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(54) **HIGH SENSITIVITY ATOMIC
MAGNETOMETER AND METHODS FOR
USING SAME**

6,472,869 B1 10/2002 Upschulte et al.
7,038,450 B1 5/2006 Romalis et al.

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G01V 3/00 (2006.01)
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See application file for complete search history.

(56) **References Cited**
U.S. PATENT DOCUMENTS
4,005,355 A 1/1977 Hopper et al.
4,525,672 A * 6/1985 Lam et al. 324/304
4,617,462 A * 10/1986 Holt 250/251
5,189,368 A * 2/1993 Chase 324/304

OTHER PUBLICATIONS

SQUID Sensors: Fundamentals, Fabrication and Applications, Ed.
Weinstock, H., Kluwer Academic (1996).
Affolderbach, C., et al., An All-Optical, High Sensitivity Magnetic
Gradiometer, Appl. Phys. (2002) B 75:605-612.
Alexandrov, E.B., et al., Double-Resonance Atomic
Magnetometers: from Gas Discharge to Laser Pumping, Laser Phys.
(1996) 6:244-251.
Aleksandrov, E.B., et al., Laser Pumping in the Scheme of an
Mx-Magnetometer, Optics and Spectr. (1995) 78:292-298.

(Continued)

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(57) **ABSTRACT**

The present invention provides a high sensitivity atomic magnetometer and methods of measuring low intensity magnetic fields that relate to the use of an alkali metal vapor and a buffer gas; increasing the magnetic polarization of the alkali metal vapor thereby increasing the sensitivity of the alkali metal vapor to a low intensity magnetic field; probing the magnetic polarization of the alkali metal vapor, the probing means providing an output from the alkali metal vapor, the output including characteristics related to the low intensity magnetic field; and measuring means that receives the output, determines the characteristics of the low intensity magnetic field, and provides a representation of the low intensity magnetic field. In addition, the invention relates to a magnetometer and methods that provide a representation of a first magnetic field originating within a sample volume. The sample volume may be part or all of a subject, such as a human subject. The representation includes a representation of a source of a magnetic field occurring within the sample volume displayed in one, two, or three of three orthogonal Cartesian coordinates, referenced to the sample volume.

73 Claims, 12 Drawing Sheets

