US006806652B1

(12) **United States Patent**
Chistyakov

(10) **Patent No.: US 6,806,652 B1**
(45) **Date of Patent: *Oct. 19, 2004**

(54) **HIGH-DENSITY PLASMA SOURCE USING EXCITED ATOMS**

(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 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/249,844**

(22) Filed: **May 12, 2003**

Related U.S. Application Data

(63) Continuation-in-part of application No. 10/249,595, filed on Apr. 22, 2003.

(51) **Int. Cl.**[7] **H01J 7/24**

(52) **U.S. Cl.** ..... **315/111.21**; 315/111.41; 156/345.44; 118/723 DC

(58) **Field of Search** ..... 315/111.21, 111.41, 315/111.61, 111.71, 111.81, 111.91; 204/298.07, 298.08, 298.121, 298.161, 298.2, 298.21, 298.22; 156/345.33, 345.35, 345.38, 345.39, 345.4, 345.41, 345.42, 345.43, 345.44, 345.46; 118/723 ME, 723 DC, 723 I, 723 IR

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,619,605	A	11/1971	Cook et al.	250/419
4,060,708	A	11/1977	Walters	219/121
4,148,612	A	4/1979	Taylor et al.	23/232

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

WO	WO 98/40532	9/1998
WO	WO 01/98553 A1	12/2001

OTHER PUBLICATIONS

Booth, et al., The Transition From Symmetric To Asymemtric Discharges In Pulsed 13.56 MHz Capacitively Coupled Plasmas, J. Appl. Phys., Jul. 15, 1997, pp. 552–560, vol. 82, No. 2, American Institute of Physics.

Bunshah, et al., Deposition Technologies For Films And Coatings, pp. 178–183, Noyes Pubications, park Ridge, New Jersey.

Daugherty, et al., Attachment–Dominated Electron–Beam–Ionized Discharges, Applied Physics Letters, May 15, 1976, pp. 581–583, 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.

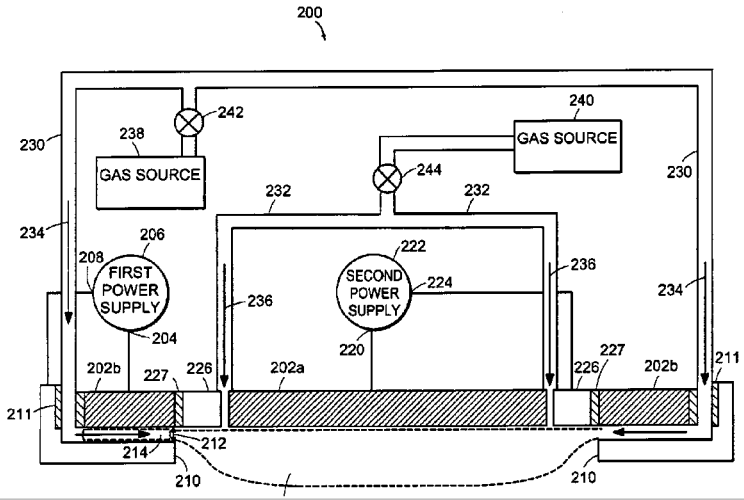
(List continued on next page.)

Primary Examiner—Don Wong
Assistant Examiner—Ephrem Alemu
(74) *Attorney, Agent, or Firm*—Kurt Ranuschenbach; Rauschenbach Patent Law Group, LLC

(57) **ABSTRACT**

The plasma source includes a cathode assembly. An anode is positioned adjacent to the cathode assembly. An excited atom source generates an initial plasma and excited atoms from a volume of feed gas. The initial plasma and excited atoms are located proximate to the cathode assembly. A power supply generates an electric field between the cathode assembly and the anode. The electric field super-ionizes the initial plasma so as to generate a high-density plasma.

35 Claims, 19 Drawing Sheets



U.S. PATENT DOCUMENTS

4,546,253	A		10/1985	Tsuchiya et al. 250/288
4,703,222	A		10/1987	Yoshikawa et al. 313/362.1
4,716,340	A	*	12/1987	Lee et al. 204/298.18
4,792,725	A		12/1988	Levy et al. 315/39
4,802,183	A		1/1989	Harris et al. 372/57
4,919,690	A		4/1990	Lovelock 55/2
4,953,174	A		8/1990	Eldridge et al. 372/87
4,977,352	A	*	12/1990	Williamson 315/111.21
5,015,493	A		5/1991	Gruen 427/38
5,083,061	A		1/1992	Koshiishi et al. 315/111.81
5,247,531	A		9/1993	Muller-Horsche 372/38
5,247,535	A		9/1993	Muller-Horsche et al. 372/86
5,382,457	A		1/1995	Coombe 427/596
5,506,405	A		4/1996	Yoshida et al. 250/251
5,733,418	A		3/1998	Hershcovitch et al. . 204/192.11
5,821,548	A		10/1998	Hinchliffe 250/492.21
6,057,244	A		5/2000	Hausmann et al. 438/706
6,094,012	A	*	7/2000	Leung et al. 315/111.81
6,124,675	A		9/2000	Bertrand et al. 315/111.91
6,137,231	A	*	10/2000	Anders et al. 315/111.21
6,207,951	B1		3/2001	Yamauchi et al. 250/251
6,296,742	B1		10/2001	Kouznetsov 204/192.12
6,395,641	B2		5/2002	Savas 438/714
6,413,382	B1		7/2002	Wang et al. 204/192.12
6,413,383	B1		7/2002	Chiang et al. 204/192.13
6,462,482	B1	*	10/2002	Wickramanayaka et al. 315/111.21
2002/0153103	A1		10/2002	Maddocks 156/345.46

OTHER PUBLICATIONS

Kouznetsov, et al., A Novel Pulsed Magnetron Sputter Technique Utilizing Very High Target Power Densities, Surface and Coatings Technology, 1999, pp. 290–293, vol. 122, Elsevier Science S.A.

Lindquist, et al., High Selectivity Plasma Etching Of Silicone Dioxdie With A Dual Frequency 27/2 MHz Capacitiv RF Discharge.

Macak, Reactive Sputter Deposition Process Of Al203 And Characterization Of A Novel High Plasm aDensity Pulsed Magnetron Discharge, Linkoping Studies In Science And Technology, pp. 1–2.

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

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

Rossnagel, 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 E x B Direction, J. Vac. Sci. Technol., Jul.Aug. 1998, pp. 2173–2176, vol. 16, No. 4, American Vacuum Society.

Steinbruchel, A Simple Formula FOr Low–Energy Sputtering Yields, APpl. Phys. A., 1985, p. 37–42, vol. 36, Sprigner Verlag.

Encyclopedia Of Low Temperature Plasma, p. 119, vol. 3, 2000.

Encyclopedia Of Low Temperature Plasma, p. 123, vol. 3, 2000.

Lymberopoulos, et al., Fluid Simulations Of Glow DIscharges: Effect Of Metastable Atoms In Argon, J. Appl. Phys., Apr. 1993, pp. 3668–3679, vol. 73, No. 8, American Inststiute of Physics.

Burnham, et al., Efficient Electric Discharge Lasers In XeF and KrF, Applied Physics Letters, Jul. 1976, pp. 30–32, vol. 29, No. 1, American Institstute of Physics.

Fabrikant, et al., Electron Impact Formation Of Metastable Atoms, pp. 3, 31, 34–37, Amsterdam.

Fahey, et al., High Flux Beam Source Of Thermal Rare–Gas Metastable Atoms, 1980, J. Phys. E. Sci. Instrum., vol. 13, The Institute of Physics.

Verheijen, et al., A Discharge Excited Supersonic Source Of Metastable Rare Gas Atoms, J. Phys. E. Sci. Instrum, 1984, vol. 17.

Eletskii, Excimer Lasers, Sov. Phys. Usp., Jun. 1978, pp. 502–521, vol. 21, N0. 6.

* cited by examiner

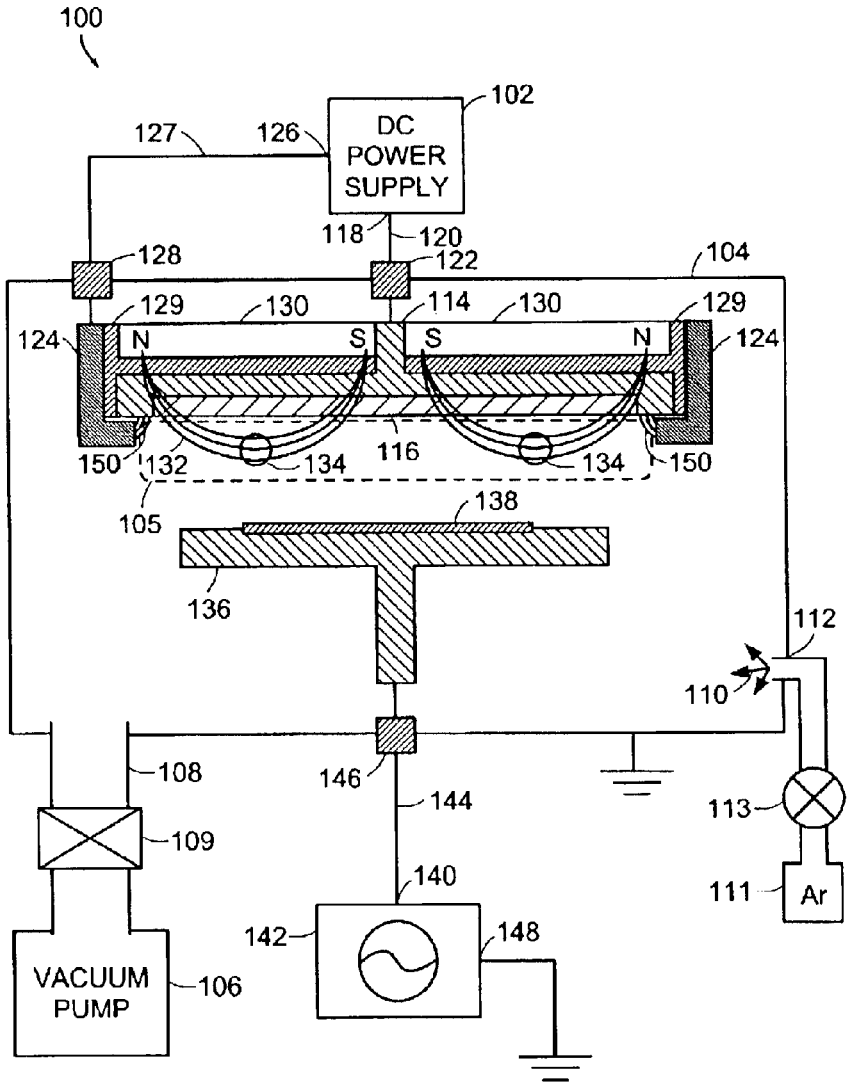


FIG. 1
PRIOR ART

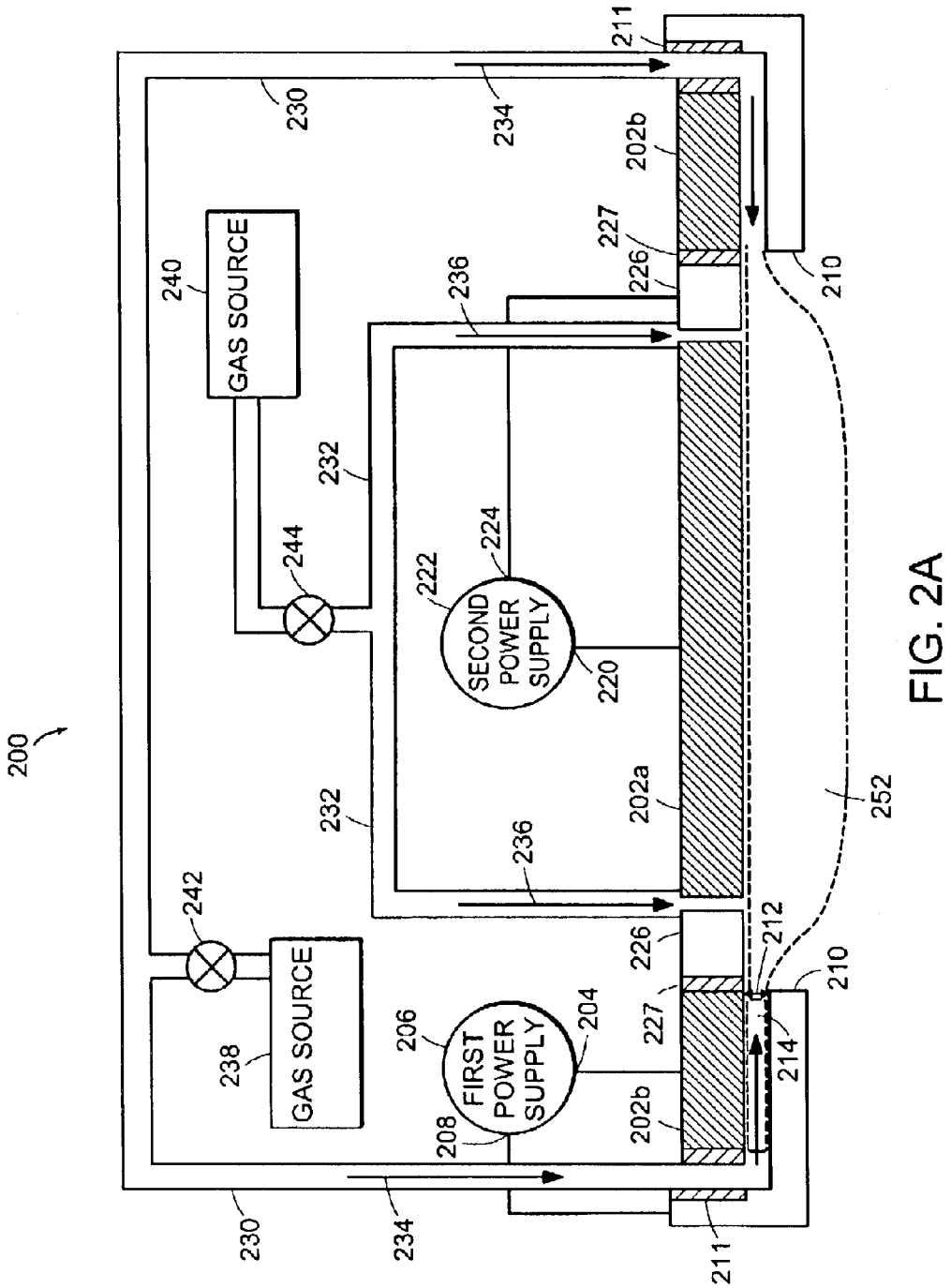


FIG. 2A

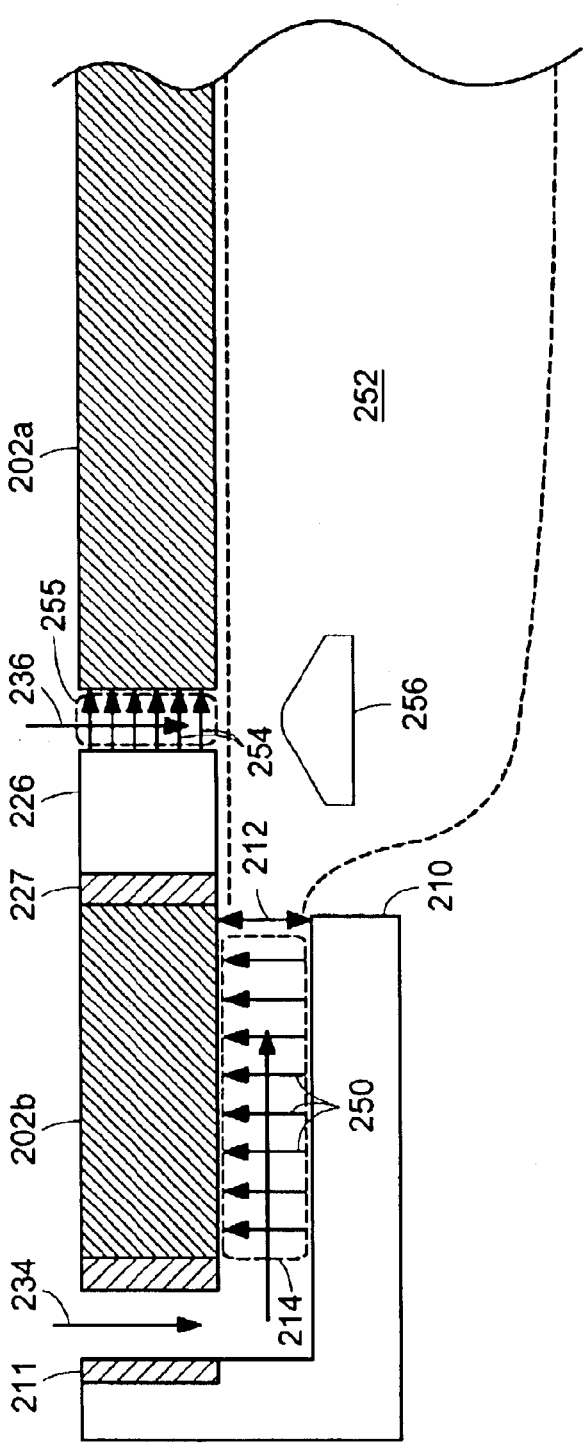


FIG. 2B

DOCKET ALARM

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.