Detection of acoustic waves with pump-probe microscopy

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PROSPECTIVE

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Motivation

In recent years pump-probe microscopy has been used in several studies to investigate laser-material interaction processes. Thereby, acoustic waves could be imaged that were released into the vicinity of the irradiated spot. Since these waves carry information about the elastic properties of the irradiated material, the question arose how pump-probe microscopy could be utilized for elastography of biological materials. For this purpose, we have realized a pump-probe microscope specifically tailored for the optical detection of laser-induced acoustic waves. In this study, its performance was tested on glass and mammoth ivory.

Material & Methods

Figure 1 shows the pump-probe microscopes setup with epi-illumination. Acoustic waves were generated by focusing a single laser pulse of 380 fs duration, 1040 nm wavelength and up to 30 µJ pulse energy through a microscope objective onto the sample. To image the propagation of the waves, a second fs pulse (λ = 520 nm) with temporal delay of up to 18 ns was used for Köhler illumination, while the sample was imaged with a sCMOS camera.

It was already show that the microscope can be used to image acoustic waves in water and glass. The waves in glass in combination with shockwaves in air are shown in the first part, also test with mammoth ivory are shown down low. The dentin of mammoth ivory is a cheap and easy to get sample. It has a growth direction, which should have an impact on the acoustic waves form.

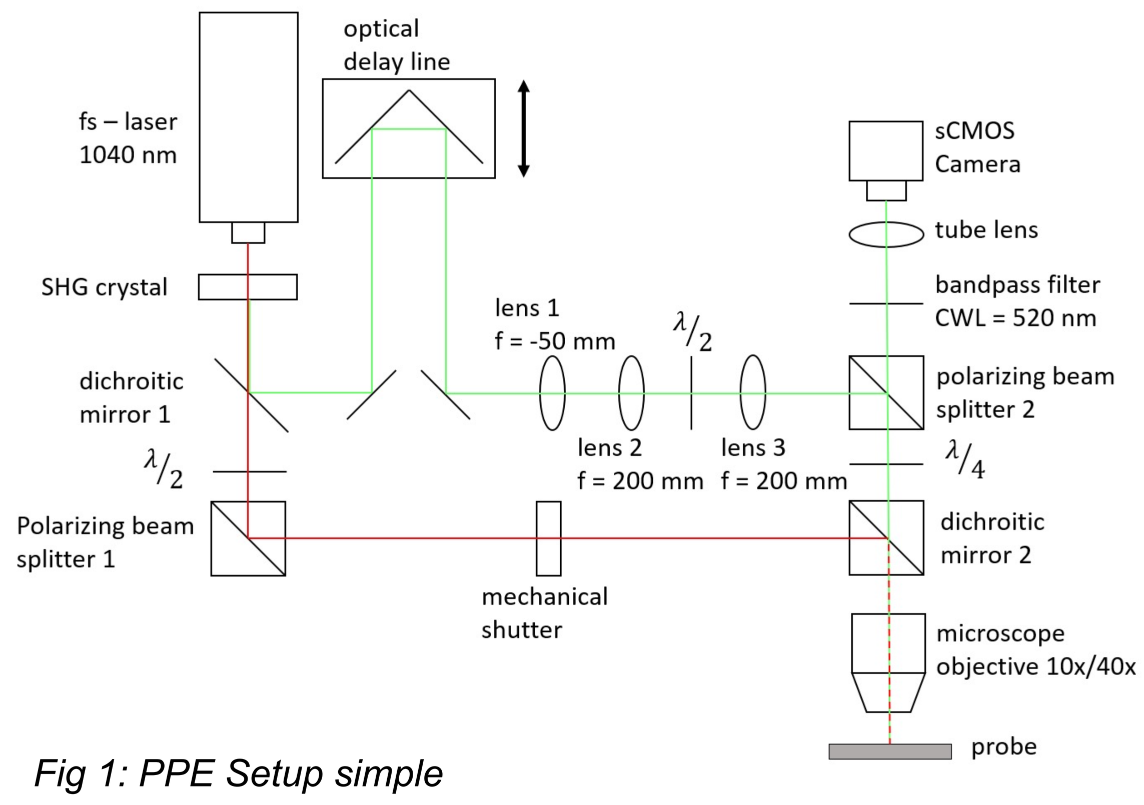

Fig 1: PPE Setup simple

Acoustic waves in glass and shockwaves in air

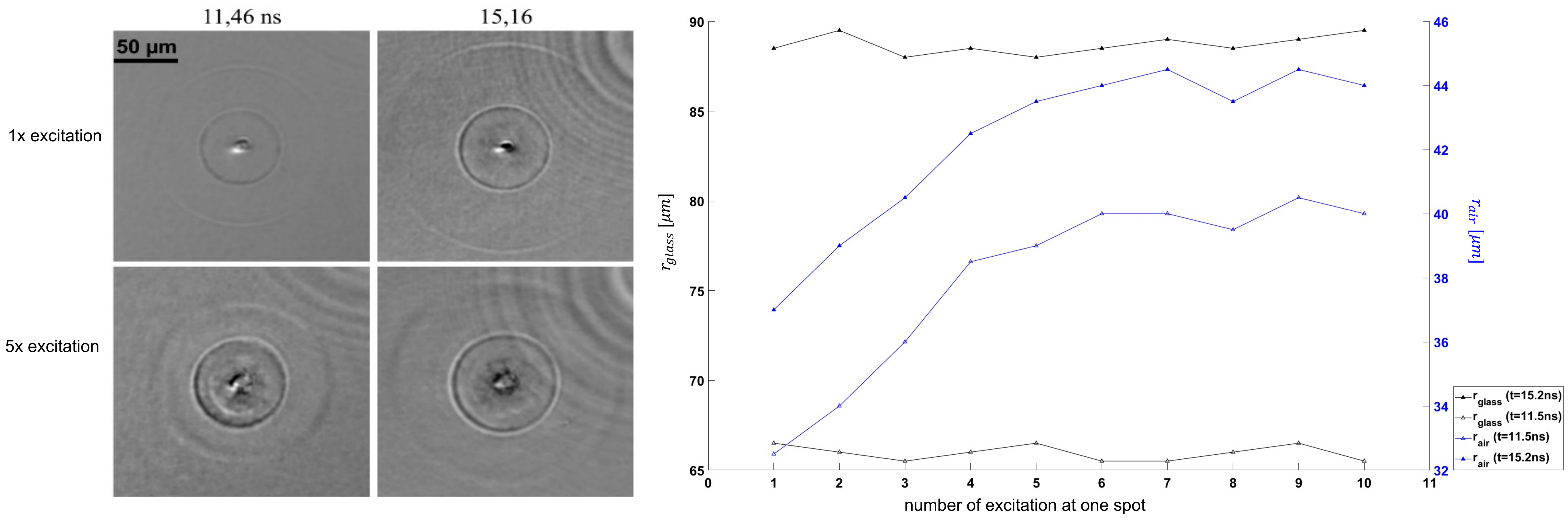

Fig. 2: Left: images of acoustic waves on the glass surface; Right: diagram of waves radii

Acoustic waves were imaged 11.5 ns and 15.2 ns after the irradiation of a glass surface. Left: the images in the top and bottom row were generated by irradiating the same spot with one and five pulses, respectively. In the upper row, the waves are very well distinguishable, with increasing excitations the wave fronts get wider. The radii of the wave fronts, r_{glass} and r_{air} are shown on the right side as a function of excitation pulses at the two delay times. Interestingly, the inner wave front is influenced by the number of excitations, whereas the outer front is not. The speed of the outer wave front is $v = 5697\ {}^{m}/_{s}$, which corresponds well to the longitudinal sound speed of soda-lime glass. The inner wave front could be identified as shock wave in air, due to its dependency on pulse energy and number of excitations.

Acoustic waves in mammoth ivory

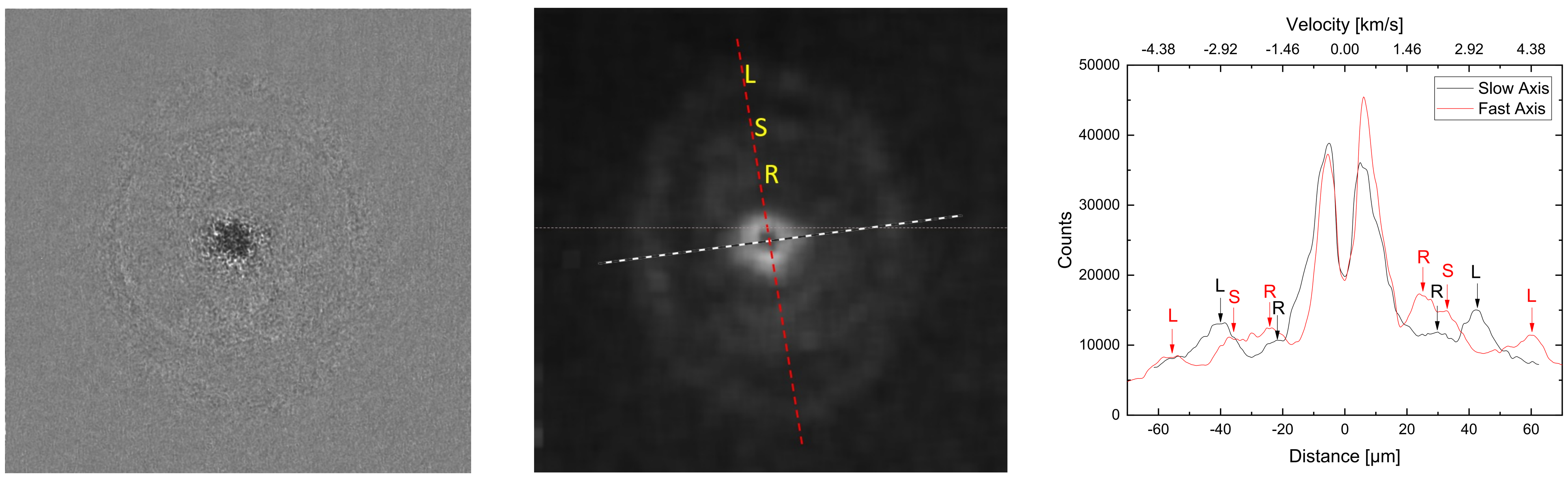

Fig. 3: Left: Mammoth Ivory at 13.7 ns delay; Middle: same image with noise filter applied; Right: profile of the axis shown in middle image
L … longitudinal wave; S … shockwave in air; R … Rayleigh wave

Figure 3 on left side show acoustic waves on the surface of mammoth ivory. The left image shows an unfiltered difference image, where some waves are already visible. The middle, shows the same image with noise filter applied. The filters were standard deviation filter and a gaussian filter.
With the filters applied the three different wavefronts are very well visible, as marked in the image. The measurements shown in Fig 3 Right give a velocity for the longitudinal wave of $v_{longi} = 4380\ {}^{m}/_{s}$ and for the Rayleigh wave of $v_{rayleigh} = 1470\ {}^{m}/_{s}$.
These two velocities in combination with the density of the material can be used to calculate the elastic modulus of the respective material.

Conclusion

This study shows that pump-probe microscopy can be used to detect laser-induced acoustic waves in and out soda-lime glass and mammoth ivory. The Studies with glass show that the position of the shock waves generated in air depend on the pulse energy and the number of excitations, while the position of the shock waves generated in air depend on the pulse energy and the number of excitations, while the position of the material waves remains constant. The studies on mammoth ivory show that the acoustic properties strongly depend on the growth direction. Both material studies showed that the visibility of the acoustic waves depends on the delay time, the pulse energy and the number of excitations. The optimum must be found for each material, otherwise the waves may not be visible or may overlap. Image filtering techniques can even be used to generate artificial intensity plots of the wave fronts.

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