TECHNIQUE FOR OPTICALLY PUMPING ALKALI-METAL ATOMS USING CPT RESONANCES

GOVERNMENT SUPPORT

This invention was made with government support under DARPA contract number N66001-02-C-8019. The government may have certain rights in the invention.

FIELD

The present invention relates generally to the field of atomic frequency standards. More specifically, the present invention pertains to techniques for optically pumping alkali-metal atoms using Coherent Population Trapping (CPT) resonances.

BACKGROUND

Atomic frequency standards are used in a number of applications demanding a high level of accuracy and precision in time keeping. In communications and navigational systems, for example, such atomic frequency standards are often used in atomic clocks as a means to maintain the long-term frequency stability necessary to accurately guide satellites, missiles, aircraft, or other objects through space. In positioning systems such as a Global Positioning System (GPS), such atomic frequency standards are often used in atomic clocks to coordinate the positioning of multiple GPS satellites in orbit. A slight variation in time measured by each GPS satellite can cause significant positioning errors in the guidance system used by many communications and navigational systems, affecting the ability of the system to accurately guide objects through space.

An atomic clock uses the principle of atomic energy transition to output a reference frequency that is relatively insensitive to vibration, shock, or other such noise. In a typical intensity-based atomic frequency standard using an alkali-metal such as cesium 133 or rubidium 85 or 87 as the source of resonance atoms, the energy states of the source atoms are often prepared by optically pumping a resonance cell containing an admixture of the alkali-metal atoms and one or more buffer gases. The intensity of a laser source such as a diode laser is then used to achieve the desired optical pumping.

More recent developments in the art have focused on the use of Coherent Population Trapping (CPT) resonances to prepare the energy states of the alkali-metal atoms. CPT is a nonlinear phenomenon in atoms in which coherences (i.e. electromagnetic multipole moments) between atomic energy levels are excited by pairs of radiation fields. Instead of controlling the intensity of the laser source to achieve the desired optical pumping, CPT systems typically rely on modulated light in order to induce resonances in the alkali-metal atoms, causing coherent optical pumping to occur from two hyperfine ground states to an excited state, commonly referred to as the lambda (Λ)transition. CPT systems thus rely on the coherence property of the laser source, and not its intensity, to accomplish the optical pumping.

For conventional optical pumping techniques using CPT, the radiation fields are usually generated by two lasers phase-locked to each other, or from the sideband of a single laser modulated at a sub-harmonic frequency of the alkali-atom hyperfine frequency. The effect of the laser radiation is to produce a strong coherence in the ground state at the hyperfine frequency, thus inhibiting all transitions to the excited "P" state. At the exact resonance, no transitions take place from the ground state to the excited P state, and no energy is absorbed from the laser radiation by means of transitions.

To increase the signal-to-noise (SNR) ratio of the system, the CPT resonances induced within the resonance cell may be enhanced by directing alternating left and right-handed circularly polarized light (σ^+, σ^-) into the cell. Such "push-pull" optical pumping allows a greater amount of the alkali-metal atoms within the resonance cell to be pumped into the important 0-0 superposition state, thus producing nearly pure, coherent superposition states. This ability to enhance CPT resonances has widespread implications in the performance of atomic clocks, laser systems, maser systems, or other such systems that utilize highly accurate atomic frequency standards to measure time.

While push-pull optical pumping is capable of producing CPT resonances several magnitudes greater than more conventional optical pumping schemes, such technique often requires additional components that are not readily miniaturized for compact systems such as microelectromechanical systems (MEMS). MEMS-based systems are typically created using semiconductor fabrication techniques by etching various components onto the surface of a silicon or glass wafer, forming structures that are often several times smaller than their non-MEMS counterparts. As a result, components such as a Mach-Zehnder intensity modulator and/or an interferometer, which are not readily miniaturized for a given wavelength, are therefore difficult to implement in smaller-scale systems such as MEMS.

SUMMARY

The present invention relates to systems and methods for push-pull optically pumping alkali-metal atoms using Coherent Population Trapping (CPT) resonances. A push-pull optical pumping system in accordance with an illustrative embodiment of the present invention may include a vapor cavity containing a source of alkali-metal atoms and one or more buffer gasses, and a laser assembly including at least two orthogonally polarized laser sources adapted to produce alternating linearly polarized light. A DC current source operatively connected to a servo mechanism can be configured to output a carrier current signal having a substantially constant intensity, inducing laser emission from the laser sources at a wavelength corresponding to the carrier wavelength of the alkali-metal atoms. An RF modulation source adapted to output an RF signal for modulating the carrier current signal can be used to induce sidebands on the carrier current signal separated by the hyperfine transition of the alkali-metal atoms. The RF modulated signal can be split, rectified, and phase-shifted such that the second laser source is modulated 180° out-of-phase with the first laser source, producing alternating pulses of orthogonally polarized light that can be used to optically pump the alkali-metal atoms into a CPT state. A photodetector or other suitable means for sensing the transmission of laser light through the vapor cavity can then be utilized to detect the presence of dark states in the broad absorption resonance.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic view showing a conventional optical pumping system for inducing CPT resonances in alkali-metal atoms using a single laser source;

FIG. **2** is a chart showing the level of radiation transmission vs. frequency for the optical pumping system of FIG. **1**;