An all-solid-state based laser system for laser cooling of relativistic ion beams*

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In 2004 and 2006 laser cooling experiments of relativistic C^{3+} beams were performed at GSI using frequency doubled Argon-ion lasers [1]. The results of these experiments were promising, but were limited by the large linewidth and the severely limited tunability of the Ar-ion lasers. While Ar-ion lasers are still quite common with applications in areas such as spectroscopy, laser pumping, medical care and even light shows, they have a relatively low efficiency and high maintenance costs [2].

Within this research project, we successfully developed an alternative laser system far superior to the existing Ar-ion laser: it is a rugged, efficient all-solid-state based system with output wavelengths of $1028\ \mathrm{nm}$, $514\ \mathrm{nm}$ and $257\ \mathrm{nm}$. It provides high output power, narrow linewidth, wide and fast tunability and a near perfect Gaussian beam profile.

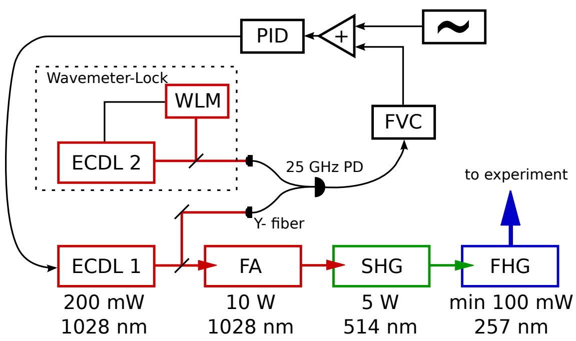

Figure 1: Schematic diagram of the system. ECDL: external cavity diode laser, FA: fiber amplifier, SHG: second harmonic generation, FHG: fourth harmonic generation, WLM: wavelength meter, FVC: frequency to voltage converter, PD: photo detector, PID: proportional-integral-derivative controller, +: signal adder, $\sim$: function generator

A schematic overview of our system is shown in Fig. 1. It mainly consists of a fiber amplifier seeded by an external cavity diode laser (ECDL). The output of this amplifier is frequency doubled and quadrupled in bow-tie built-up cavities using LBO and BBO crystals, respectively. The fiber amplifier delivers up to $15.3\ \mathrm{W}$ of optical power at 1028 nm. In Fig. 2 the output of the first cavity is plotted over the input power. We achieved nearly $5\ \mathrm{W}$ with a conversion efficiency of $57\ \%$ at 514 nm. The second cavity delivered up to $180\ \mathrm{mW}$ of UV light with a conversion efficiency of $12\ \%$.

The system is stabilized to an absolute frequency using an offset lock on another identical ECDL (master), which

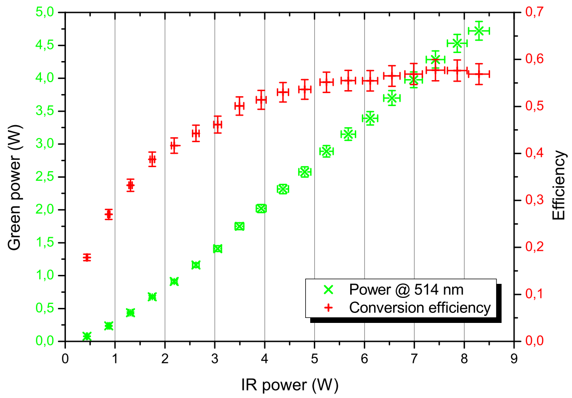

Figure 2: Optical power at $514\ \mathrm{nm}$ and conversion efficiency over infrared power in the first build-up cavity. The error bars result from the uncertainties of the detectors.

itself is locked to a high-precision wavelength meter. By adding an arbitrary ramp from the function generator to the error signal of the offset lock, the seed ECDL of the fiber amplifier can be scanned with respect to the master ECDL. In the UV it was possible to scan $12\ \mathrm{GHz}$ in $10\ \mathrm{ms}$. Mode hops were suppressed by a novel locking scheme developed in our group [3]. The offset lock is achieved by mixing small amounts of light of both ECDLs in a Y-fiber and observing the resulting beat signal with a fast photo detector. The beat frequency is divided by a factor of 1000 and fed into a frequency to voltage converter whose output serves as the error signal. By observing the beat signal of the two identical ECDLs, their linewidth was determined to $890\ \mathrm{kHz}$ in a $60\ \mathrm{s}$ time interval. This corresponds to $\frac{\Delta f}{f} \approx 3 * 10^{-06}$.

In conclusion, we were able to replace the Argon-ion laser with a more versatile light source. During a beam time in August 2012 stable long term operation was successfully demonstrated. Another beam time in Lanzhou (China) is planned in 2013 and further experiments at FAIR are possible.

References

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