

Multiwavelength interferometer-based HSRL

Ilya Serikov^(a), Björn Brüggmann^(a), Livio Belegante^(b), Anca Nemuc^(b),
Doina Nicolae^(b), Iwona S. Stachlewska^(c), Vassilis Amiridis^(d)

^(a) Max Planck Institute for Meteorology
Bundesstraße 53, 20146 Hamburg, Germany

^(b) National Institute of Research and Development for Optoelectronics INOE 2000
Atomistilor Street 409, RO077125 Magurele, Romania

^(c) University of Warsaw, Faculty of Physics
L.Pasteura 5, 02-093 Warsaw, Poland

^(d) National Observatory of Athens
I. Metaxa & Vas. Pavlou St., Penteli, GR-15236, Greece
ilya.serikov@mpimet.mpg.de

Abstract: We present a lab prototype of a high spectral resolution UV lidar channel dedicated to calibrate and validate EarthCare lidar. A solution with two Fabry-Pérot etalons combined in line is proposed to achieve high spectral purity in splitting aerosol and molecular backscatter returns. Targeted spectral purity predicted in a model for molecular signal has been achieved with the prototype version. Decoupling etalons by turning wave polarization confirmed to be successful. Compact design implementing pressure tuning solution to adjust etalon effective mirror spacing proved to be efficient. Illuminating etalon from “the back” with He:Ne laser light and monitoring interference fringe diameter demonstrated to be a feasible technique to control etalon alignment.

1. Introduction

With a primary target to design an airborne-based reference system to calibrate and validate high spectral resolution lidar deployed on-board of EarthCare satellite we have developed a multiwavelength HSRL system to be capable of measuring particle backscatter, extinction and depolarization ratio at 355, 532, and 1064 nm [1]. While 532-nm-channel design follows a well-developed solution with iodine filtering technique [2], the interferometer-based HSRL filtering at 355 and 1064 nm was the major focus of our research.

Modeling the performance of Fabry-Pérot interferometer (FPI) we came to a conclusion that in order to achieve a reasonable spectral purity of molecular return detected in presence of clouds it would be sufficient to filter the spectra sequentially with two interferometers in line. Details of this analysis as well as the specifications for the optimum configuration could be found in [1].

Principle optical layout of HSRL spectrometer is shown in Figure 1. Unpolarized input light delivered to the spectrometer from receiving telescope with multimode optical fiber is split in two parts with polarizing beam splitting cube.

The reflected beam representing the natural mixture of aerosol and molecular returns is

detected directly. Transmitted beam being linearly polarized when exiting the cube gets circular polarization behind the quarter wave plate and enters the vacuum chamber with the first etalon.

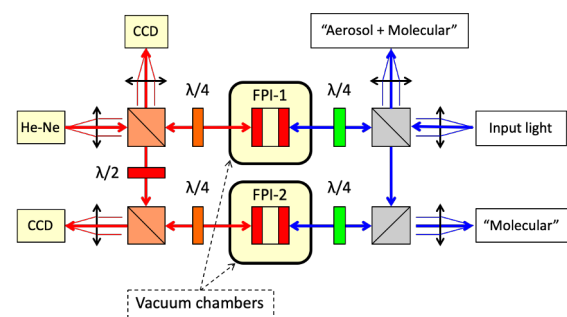


Figure 1 Spectrometer optical layout.

With appropriate optical thickness of etalon mirror spacing the spectrally narrow aerosol scattering is transmitted by etalon almost completely, while the much wider line of molecular return is rejected in wings, Fig. 2.

The rejected light passing the quarter wave plate for the second time turns into linearly polarized one with orthogonal polarization and therefore is reflected by the beam splitting cube.

Reflected sequentially in another cube the beam enters the second etalon filtering line that is absolutely identical to the first one. The light rejected by second interferometer is matched in

polarization with the wave plate to pass the cube coming to the detector for molecular channel.

Decoupling two filtering stages with high-quality polarizing beam splitting cubes (cross-talk suppression >1000, wave front error below $\lambda/4$ over 50x50 mm aperture, manufactured by Laseroptik GmbH), allows the interference happening in both etalons independently, which is a key requirement in achieving high transmission efficiency for “aerosol” light, i.e. high spectral purity of “molecular” signal.

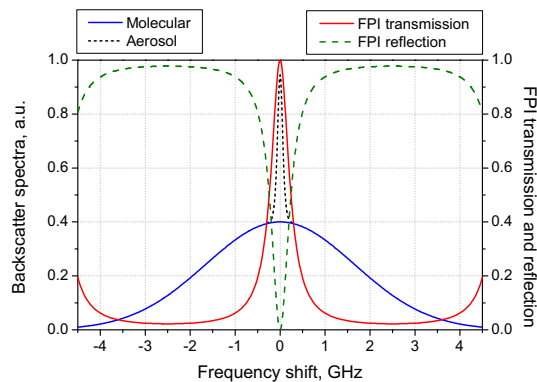


Figure 2 FPI transmission and reflection for aerosol and molecular spectra at 355 nm.

Implementing the concept into running prototype has been accomplished to test the feasibility of interferometric filtering for 1064 and 355 nm channels. Here we present the results achieved for UV prototype.

2. Single-etalon test

Following the simulation [1], we have defined the etalon requirements, Table 1.

Table 1. Etalon specs, HSRL@355 nm

Parameter	Value
Air gap thickness, mm	30
Clear aperture, mm	45
Air gap uniformity (rms), nm	< 3
Air gap wedge, arc seconds	< 0.04
Mirror reflectivity @355 nm	0.35
Mirror reflectivity @633 nm	>0.5
Substrate AR coating @355 nm	<0.0025
Substrate AR coating @633 nm	<0.005

Etalons matching the specs and even going for some parameters beyond the requirements have been manufactured by LightMachinery Inc.

The first feasibility tests performed in a “breadboard” setup with one etalon in line (Fig. 3) proved the feasibility of achieving the required blocking level for laser light in reflected beam.

Interferometer placed in evacuated chamber filled with dry nitrogen has been pressure-tuned to allow either maximum or minimum amount of laser light present in the reflected beam. Maximum reflection (corrected for etalon transmission at maximum reflection) has been used to estimate the total intensity of light entering interferometer.

The light intensity measured at minimum reflection normalized to the total intensity gave a suppression level of 39, which is slightly better than the expected suppression targeted at 34.

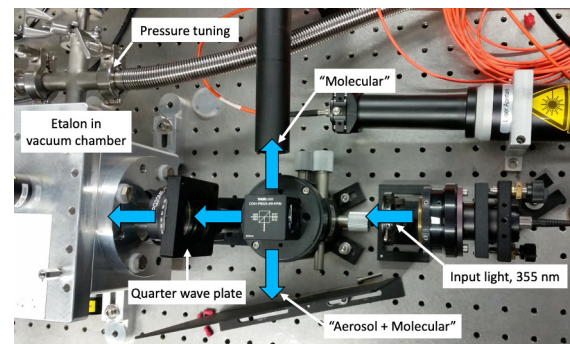


Figure 3 Breadboard test, single etalon setup.

If to project the suppression achieved with one etalon for two etalons in line, i.e. taking a square of the number and multiplying it by 0.3, being the theoretical transmission in double-etalon setup for molecular line (reflection happens in line wings only), we get to slightly above 450, which is again better than the targeted level of 350 [1].

3. Double-etalon prototype

To test a double-etalon setup we have designed a compact unit incorporating two separate vacuum chambers with coupling optics for HSRL channel and for the He-Ne light used for alignment control.

In Fig. 4 presenting the CAD model of double-etalon setup, the housing of unit is omitted to bring in better focus the layout of elements as those are arranged in the assembly shown in Fig. 5.

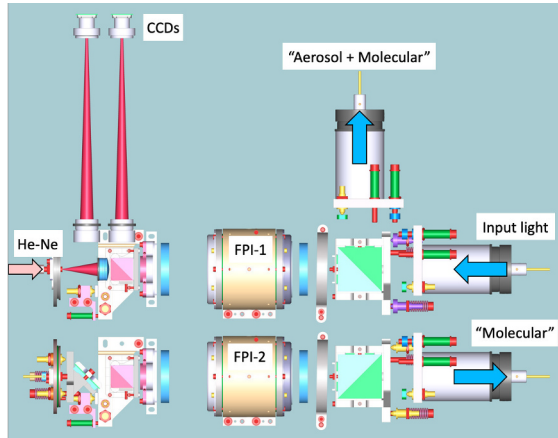


Figure 4 Double-etalon CAD model.

Separately for each vacuum chamber, we evacuate and flash the chamber with dry nitrogen to get rid of residual contamination (water vapor, for instance). Then we fill it with dry nitrogen to about 50-100 mbar to approach roughly to the maximum of etalon transmission for 355 nm.

Fine tuning is achieved with an actuator stretching or shrinking a bellow integrated into the chamber. By modifying the chamber volume, and, therefore, the gas pressure inside, we adjust effective optical path of etalon “air” gap.

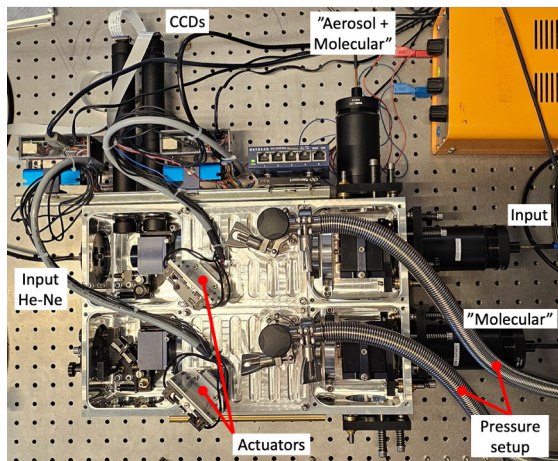


Figure 5 Double-etalon in lab test.

To control the interferometer alignment, we “compare” the mirror spacing with the wavelength of frequency-stabilized He-Ne laser emission. Illuminating etalon from the “back” (Fig. 1) with divergent He-Ne light we observe in reflection an interference pattern with a black fringe, corresponding to positive interference for the He-Ne light (therefore transmitted by etalon and missing in reflection), Fig. 6.

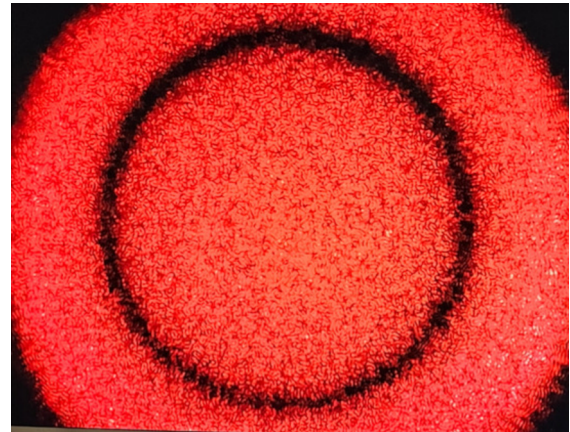


Figure 6 He-Ne light reflected from etalon.

The fringe diameter characterizes the etalon mirror spacing, and could be used to monitor the alignment. To be able to implement this technique, the etalon mirror spacer should be manufactured specifically, it should be polished precisely to the length that would allow simultaneously (a) achieving maximum transmission in HSRL channel and (b) to have He-Ne fringe size highly sensitive to tiny pressure modulation to be applied to tune and keep at maximum the HSRL filtering efficiency. Modeling etalon behavior we found that in our configuration the optimum He-Ne fringe diameter should be within 1.6-4.4 mrad.

A snapshot with screens of two Raspberry PI computers (one per etalon) used to control the etalon alignment is shown in Fig. 7. Video stream capturing the fringe-centered frame of interference pattern is visualized in the bottom of the screens. Intensity distribution along horizontal slices of the frame characterizes the etalon alignment, it is the width of the gap between two peaks in the intensity distribution we are looking for.

Inverted intensity distribution is shown in the upper plot of user interface window of either screens in Fig. 7. Height of the frame is chosen to accept the fringe elements that are “almost vertical”. Integrating along the height we improve the fringe width detection accuracy without seriously smearing the distribution. Identifying the fringe width that matches the maximum etalon transmission for HSRL channel, we form a feedback signal for the bellow actuator to keep the fringe width at the target.

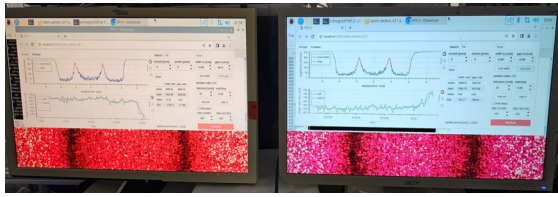


Figure 7 Etalon alignment monitors.

To monitor the alignment, it is sufficient to use only a portion of etalon clear aperture, equal to 45 mm in our case. Taking one-inch optics for monitoring channel, we match it with another one-inch-aperture channel to capture “aerosol-only” signal behind the etalon. This is for the calibration purpose that could be built on the assumption that the weighted sum of “molecular” and “aerosol-only” signals should be equal to the signal in “aerosol + molecular” channel.

To characterize the efficiency of HSRL filtering we started first with power measurements implementing the same technique we used for the single-etalon setup. The successful measurement would require simultaneous and accurate detection of “aerosol + molecular” and “molecular” signals that differ from each other by more than three orders of magnitude.

Usually with power measurement this is hard to achieve, especially if wishing to avoid exposing optics with too strong UV light. Therefore, keeping low UV light intensity we switched to photon counting detection. The “aerosol + molecular” and “molecular” outputs of HSRL unit (Fig. 5) were fiber coupled to photo-multiplier tubes (PMT) with neutral density filters in front of the detectors to allow (a) operating detectors in linear mode and (b) keeping the two signals equal in strength when both etalons were tuned for maximum transmission at the laser line of 355 nm.

Swapping the two fibers at the PMTs resulted the accumulated signal ratio changing from 1 to above 1600. While swapping the fibers the signal count rate was proved to be within the linear detection range on both detectors.

4. Conclusion

Implementing Fabry-Pérot interferometers for HSRL filtering in UV and IR spectral range has been tested. The results (presented here for UV prototype) confirm the feasibility of achieving sufficient spectral purity for molecular signals as it would be required for atmospheric measurements.

Independent filtering functionality of etalons when decoupled by means of switching wave polarization has been proved. Dense opto-mechanics packing with pressure tuning assembly integrated directly into vacuum chamber allowed for extremely compact design. Monitoring etalon tuning with He-Ne light has been demonstrated to allow stable and reliable alignment control.

The project initiated and funded by European Space Agency has got successful also thanks to a strong administrative and financial support from every institute involved.

5. References

- [1] I. Serikov, H. Linné, B. Brüggemann, L. Worbes, D. Nicolae, L. Belegante, V. Amiridis, “ESA Airborne 3+2+2 HSRL for Aladin/Atlid CAL/VAL”, presented at International Geoscience and Remote Sensing Symposium (IGARSS) Valencia, Spain, July 2018, pp. 1869-1872.
- [2] I. Razenkov, E. Eloranta, “High spectral resolution lidar at the university of Wisconsin-Madison”, presented at 28th International Laser Radar Conference (ILRC), Bucharest, Romania, June 2017