Efficient picosecond ultrasonics with a common-cavity dual-comb laser

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We show how to predict the equivalent time sampling (also known as asynchronous optical sampling (ASOPS)) pump-probe measurement noise floor based on the laser parameters. We use this knowledge to obtain a high-sensitivity measurement configuration reaching <5x10^{-5} sensitivity for the relative reflectivity change ΔR/R in a single 12-ns-long trace with 250-fs delay resolution and an acquisition time of only 2 ms. We demonstrate the usefulness of this highly sensitive measurement configuration by studying ultrasonic signals in ruthenium thin films.

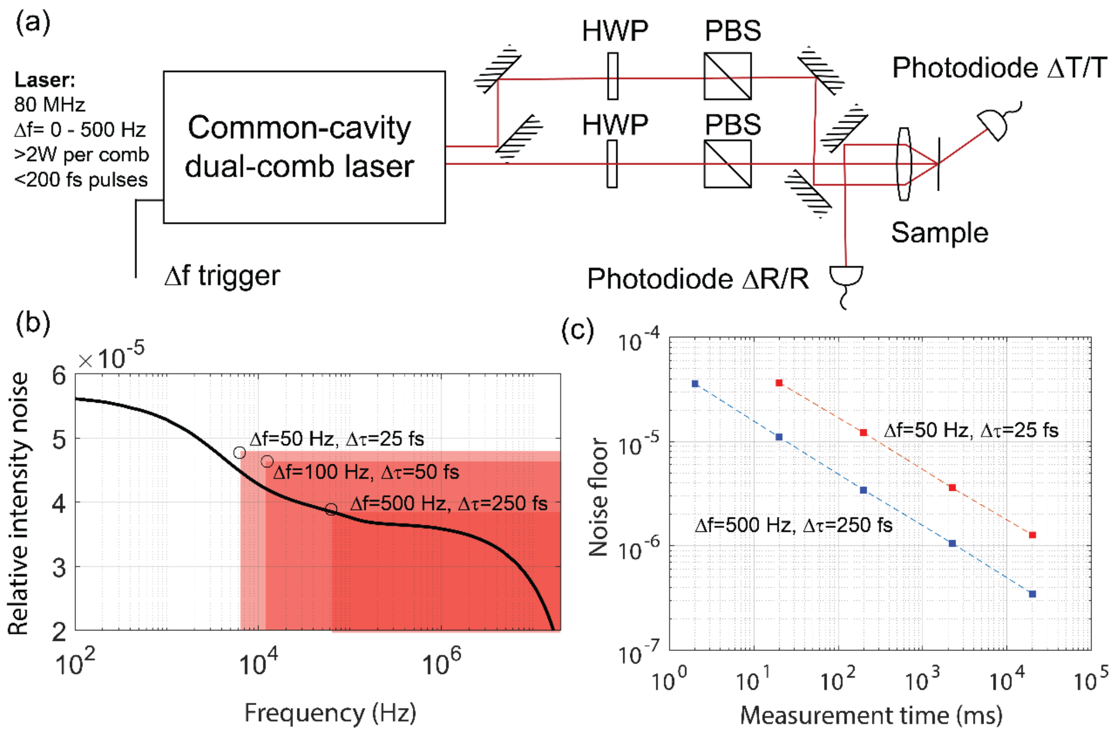

Fig. 1. **(a)** Experimental setup. HWP – half-waveplate, PBS – polarizing beam splitter. **(b)** Probe beam relative intensity noise (RIN) measured with a signal source analyser and integrated from 25 MHz (black curve). Black circles indicate the noise floor (standard deviation of the background) of a 100 ps long pump-probe time window. Δf indicates the repetition rate offset of the two combs and Δτ indicates the measurement time resolution based on the signal detection bandwidth (here set to 25-MHz acquisition bandwidth). The lower frequency bound is determined from the 100 ps acquisition window and the comb scale factor Δf/f. **(c)** Measurement noise floor versus acquisition time (averaging) for two different acquisition cases.

Picosecond ultrasonics is a widely adopted ultrafast measurement technique which allows for the characterization of thin-film structures. One advantageous approach to picosecond ultrasonics is the use of the ASOPS method. However, the classical ASOPS implementations are complex since two lasers and locking electronics are required. Lately, common-cavity dual-comb lasers have emerged as a cost- effective alternative and have proven to be well-suited for picosecond ultrasonics [1]. In this submission we apply a new common-cavity dual-comb laser [2] to picosecond ultrasonics and study signal to noise properties using the setup shown in Fig. 1(a).

Firstly, we show that the laser relative intensity noise (RIN) measurement can be used to predict the noise floor in the picosecond ultrasonics measurement (Fig. 1(b)) if the probe power arriving on the photodiode is known. Secondly, we show that an ultra-low noise floor can be obtained by averaging the traces (Fig. 1(c)) reaching $3.5x10^{-7}$ in 20-second-long acquisition.

We apply this high-sensitivity pump-probe setup to study ruthenium thin-films at different thicknesses. Ruthenium it is a promising replacement for copper interconnects in computer chips [3]. The pump-probe response of ruthenium films of different thicknesses is shown in Fig. 2(a). We observe clear localized strain waves in the 100 nm thick sample. As the sample thickness is reduced, instead of a localized strain wave, we observe a standing wave motion, showing an oscillatory signal. Furthermore, we look at relative transmission and reflection channels as shown in Fig 2(b). We find that a measurement of the change in relative transmission ΔT/T gives the same but sign-inverted response as the corresponding ΔR/R measurement.

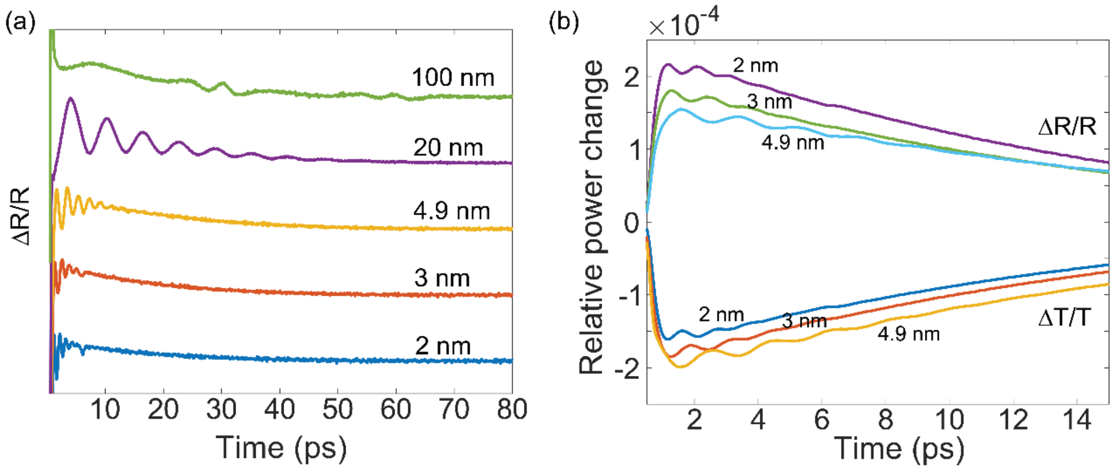

Fig. 2. (a) Relative reflectivity change ΔR/R for five different ruthenium thin films. The shown signal traces are offset vertically for better visibility. The background was removed with a slowly moving average to enhance the visibility of the fast signals. **(b)** Corresponding measurements of relative transmission and reflectivity of ruthenium samples of different thicknesses.

To conclude, we have demonstrated that a common-cavity dual-comb laser presents an efficient approach to pump-probe measurements. Firstly, the ultra-low RIN of the solid-state laser architecture enables excellent measurement sensitivity. Secondly, by using a sufficiently high repetition rate difference, we can position the signal frequencies to be close to the shot-noise limit. This is a cost-effective approach to high-performance measurements.

References

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