Laser Aging Studies for Rubidium Atomic Clocks

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***Abstract*—We report on the development of a long-term laser diode aging test bench that measures the spectral behavior of laser diodes over several years, in view of their applications in space Rb atomic clocks. First aging data on the current on resonance and threshold current is reported for three laser diodes, for a duration of more than 900 day - almost three years.**

Keywords—DFB laser, aging, rubidium atomic clock

I. Introduction

Rubidium (Rb) atomic clocks for space applications usually need to have a lifetime of up to 20 years and their components need de facto to fulfill their purpose during this time period. Laser diodes are one of the key components for such atomic clocks and their spectral properties play an important role in the overall clock frequency instability budget [1]. Here we report on the development of an automated laser aging test bench as well as on the measurement of the spectral behavior of laser diodes over several years, notably their operation at the precise Rb atomic transition.

II. Setup Description

In order to study the evolution of the laser's spectral properties on long-term timescales, we developed a long-term laser diode aging test bench that measures the spectral behavior of laser diodes over several years. The setup scheme is shown in Fig. 1. Three laser diodes are currently under test, two 780 nm Distributed Feedback (DFB) lasers from Eagleyard Photonics and one frequency-doubled 1560 nm DFB laser from Alcatel. We measure the "current at resonance", i.e. the laser drive current needed to keep the lasers' emission frequency at the precise resonance of the ^{87}Rb D2 transition (at fixed laser temperature), as well as their threshold currents. The lasers' temperatures are fixed close to room temperature meaning that this aging does not consist in high temperature accelerated aging. Measurement of frequency noise and relative intensity noise can also be performed.

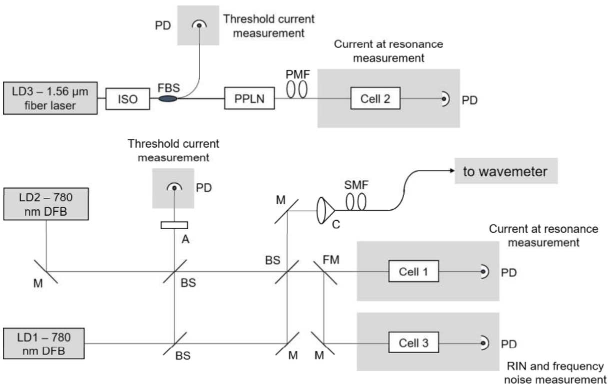

Fig. 1. Scheme of the laser aging optical setup. A: attenuator, BS: beamsplitter, C: fiber collimator, FBS: fibered beamsplitter, FM: flip mirror, ISO: optical isolator, M: mirror, PD: photodiode, PMF: polarization maintaining fiber, SMF: single-mode fiber.

A. Optical setup and components

Two types of laser systems have been selected for these aging studies.

The first type consists in two nominally identical 780 nm DFB lasers mounted in TO-3 can with integrated Thermoelectric Cooler (TEC). Two signals are monitored over time, a Rb absorption signal obtained using a homemade evacuated Rb cell to measure the lasers' frequency and a DC signal to determine their threshold current. Relative intensity noise (RIN) and frequency noise can also be punctually measured on 780 nm DFB lasers.

The second type is also a DFB laser but emitting at 1560 nm and mounted in a fiber-pigtailed butterfly package. This system is all-fiber-coupled and the laser output is frequency doubled to the 780 nm Rb wavelength using a periodically poled lithium niobate second-harmonic generation crystal (PPLN SHG). The laser's frequency is also measured using Rb spectral absorption through a frequency reference unit (FRU) with similar features as previously reported in [2] and a dedicated fibered InGaAs photodiode is used for the threshold measurement à 1560 nm. All components can be seen on Fig. 2.

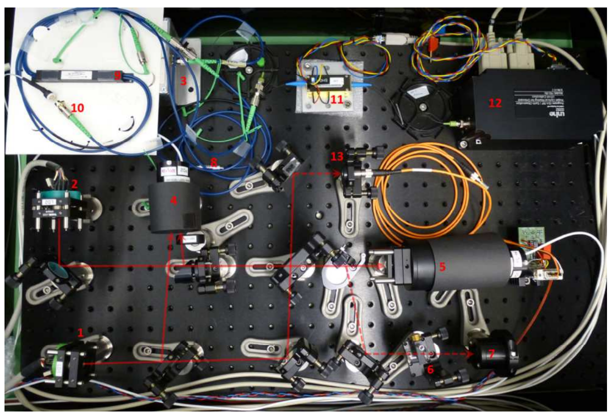

Fig. 2. Photo of the laser aging optical setup. 1. LD1 780 nm DFB, 2. LD2 780 nm DFB, 3. LD3 1560 nm DFB, 4. PD threshold 780 nm, 5. Rb cell 780 nm, 6. Rb cell for noise measurement, 7. photodetector for noise measurement, 8. fibered optical isolator, 9. PMF, 10. PD threshold 1560 nm, 11. PPLN SHG, 12. FRU, 13. fiber coupler.

This separated optical paths for the 780 nm and 1560 nm lasers is due to the lower optical power available after the frequency doubling of the 1560 nm laser resulting in a too big power difference compared to the 780 nm lasers. Three lasers are currently aging but the setup is designed to accommodate up to six lasers in total, four at 780 nm and two at 1560 nm.

B. Electronics and data acquisition

The drive electronics consist in a commercial chassis for laser diode current and temperature control PRO8000 from Thorlabs containing 8 card slots for either laser control or photocurrent measurement. Three laser current and temperature control cards and two photocurrent measurement cards are presently used, leaving three extra slots allowing the addition of three potential new lasers.

The measurement procedure is automated using a custom-made software realized in LabWindows. Measurements of the laser drive current at resonance as well as the threshold current for the three lasers are repeated every three hours. Each measurement consists in a sequence that generates a Rb absorption and threshold current spectra (see Fig. 3) for each laser. The precise value of the current at resonance and threshold current is then extracted for these spectra. Between two such consecutive measurements, all lasers are kept emitting at their nominal drive current. Such sequence is shown in Fig. 4.

III. Measurement Results

The measurement has been running for almost three years now and current results are reported hereunder, covering data from June 2021 to April 2024. Data is reported for the two 780 nm DFB lasers LD1 and LD2, as well as for the fiber-based frequency-doubled 1560 nm laser LD3.

Some correlation of the current on resonance with the laboratory temperature is detectable for the two DFB lasers LD1 and LD2 (packaged in TO-3 can, see e.g. Fig. 5 top) but are not visible for the frequency-doubled 1560 nm laser LD3 (butterfly package mounted in an aluminum box). Correction of the temperature effects on LD1 and LD2 might be performed in the future to obtain more precise results.

The upper graph of Fig. 4 shows the evolution over time of the current at resonance (I_{res}), i.e. of the laser drive current needed to keep the DFB laser LD2 at the precise resonance frequency of the ^{87}Rb D2 line (red curve) as well as the evolution over time of the ambient temperature (grey curve). The sensitivity to temperature is perceptible, especially when the air conditioning of the lab was turned off, leading to heat

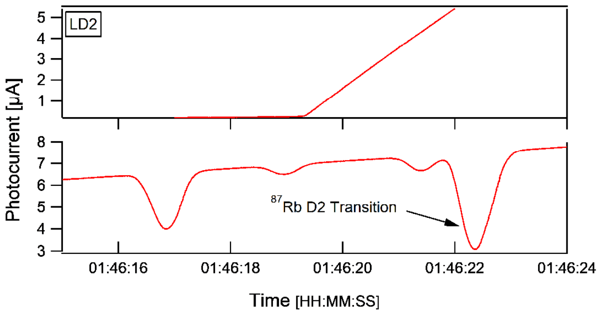

Fig. 3. Typical spectra obtained from the data acquisition. Up: threshold current. Down: current at resonance

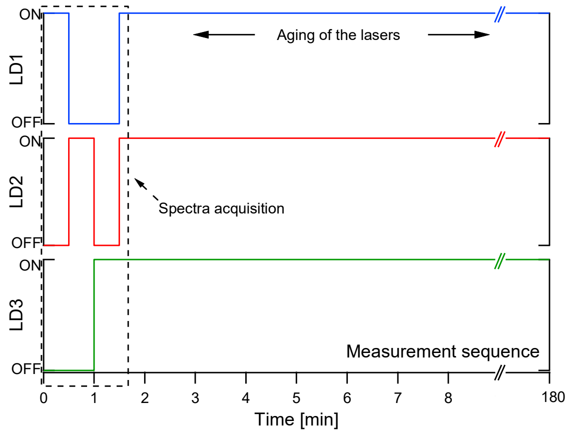

Fig. 4. Laser aging measurement sequence.

peaks of 3 to 4 K in the lab. The aging rate of LD2 shown here, represented by the linear fit of the current at resonance (blue line), is measured at -6.7 µA/month during this measurement period.

The lower graph of Fig. 5 represents the evolution over time of the threshold current of the frequency-doubled DFB laser LD3 (red curve). No effect of external temperature fluctuations is observed here and the aging rate of the threshold current, represented by the linear fit (blue line) is measured at +16.4 µA/month.

Table 1 compares the aging rates of the three tested laser diodes, for both the current at resonance and the threshold current. The aging rate of the lasers in this study is lower by a factor of 2 to 30 compared to our previous laser aging study based on 780 nm DFB lasers [3]. A surprising observation is the positive value of the aging rate of the current at resonance of LD1 that seems counter-intuitive.

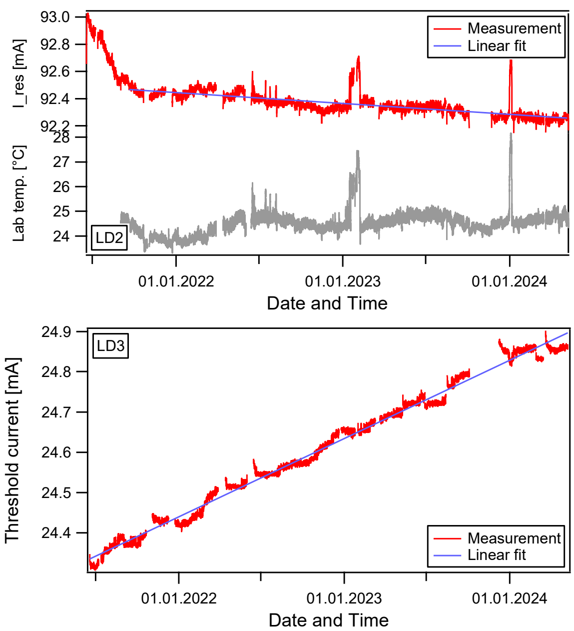

Fig. 5. Up: evolution over time of the drive current needed to keep the 780 nm laser diode LD2 at Rb D2 resonance (red) and lab temperature (grey). Down: evolution over time of the threshold current of the 1560 nm DFB LD3

TABLE 1. SUMMARY OF AGING RATES AND COMPARISON TO PREVIOUS DATA

	Current at resonance (µA/month)	**Threshold current (µA/month)**
LD1	+ 18.6	+ 2.4
LD2	- 6.7	+ 2.1
LD3	- 2.1 *	+ 16.4
Data of previous study [3]		
L#1 (TO-3)	- 45	No data
L#2 (TO-9) #	≈ - 60	No data
L#3 (TO-9, vac) #	- 48	No data

* Aging rate at the end of the current data set.

L#2 and l#3 had no NTC within the TO-9 housing, thus suffering from thermal instabilities, while L#3 was operated in vacuum.

IV. CONCLUSION

We have presented the development of an automated test bench for aging studies on the spectral properties of diode lasers emitting at the 780 nm wavelength of the Rb D2 transition, of relevance for applications in Rb atomic clocks. The bench is currently running with three lasers under study, but can easily be extended to six lasers. The three lasers have now been running for over 900 days and measurements are continuing. With an improvement by a factor of 2 to 30 of the aging rate compared to our previous study, this might hint to an improvement of the aging behavior of these laser diodes produced during these last ten years and tends to confirm their compatibility for implementation in advanced atomic clocks with at least 20 years lifetime.

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