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# Spectral Structures of 230 GHz-bandwidth 821 nm Seeder by a Broad-area LD for Muonium Lyman-alpha Generation

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## 1. Introduction

Novel ultraslow muon microscope is under construction at J-PARC MLF. Muon generation scheme being used is the combination of thermalization in a solid target plus two-step laser ionization (excite 2S ground state muonium to 2P state with Lyman-alpha (Ly-α, 122.09 nm) pulse, then ionize with 355 nm pulse irradiated simultaneously).

Although the scheme is already in operation at ISIS RIKEN-RAL [1], to realize useful microscope, many improvements are required for Ly-α and several novel techniques are utilized. We utilized all-solid-state laser configuration and master oscillator - power amplifier (MOPA) configuration for the realization of both two orders of magnitude energy increase and vast system stability improvement, including timing jitter reduction. We changed frequency conversion scheme and fundamental laser wavelength for system size reduction by the factor of three.

In MOPA system, the oscillators or the seeders determine the spectral and in some cases, spatial properties of outputs. Thus, especially here-described 820.65 nm (O2) seeder demanded a novel configuration.

## 2. Spectral requirements for the Lyman-alpha and 820.65 nm seeder

The requirements for Ly-α pulses are as follows. The first is the tunability and bandwidth-match with the Doppler-broadened (210 GHz FWHM for 2100 K thermalization target) muonium resonance. The second is dense spectral structure for the uniform excitation in muonium velocity-space, else the concentration of excitation energy to particular frequency leads to saturation of muonium and reduction of total excitation efficiency.

We use two-photon resonant sum-difference frequency mixing (TPR-SDFM) in gaseous Kr-Ar mixture for Ly-α generation. For TPR, we need narrow-bandwidth 212.55 nm nanosecond pulses. The detail of its generation will be described elsewhere [2]. For SDFM, we need O2 pulses and we selected seeded OPO scheme to fulfill system requirements. Because the spectral properties of Ly-α pulses are determined by those of O2 pulse, which in turn determined by the seeder, rather uncommon more than 200 GHz bandwidth requirement was placed upon O2 seeder.

## 3. Configuration of 820.65 nm seeder

To meet the spectral requirements, we selected a broad-area laser diode (BALD) of 830 nm as the starting point of O2 seeder. Firstly, we successfully obtained longitudinally and spatially multimode output with the wavelength of O2 by cooling BALD down to -6 degree Celsius and pulsed (QCW) driving (15 μs / 250 Hz). Then, because BALD output bandwidth was typically 2-1 nm (FWHM) or 900-450 GHz, we narrowed it down with a thin (50 μm) solid etalon. The etalon was rotated for desirable bandwidth. Finally, the beam was coupled to a single-mode (SM) fiber via mode-match optics for spatial mode-cleaning. Final SM fiber-coupled peak output power was around 10 mW.

## 4. Observed 820.65 nm seeder spectrum

Time-resolved spectrum taken using a tunable high-finesse Fabry-Perot etalon has shown the bandwidth to be 235 GHz. Longitudinal mode-spacing was 24.5 GHz. Low (< 6) transverse mode structure calculated from observed longitudinal mode-spacing and cavity width specified on the datasheet reproduced observed repetitive triplet-peak spectrum structure.

For the spectral density, current seeder has around-8 GHz mode-spacing. Although later OPO stage pumped with nanosecond pulses will broaden the spectrum, such large mode-spacing can be problematic. We are currently investigating the expected muonium excitation efficiency and considering the introduction of frequency spreading by phase modulation with a dual radio-frequency (a few GHz and a few 100 MHz) using an EOM.

## 5. Conclusions

We obtained wavelength- and bandwidth- tunable QCW output around 820 nm from a SM fiber by a laser diode setup. Time-resolved spectrum observation revealed the need of further optimization by frequency spreading. Theoretical calculation of muon production efficiency needed for the optimization is underway.

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**References**

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