was turned off and the trapping beam intensity was reduced (3.6 mW/cm²) to form optical molasses to cool the atoms for 300 µs. This reduced the temperature of the atomic sample to approximately 25 µK, while the sample expanded from 0.8 to 1.2 mm in diameter by the time the molasses beams were turned off. A single-pass weak UV beam (180 µW/cm²) was then turned on for 40 µs to excite the transition, during which data were collected. The trapping beams and the magnetic field were now turned on again to recollect atoms. When the probing window ends, most of the cooled atoms are still in the trapping region, so that a 1.5-ms trapping time is enough to refill the trap for the next measurement cycle.

For comparison, we used both fluorescence photon counting and FM spectroscopy. Fig. 1 shows a typical photon counting data set for the transition $3S^2S_{1/2}$ ($F = 2$) to $5p^2P_{3/2}$. The preliminary results yield smaller uncertainties for the hyperfine constants than have previous measurements.[4,5] Fig. 2 shows the rms velocities versus molasses beam intensity. Updated results will be presented at the conference.

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## QThE6 12:00 m

### High-resolution spectroscopy of laser-cooled rubidium in a vapor-cell trap

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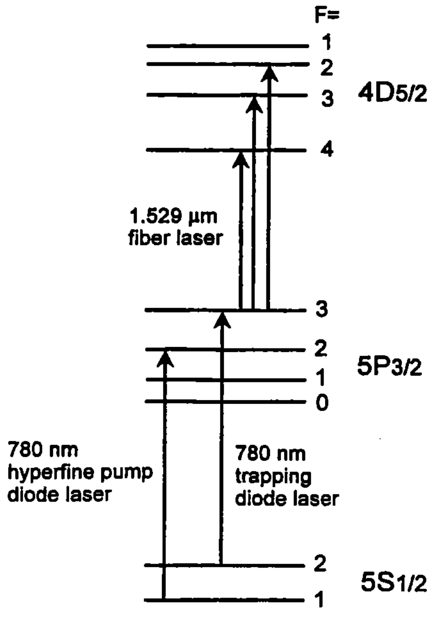
A goal of the wavelength-standard research at NIST is to produce a primary wavelength standard in the 1.5-µm region with a linewidth and reproducibility of better than 1 MHz. Accurate wavelength standards in this region are important for many of the proposed optical-communication schemes involving frequency-division multiplexing and coherent detection.

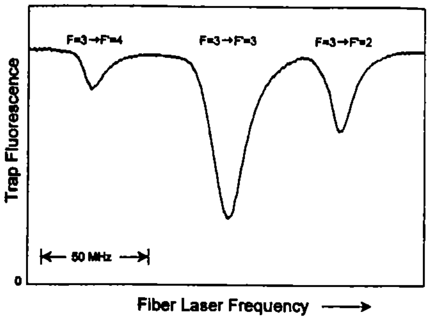


**QThE6 Fig. 1.** Energy-level diagram of ⁸⁷Rb showing the 780-nm trapping and hyperfine pumping diode-laser transitions and the 1.529-µm $5P_{3/2} \rightarrow 4D_{5/2}$ fiber-laser-induced transitions.

Rubidium is a promising narrow-linewidth atomic reference at 1.529 µm. A two-step excitation scheme is required: the $5S_{1/2} \rightarrow 5P_{3/2}$ transition at 780 nm followed by the $5P_{3/2} \rightarrow 4D_{3/2}$ or $5P_{3/2} \rightarrow 4D_{5/2}$ transition at 1.529 µm. Other references can be obtained by frequency doubling 1.56-µm light and probing the 780-nm transition. Rubidium also has a transition at 1.32 µm ($5P_{1/2} \rightarrow 6S_{1/2}$), another optical-communications region.

To produce a highly stable NIST wavelength standard, I have constructed a vapor-cell Zeeman optical trap (ZOT) for neutral rubidium similar to that of Monroe *et al.*[1] The Doppler broadening of optical transitions is negligible in a ZOT trap since the atoms are laser cooled to below 1 mK. Light from two 780-nm diode lasers illuminates Rb atoms in the presence of a small magnetic field gradient. Figure 1 is an energy-level diagram showing the pertinent states of ⁸⁷Rb. The trapping laser is tuned to the low-frequency side of the $5S_{1/2}$, $F = 2 \rightarrow 5P_{3/2}$, $F = 3$ cycling transition, and it cools and traps the atoms. The hyperfine pump laser prevents the atoms from accumulating in the $F = 1$ ground state.

Using a tunable single-longitudinal-mode erbium-doped fiber laser,[2] I have probed the 1.529-µm $5P_{3/2} \rightarrow 4D_{5/2}$ transitions in trapped Rb atoms.[3] The fiber laser has a free-running linewidth of approximately 1 MHz. When the fiber laser is tuned into resonance, it removes population from the $5P_{3/2}$, $F = 3$ level and causes a reduction in the 780-nm fluorescent light emitted by the trapped atoms. The trap fluorescence is a direct monitor of the number of atoms that are excited by the trapping laser. Figure 2 shows the trap fluorescence as the fiber laser is scanned through the $5P_{3/2}$, $F = 3 \rightarrow 4D_{5/2}$, $F = 4$, $F = 3$, and $F = 2$ transitions. The effect of the fiber laser is much larger on the last two transitions since it allows the atoms to leave the $5S_{1/2} \rightarrow 5P_{3/2}$ cycling transition. Similar spectra have been obtained for ⁸⁵Rb atoms confined in this vapor-cell trap.



**QThE6 Fig. 2.** Trap fluorescence (780 nm) as the fiber laser is scanned through the $5P_{3/2}$, $F = 3 \rightarrow 4D_{5/2}$, $F = 4$, $F = 3$, and $F = 2$ transitions of ⁸⁷Rb.

By applying a small modulation on the fiber-laser frequency and using phase-sensitive detection, I obtained the first derivative of Fig. 2. I then used this signal as a sensitive measure of the line shape of the transitions and to actively stabilize the fiber laser to the $5P_{3/2}$, $F = 3 \rightarrow 4D_{5/2}$, $F = 3$ transition. When the fiber laser was stabilized, the fluctuations of the error signal with a 10-ms time constant corresponded to fiber-laser frequency excursions of less than 400 kHz peak to peak.

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