DIODE LASERS FOR PRECISION SPECTROSCOPY OF CALCIUM*

Carl S. Weimer, V.L. Velichansky[a], R.W. Fox,
A.S. Zibrov[a] and L. Hollberg
National Institute of Standards and Technology
325 Broadway
Boulder, CO 80303

Abstract

Diode lasers at 657 nm are used with an atomic beam and a high-flux calcium beam-cell to provide narrow saturated-absorption resonances. Stability of $\approx 3\times10^{-14}\tau^{-1/2}$ is projected based on signal-to-noise ratios. Laser cooling will be possible with a frequency doubled diode laser system that produces a usable 35 mW at 423 nm.

The 657 nm line in calcium is an internationally recognized reference wavelength that has demonstrated a very high precision in atomic-beam spectroscopy, and is expected to provide very high accuracy when laser cooling is used.[1-4] Other neutral-atom candidates are promising as shown in recent work on magnesium.[5] One of the attractions of calcium is that the wavelengths of both the reference line and the cooling transition (423 nm) are well-suited to diode laser sources. This gives the potential for simplified lasers, lower power, lower cost, and even portable systems that could be used as transfer standards.

We have been exploring the use of diode lasers with calcium in a variety of different configurations, including: a heat-pipe with buffer gas, a high-flux beam-cell, and a compact traditional atomic beam. Saturation signals were detected in the heat pipe with good signal-to-noise ratio, but the buffer gas used to protect the windows broadened the resonance widths to about 800 kHz. Our best results to date have come from a system based on a high-flux beam-cell that uses an 8 cm long atomic nozzle and provides a 1% saturated absorption signal without a buffer gas.[6] We have observed 65 kHz wide (fwhm) saturation resonances with signal-to-noise ratios of ≈30 in a 40 kHz detection bandwidth. These high signal-to-noise ratios are possible because the detection is done by direct absorption (thus no loss due to the long life and fluorescence solid angle) and because the laser amplitude noise is very small. If limited only by signal-to-noise ratio, this system could provide a stability of $\sigma_y(\tau)\approx 3\times10^{-14}\ \tau^{-1/2}$. Resolution limits are now set by broadening due to transit and wavefront curvature effects. Experiments are now under way to realize the advantages of laser cooling. For this we are using a relatively small (1 m length) ion-pumped atomic beam and fluorescence detection.

For the red (657 nm) transition we are using extended-cavity diode laser systems that have free running, fast-linewidths of about 50 kHz. An electro-optic modulator is used in one of the extended cavity lasers to lock its frequency to a precision reference cavity. When locked, the laser has a fast-linewidth of about 500 Hz with a residual frequency jitter of the reference cavity of about 5 kHz. To provide precise frequency scanning and additional power for the saturated absorption we phase-lock a second laser to the first with a variable frequency offset provided by a synthesizer.[7]

To generate the 423 nm radiation that is required for laser cooling of calcium we are using the system diagrammed in Fig. 1. A grating-tuned, extended-cavity laser that provides a wavelength tunable output of about 20 mW is used to injection lock a 150 mW, single-mode diode laser. Two optical isolators allow injection locking without perturbation of the master laser by the high power slave laser. After mode-shaping and isolation, we have ≈105 mW incident on a ring buildup cavity that contains the temperature-tuned $KNbO_3$ crystal. A build-up of a factor of ≈20 is achieved with no blue output. When phase-matched, second harmonic generation causes a significant conversion of the fundamental power into the blue. Electronic feedback is used to lock the buildup cavity to the laser frequency. This system provides 35 mW of 423 nm light at the output of the ring, which if used efficiently, should be adequate for laser cooling and trapping of calcium.

The actual system one chooses to use will depend on the specific application and the required accuracy and stability. Our present indication is that of these different systems, the beam-cell technology can provide the better short term stability. The highest accuracy however, will require laser cooling which will necessarily mean a smaller number of atoms and hence a low-density beam or cell. In any case, our results indicate that for calcium optical references all of the required laser light can be provided by diode laser sources.

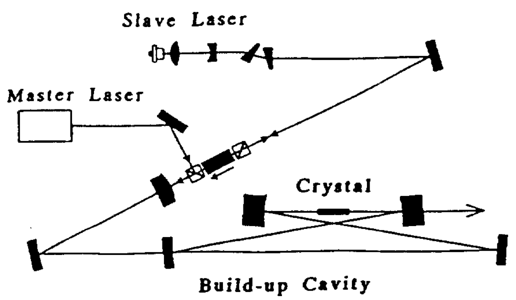

Fig. 1 Diode laser second-harmonic generation of 423 nm light.

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[a] Lebedev Institute of Physics, Moscow

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