An Interferometric Instrument for the Determination of Spectral and Angular Dependence of Back-reflected Light from Smooth Optical Surfaces

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Abstract

Here we present the experimental results obtained for backscattered and retro-reflected light from optical components, including uncoated and anti-reflective coated windows and mirrors, using the BARRITON (**BA**ck-scattering and **R**etro-**R**eflection by **I**nterferome**T**ry with l**O**w cohere**N**ce) instrument. BARRITON is an interferometric set-up based on the Fourier transform spectrometry technique, where the use of balanced optical detection suppresses the relative intensity noise of the input light source, thus improving the signal-to-noise ratio and allowing the measurement of the angular dependence of the back reflection on the order of 10^{-10} (10^{-4} sr^{-1} in terms of ARS measurement). In addition, the low coherence nature of the broadband light source allows accurate identification of the different optical interfaces and their respective back reflection and back scattering contributions. Finally, we demonstrate the recording of the spectral dependence of the reflection coefficient of anti-reflective coated windows with tunable spectral resolution from 0.2 nm to a few nanometers, with the lowest recorded value for an AR-coated interface between 80 ppb and 1.6 ppm. This work is performed in the context of the Stray Light Working Group of the LISA Consortium.

Optical Layout

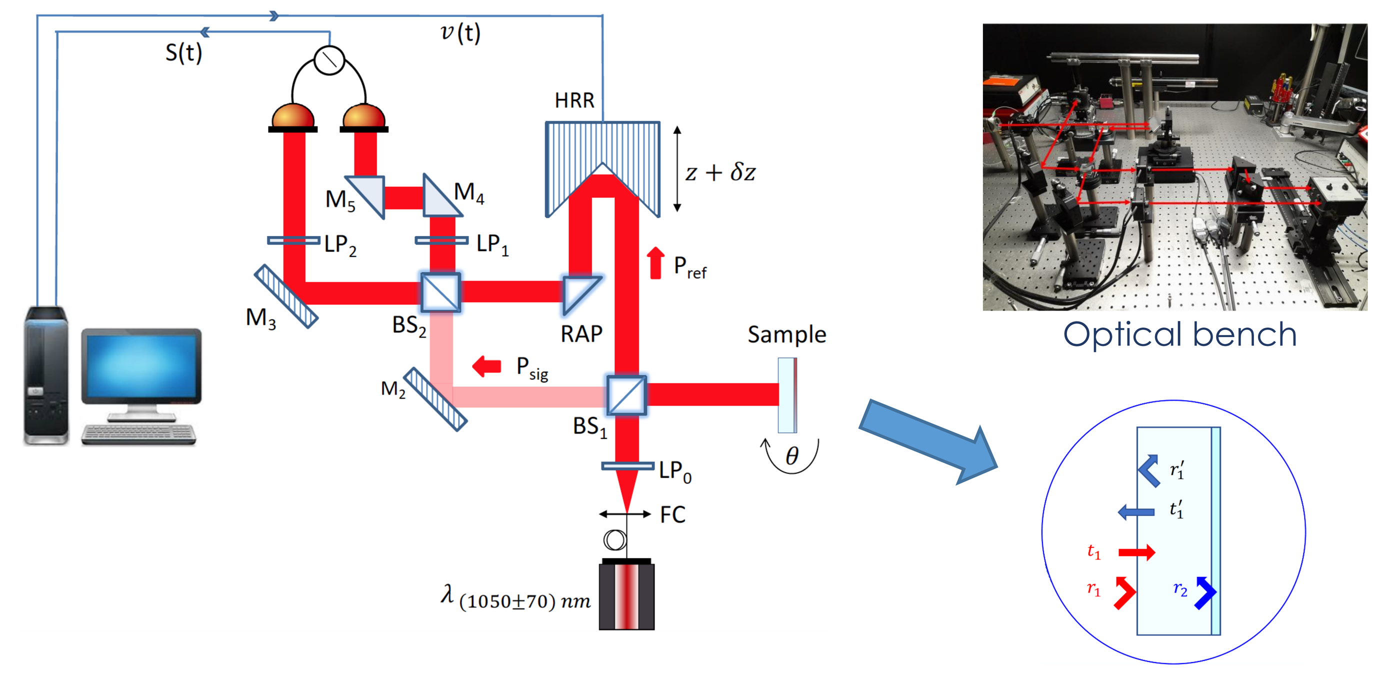

Fig. 1. Schematic of the experiment and the implemented bench.

We use balanced optical detection scheme to improve the signal to noise ratio as such the differential output of the balanced receiver as voltage signal is given by

$$V = G(I_2 - \alpha I_1) \quad \text{with} \quad I_{dc,2} = \alpha I_{dc,1} \qquad V = G\mathcal{T}\,\Re\left\{\int_0^\infty S(f)\mathcal{P}(f)r(f)\,e^{-ik_a\Delta L}\,df\right\}$$

We take the numerical Fourier transform of this time series signal using the equation

$$\tilde{S}_m(F) = \int_{-\infty}^{+\infty} V_m(t)\,e^{-2i\pi F t}\,dt \qquad m = 1,2,3,\ldots$$

The ratio of the power spectral densities of the Fourier transforms of the first two echoes allows us to determine the spectral dependence of the reflection coefficient of the coated side of the sample

$$\frac{|S_2(F_l)|^2}{|S_1(F_l)|^2} = \frac{|\rho_2(f_l)|^2}{|\rho_1(f_l)|^2} = \frac{|t_1(f_l)t_1'(f_l)r_2(f_l)|^2}{|r_1(f_l)|^2} = \frac{T_1^2(f_l)R_2(f_l)}{R_1(f_l)}$$

Depending on the orientation of the sample relative to the incidence beam, spectral dependence of the reflectance can be written as

$$R_{coat}(f_l) = \frac{R_s(f_l)}{[1-R_s(f_l)]^2}\frac{|S_2(F_l)|^2}{|S_1(F_l)|^2} \qquad \frac{R_{coat}(f_l)}{[1-R_{coat}(f_l)]^2} = R_s(f_l)\frac{|S_1(F_l)|^2}{|S_2(F_l)|^2}$$

Measurement Results: Back-reflected light

Back-reflected light from uncoated optical windows

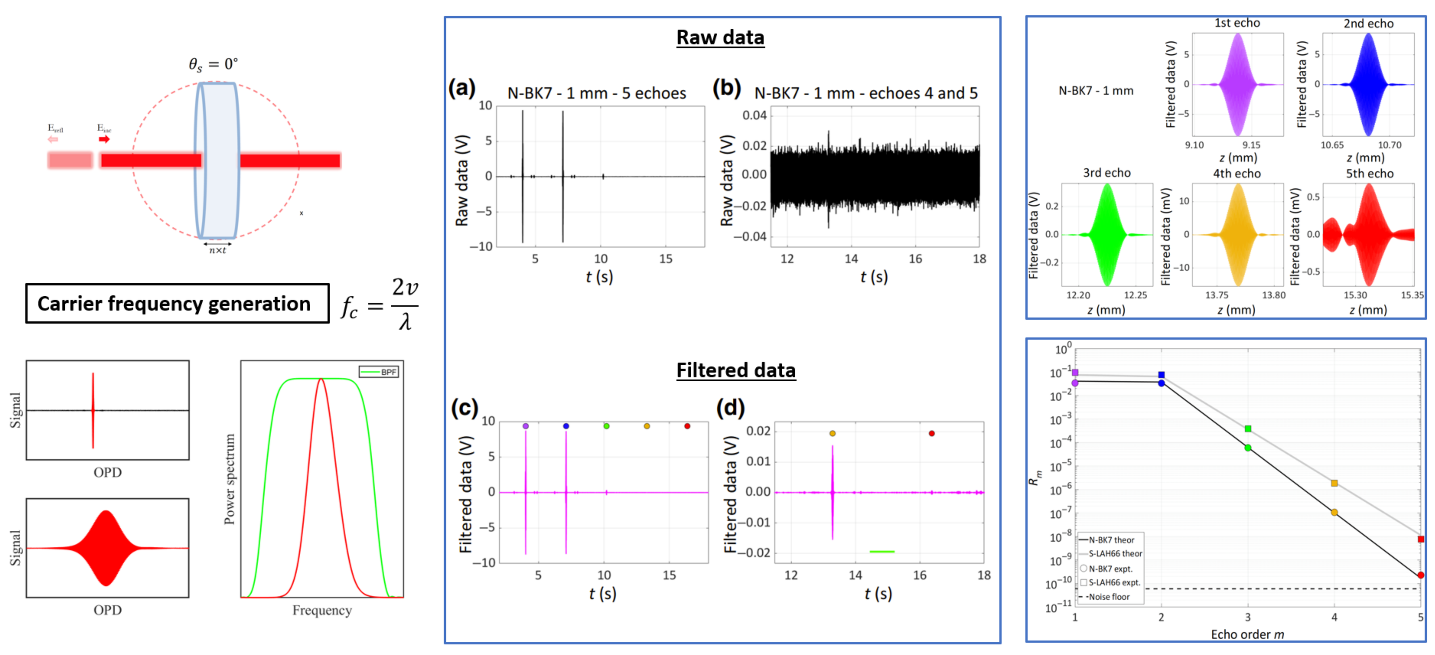

Fig. 2. **(left)** Back-reflection of an optical window and the frequency filtering of the recorded signal. **(middle)** Recorded signals from an uncoated N-BK7 window [black curves – raw signals, colored curves – frequency filtered signals]. **(right)** Summary of results for both N-BK7 and S-LAH66 uncoated windows.

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Measurement Results: Back-reflected light

Back-reflected light from AR-coated Silica window

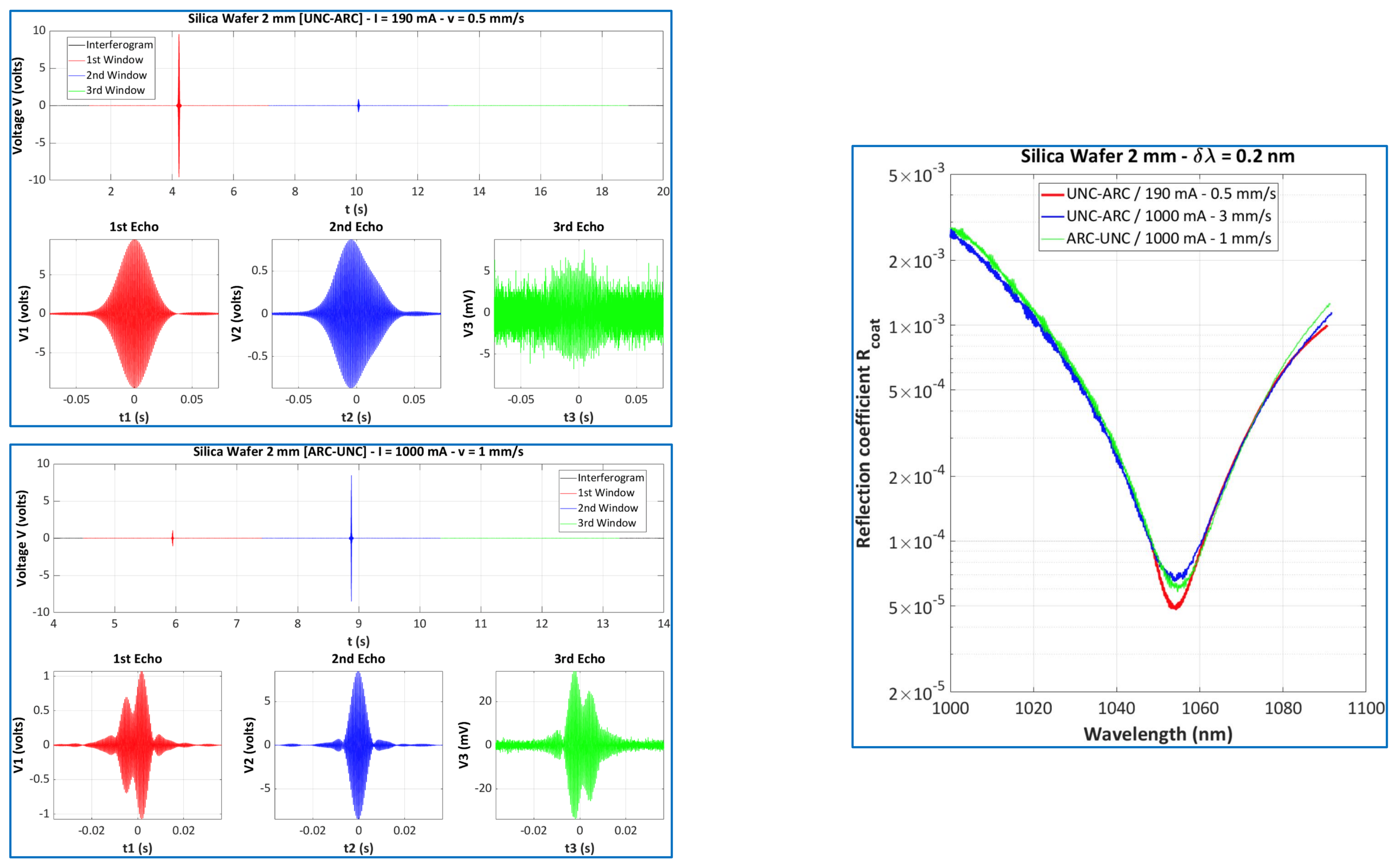

Fig. 3. **(left)** Recorded time domain signals from AR-coated Silica window at different source bandwidths. **(right)** The V-shaped curves show the spectral dependence of the reflectance.

Measurement Results: Back-scattered light

Spectral and angular dependence of the light flux backscattered is given by

$$|\rho_m(f_l,\theta_0^i)|^2 = R_m(f_l)\frac{|S_m(f_l,\theta_0^i)|^2}{|S_m(f_l,0)|^2} \qquad m = 1,2$$

Back-scattered light from Silver coated mirror

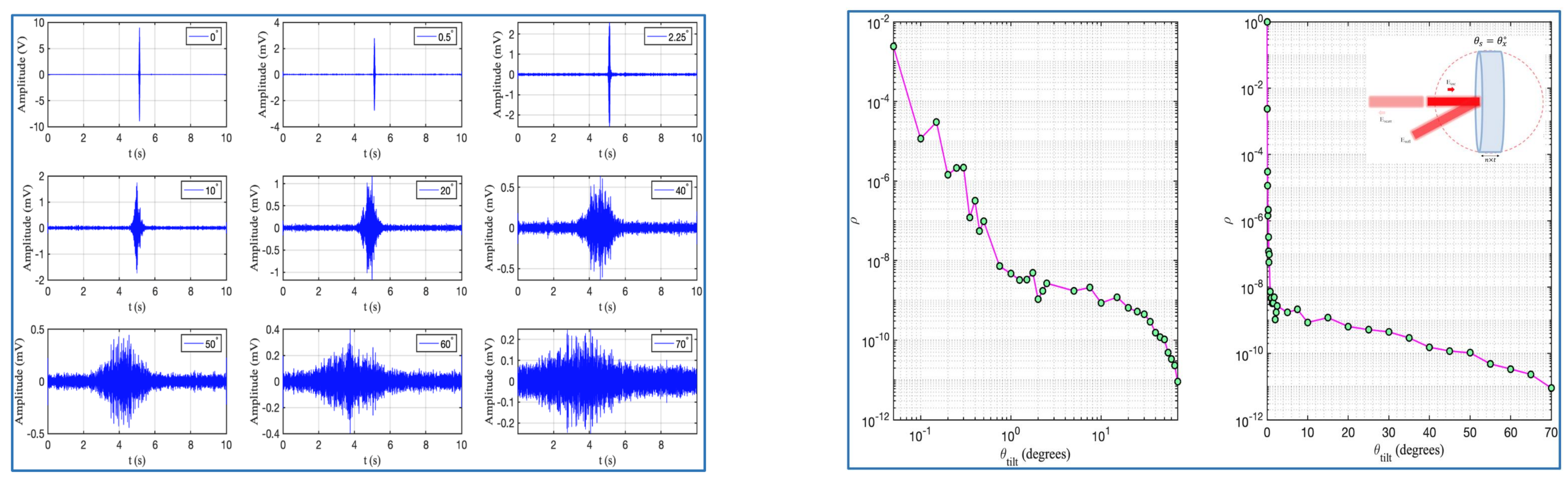

Fig. 4. **(left)** Back-scattered light from a Silver coated mirror at different angles. **(right)** Angular dependence of back-reflectance as function of tilt angles (The lowest measured value is on the order of $\rho \sim 10^{-11}$)

Back-scattered light from AR-coated optical window

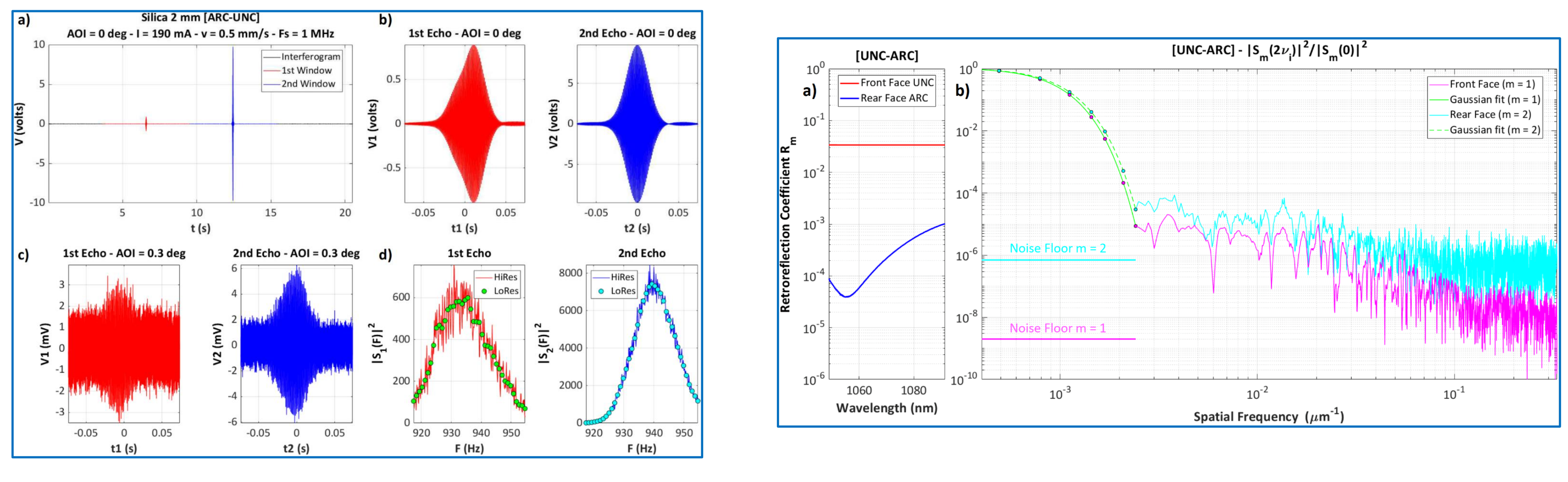

Fig. 5. **(left)** Retroreflection and backscattering of AR-coated Silica window. **(right)** Evolution of the ratios $|S_m(\nu)|^2/|S_m(0)|^2 (m = 1,2)$ as function of the spatial frequency $\nu = 2\nu_i$ where $\nu_i = \frac{\sin\theta_0^i}{\lambda}$ from the two faces.

Discussion and Conclusion

We presented the results obtained in terms of back-reflectance from uncoated windows with the minimum measured value on the order of $\rho \sim 10^{-10}$. And in terms of back-scattering, the ARS measurement is on the order of $10^{-4}sr^{-1}$ with minimum determination of reflection coefficient of AR coating on the order of 80 ppb to 1.6 ppm. To conclude, BARRITON instrument can measure (for a given sample)

- Back- reflectance of an optical interface
- Spectral dependence of back-reflectance of optical coatings
- Back- scattering of light from an optical interface
- Sample geometrical thickness

*BARRITON is part of the DIFFUSIF platform (**www.fresnel.fr/diffusif**) as scattered light metrology instrument.*

Related Publications

1. M Lequime, I Khan, M Zerrad, and C Amra, "Low-coherence interferometric measurement of the spectral dependence of the light field backscattered by optical interfaces", *Appl. Phys. Lett.* 122, 191103 (2023)
2. M Lequime, I Khan, M Zerrad, and C Amra, "Low coherence interferometric detection of the spectral dependence of the retro-reflection coefficient of an anti-reflective coated interface", Optics Express Vol. 31, Issue 5, pp. 8748-8774 (2023).
3. I Khan, M Lequime, M Zerrad, and C Amra, "Interferometric Quantification and Identification of Back-reflected and Back-scattered Light from a System of Two Optical Components", SPIE Proceedings for International Conference on Space Optics – ICSO2022.
4. I Khan, M Lequime, M Zerrad, and C Amra, "Measurement of the spectral dependence of the amplitude and phase properties of laser line antireflection coatings using balanced low coherence interferometry", Optical Interference Coating Conference, OIC2022 @ Optica Publishing Group (2022).
5. I Khan, M Lequime, M Zerrad, and C Amra, "Detection of Ultra-Low Light Power Backreflected or Backscattered by Optical Components using Balanced Low Coherence Interferometry", Phys. Rev. Applied, Vol. 16, 044055 (2021).
6. I Khan, M Lequime, M Zerrad, and C Amra, "Characterization of light backscattered from optical components using balanced low coherence interferometry ", SPIE Proceedings Volume 11872, Advances in Optical Thin Films VII, 118720S (2021).
7. I Khan, M Lequime, M Zerrad, and C Amra, "Coherent detection of the light backscattered by on optical surface", SPIE Proceedings Volume 11852, International Conference on Space Optics - ICSO (2020).