Blue and IR alkali lasers pumped by multiphoton absorption

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Red pumping produces both blue and mid-IR beams without resonator or thermal load, offering enhanced underwater communication and blinding heat-seeking missiles.

A new class of diode-pumped laser based on excitation of the D$_2$ hyperfine-transition line in alkali atoms and subsequent lasing on the D$_1$ line is currently receiving considerable attention.$^1$ Diode-pumped alkali lasers (DPALs) have been demonstrated in rubidium (Rb) and cesium (Cs) at 17 and 48W with 53 and 52% slope efficiency, respectively.$^2, 3$ They require high buffer-gas pressures to match the width of the absorption profile to the laser’s spectral line shape, and a collision partner such as ethane to relax the electron population in the pumped level to the upper laser.

While a few groups have extended and adapted these alkali systems to operate at shorter wavelengths, such schemes require pumping with two distinct light sources. For example, two low-power continuous-wave diode lasers operating at 852 and 917nm yield an ~ 4µW blue beam at 455nm.$^4$ Lasing without inversion has also been demonstrated in Rb based on both V-type and sequential double-resonance processes.$^5–8$ In the latter experiment, two 20mW lasers at 780 and 776nm produce a blue beam with a power of up to 40µW.$^6$ Such sources might find application in laser communications through water. However, the two-wavelength pump requirement adds complexity to the system.

We have produced a blue beam using a single far-red laser tuned to the two-photon absorption excitation of the 2^D$_3/2, 5/2$ and excited 2^S$_{1/2}$ states in Rb and Cs. Lasing is simultaneously achieved at mid-IR and blue wavelengths after excitation in the red through the processes illustrated in Figure 1. The system operates at low pressure without collisional energy transfer, offering minimal heat load, and requires only a single pump source. The conversion efficiency at blue wavelengths is about 0.4%, exceeding that achieved in double-resonance experiments. We also achieved several mid-IR lasing transitions in the 2–5μm atmospheric-transmission window.

![Figure 1. Energy-level diagram and lasing mechanism for rubidium (Rb).](image)

We observed a blue beam, accompanied by a dispersed red pump-laser spot, when tuning a pulsed dye laser through the two-photon absorption wavelengths in both Rb and Cs (see Figure 2). The threshold is modest (~0.3mJ/pulse for Rb). Slope efficiencies increase dramatically with higher alkali concentrations and peak at 0.4%. We achieved almost 10µJ/pulse or 0.1mW average power for the Cs system. The spectral width of the absorption feature is about 25 times smaller than the pump bandwidth, and only a few percent of the incident pump energy is absorbed. The slope efficiency (based on absorbed photons) exceeds 3%.

To confirm that the alkali atoms were pumped by two-photon absorption, we obtained an excitation spectrum based on blue stimulated emission (see Figure 3). The blue spots for Rb occurred at pump wavelengths of 778.1, 778.2, and 760.1nm, corresponding to the 5^2S$_{1/2}$ to 5^2D$_{3/2}, 5^2D_{5/2}$, and 7^2S$_{1/2}$ transitions, respectively. A small leakage of the pump beam through the blue bandpass filter produces the baseline intensity, and increased absorption at the D$_2$ spectral feature is evident.

The intensity of the IR beam increased linearly with pump energy to 100mJ, with a very small threshold. Given the minimal
delay between the pump pulse and the appearance of the blue beam, it appears that stimulated emission on IR transitions is required to complete the three-step cycle. In Cs, the IR transitions range between 1.94 and 2.43 μm and in Rb at 3.85–5.2 μm.

In summary, we have achieved stimulated emission on the blue atomic transitions in Rb and Cs by pumping at a single wavelength. The slope efficiency of 0.4% in Rb is considerably higher than that achieved in sequential double-resonance experiments. Incomplete (10%) absorption of pump photons is an important contributor to the decreased efficiency and might be improved with narrow-band pumping or pressure broadening. Cascade lasing on IR lines followed by blue transitions does not lead to quantum defects, offers the potential for low heat loads, and does not require spin-orbit-coupling gas. The latter has caused soot buildup problems in traditional DPAL cells. It appears that the performance of our new system can be enhanced by scaling to higher alkali concentrations, possibly in a heat-pipe configuration. Threshold pump intensities are high, but we have not assessed the ultimate performance limits of this system. We will next perform a full analysis of the kinetic mechanism to evaluate both the system’s scaling and efficiency.

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