 345; 204/298.06, 298.04, 298.08; 118/723 FE, 723.1, 723 MP; 423/210, 246, 248

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,588,490 A	5/1986	Cuomo et al.	204/298
4,953,174 A	8/1990	Eldridge et al.	372/87
5,015,493 A	5/1991	Gruen	427/38
5,041,760 A *	8/1991	Koloc	315/111.41
5,083,061 A	1/1992	Koshiishi et al.	315/111.81
5,247,531 A	9/1993	Muller-Horshe	372/38
5,286,360 A	2/1994	Szcyrkowski et al. .	204/298.08
5,433,258 A	7/1995	Barnes et al.	156/643.1
5,696,428 A	12/1997	Pasch	315/111.21
5,718,813 A	2/1998	Drummond et al. ...	204/192.12
5,728,278 A	3/1998	Okamura et al.	204/298.11
5,733,418 A	3/1998	Hershcovitch et al. .	204/192.11
5,795,452 A	8/1998	Kinoshita et al.	204/298.37
5,916,455 A	6/1999	Kumagai	216/68
5,993,761 A *	11/1999	Czernichowski et al. ...	423/210

6,057,244 A	5/2000	Hausmann et al.	438/706
6,238,537 B1	5/2001	Kahn et al.	204/598.04
6,296,742 B1	10/2001	Kouznetsov	204/192.12
6,361,667 B1	3/2002	Kobayashi et al.	204/298.11
6,413,382 B1	7/2002	Wang et al.	204/192.12
6,413,383 B1	7/2002	Chiang et al.	204/192.13
6,432,260 B1	8/2002	Mahoney et al.	156/345.35
6,436,251 B2	8/2002	Gopalraja et al.	204/298.12
6,451,703 B1	9/2002	Liu et al.	438/710

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

EP	0 650 183 A1	4/1995
WO	WO 98/40532	9/1998
WO	WO 01/98553 A1	12/2001

OTHER PUBLICATIONS

US 5,863,392, 1/1999, Drummond et al. (withdrawn) Booth, et al., The Transition From Symmetric To Asymmetric Discharges In Pulsed 13.56 MHz Capacity Coupled Plasmas, J. Appl. Phys., Jul. 15, 1997, pp. 552-560, vol. 82(2), American Institute of Physics.

(List continued on next page.)

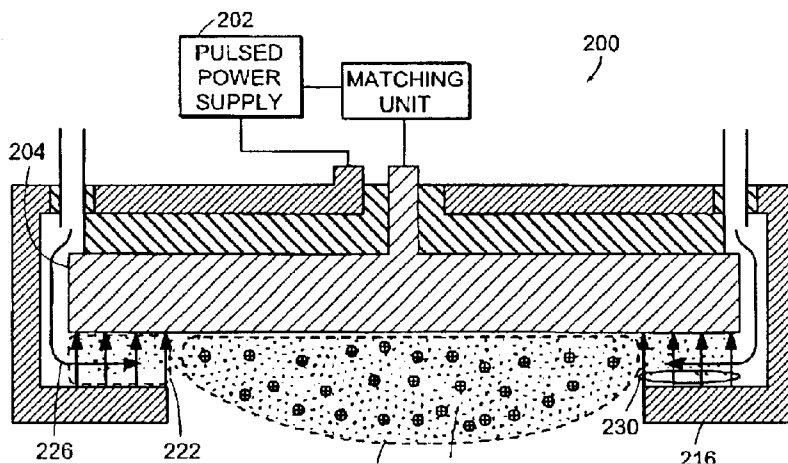
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(57) **ABSTRACT**

Methods and apparatus for generating a strongly-ionized plasma are described. An apparatus for generating a strongly-ionized plasma according to the present invention includes an anode and a cathode that is positioned adjacent to the anode to form a gap there between. An ionization source generates a weakly-ionized plasma proximate to the cathode. A power supply produces an electric field in the gap between the anode and the cathode. The electric field generates excited atoms in the weakly-ionized plasma and generates secondary electrons from the cathode. The secondary electrons ionize the excited atoms, thereby creating the strongly-ionized plasma

43 Claims, 13 Drawing Sheets



U.S. PATENT DOCUMENTS

6,471,833	B2	10/2002	Kumar et al.	204/192.37
6,488,825	B1 *	12/2002	Hilliard	204/298.06
2002/0019139	A1	2/2002	Zhang et al.	438/714
2002/0114897	A1	8/2002	Sumiya et al.	427/569
2003/0006008	A1	1/2003	Horioka et al.	156/345.46

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 Al₂O₃ 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.

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

Chistyakov, Roman, High-Power Pulsed Magnetron Sputtering, Application No.: 10/065,277, Filed: Sep. 30, 2002.

Chistyakov, Roman, High-Power Pulsed Magnetically Enhanced Plasma Processing, Application No.: 10/065,551, Filed: Oct. 30, 2002.

Encyclopedia Of Low Temperature Plasma, p. 119, 123, vol. 3.

* cited by examiner

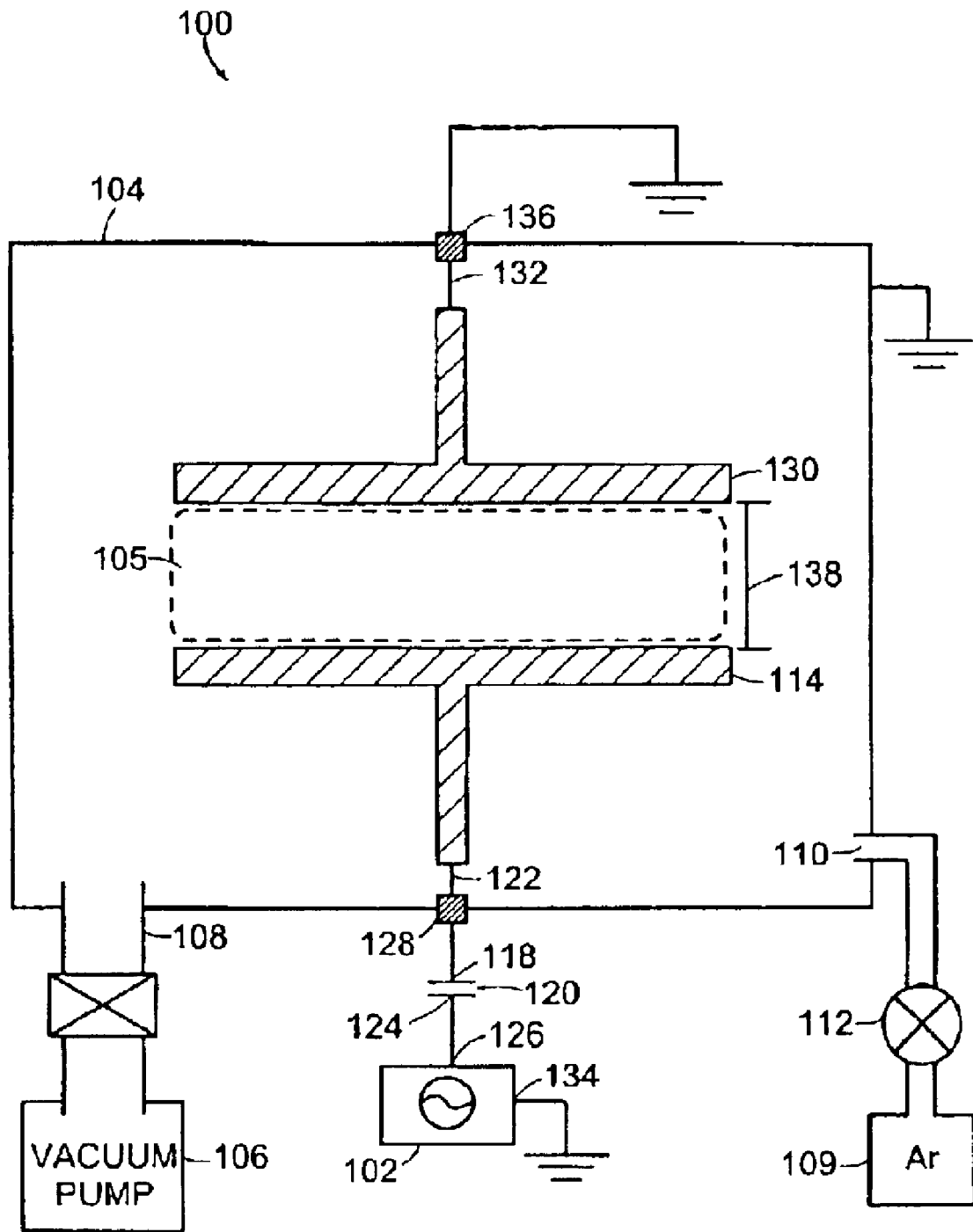


FIG. 1
PRIOR ART

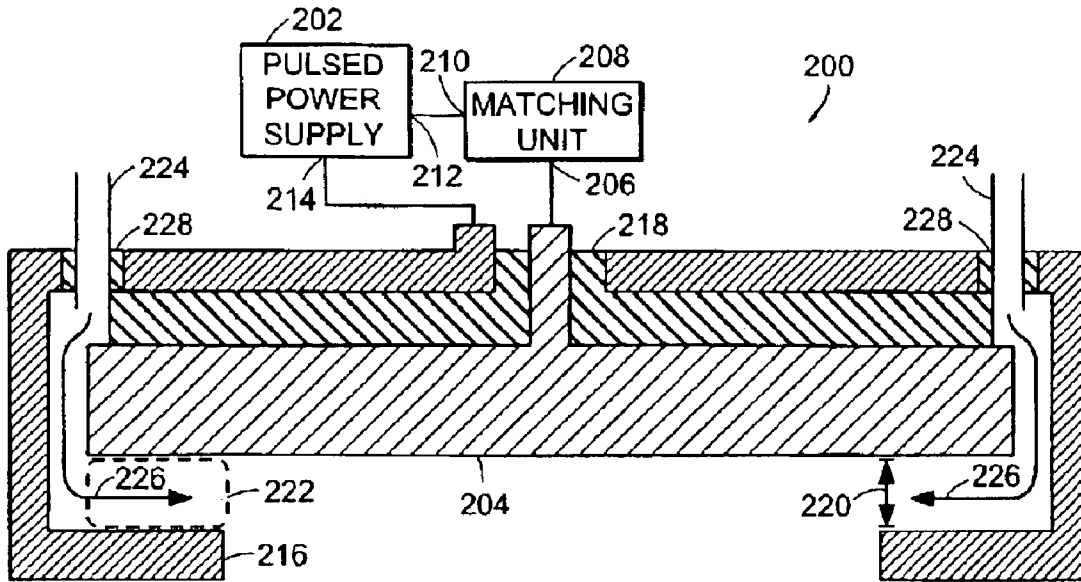


FIG. 2A

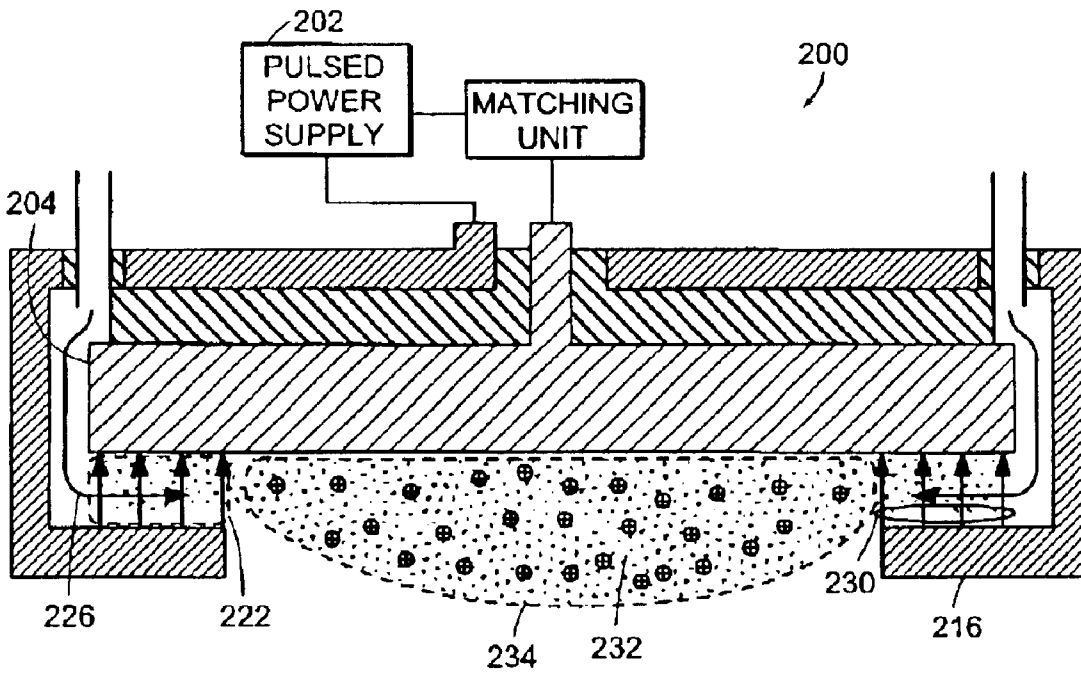


FIG. 2B

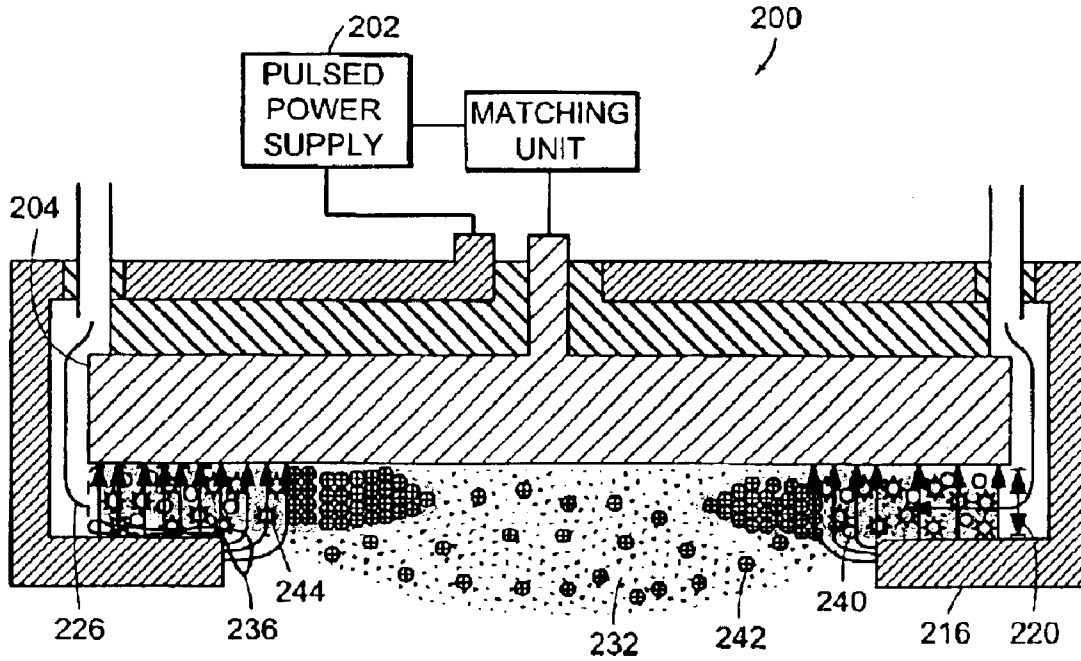


FIG. 2C

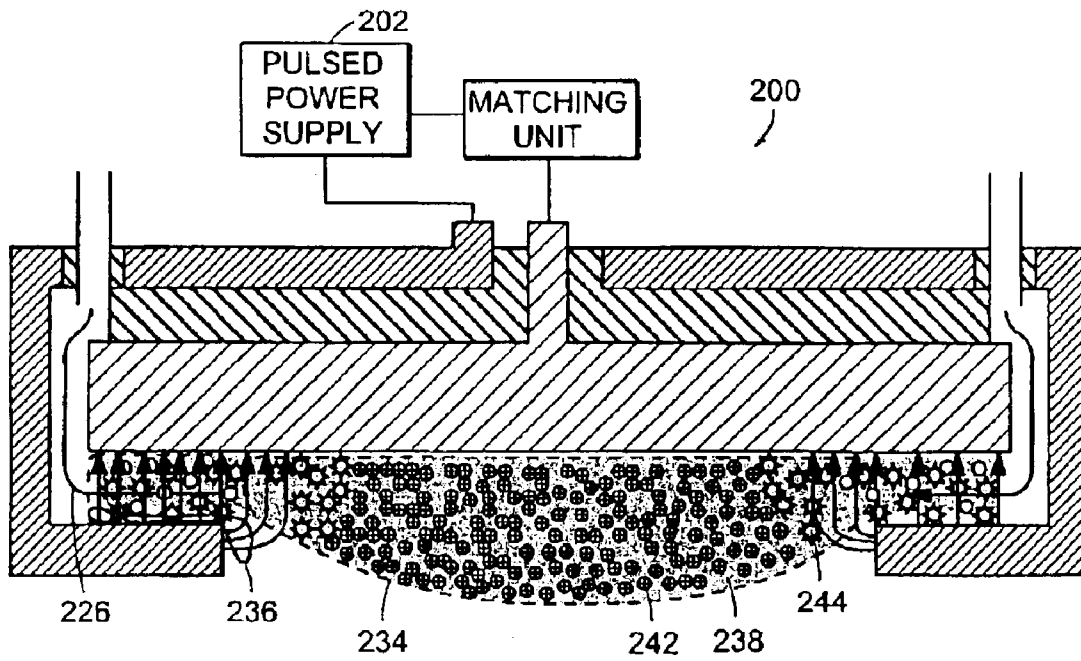


FIG. 2D

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