Towards quantitative photoacoustic spectroscopy using acousto-optic modulation

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Introduction

Photoacoustic spectroscopy (PAS) has enabled deep tissue functional imaging. However photoacoustics alone inherently lacks the ability to do quantitative imaging, since the local light fluence $\varphi(\lambda)$ is unknown.

$$\sigma_o(\lambda) = \Gamma \mu_a(\lambda)\varphi(\lambda)$$

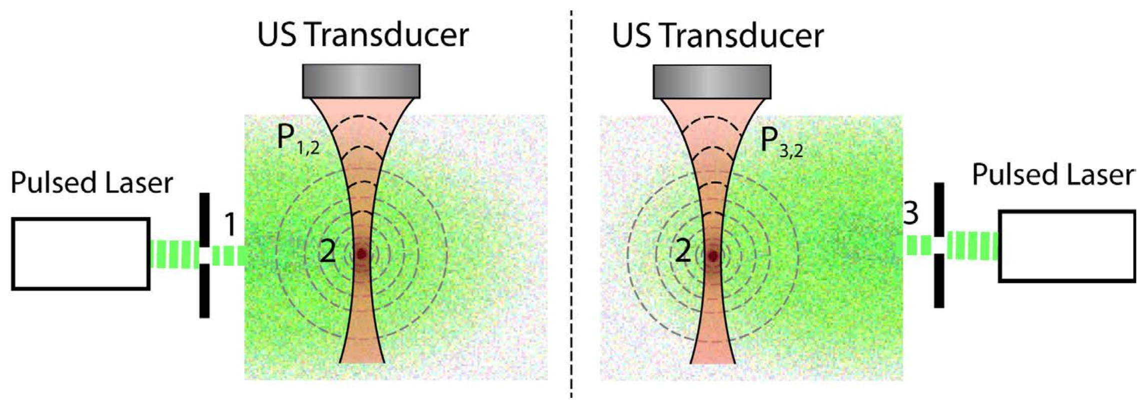
$\sigma_o(\lambda)$	Initial stress distribution, quantity measured in PA imaging
Γ	Grüneisen parameter
$\mu_a(\lambda)$	Absorption coefficient, enables estimation of chromophore concentration
$\varphi(\lambda)$	Local light fluence, unknown parameter in PA imaging

Goals

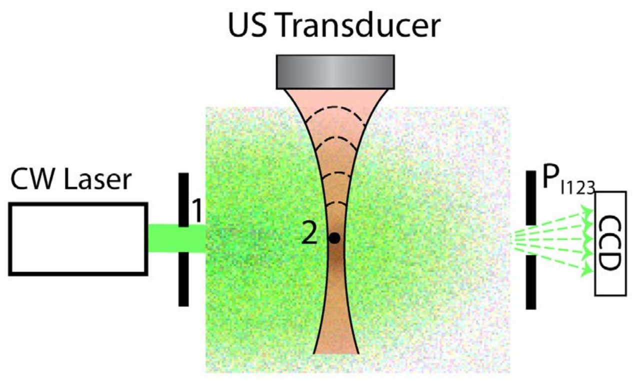
1) correction of fluence variations experimentally in PAS using acousto-optics (AO) modulation
2) quantitative estimation of simulated blood oxygenation using combination of PA and AO at two wavelengths

Method

- **PA Spectroscopy:** estimation of locally absorbed energy using PA at excitation wavelengths



- **AO Spectroscopy:** measurement of locally modulated light power $P_{l,123}$ using AO at excitation wavelengths, where $P_{l,123} \propto \lambda^2 \Delta C$



- Combination of PA and AO measurements using photon path reversibility principle $\Pr(1,2) = \Pr(2,1)$ for wavelength dependent fluence variations

$$\mu_a(\lambda) = k\sqrt{\frac{P^*_{1,2}(\lambda)P^*_{3,2}(\lambda)}{\lambda^2 \Delta C}} = M(\lambda)$$

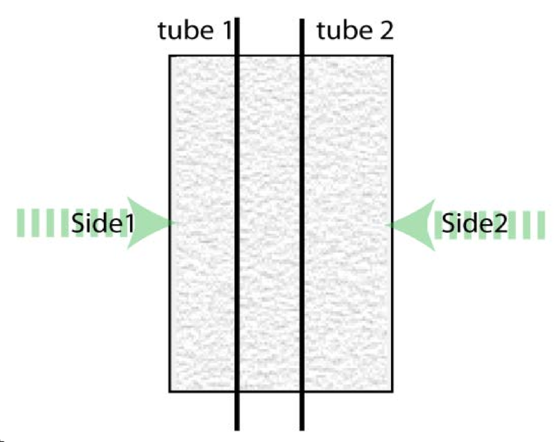
- Quantification of simulated blood oxygen saturation So2 using,

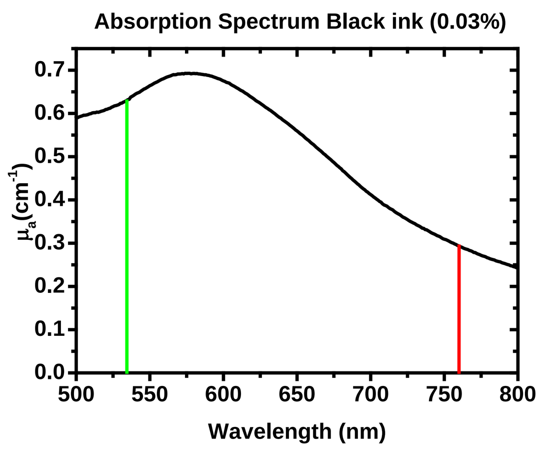
$$So2 = \frac{C_g}{C_T} = \frac{M^{\lambda_1}\varepsilon^{\lambda_2}_b - M^{\lambda_2}\varepsilon^{\lambda_1}_b}{M^{\lambda_2}\Delta\varepsilon^{\lambda_1} - M^{\lambda_1}\Delta\varepsilon^{\lambda_2}}$$

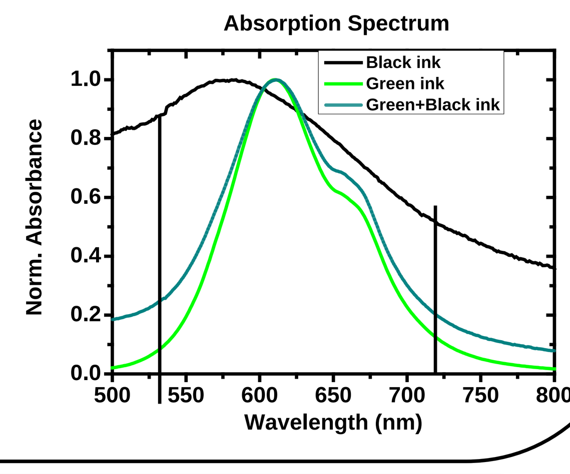
Phantom

Background: $\mu_s' = 11.5\ cm^{-1}$ @532 nm, $8.0\ cm^{-1}$ @ 760 nm, $8.5\ cm^{-1}$ @ 720 nm

Absorbers: two nylon tubes 4 mm and 8 mm deep from side1, containing different types of ink



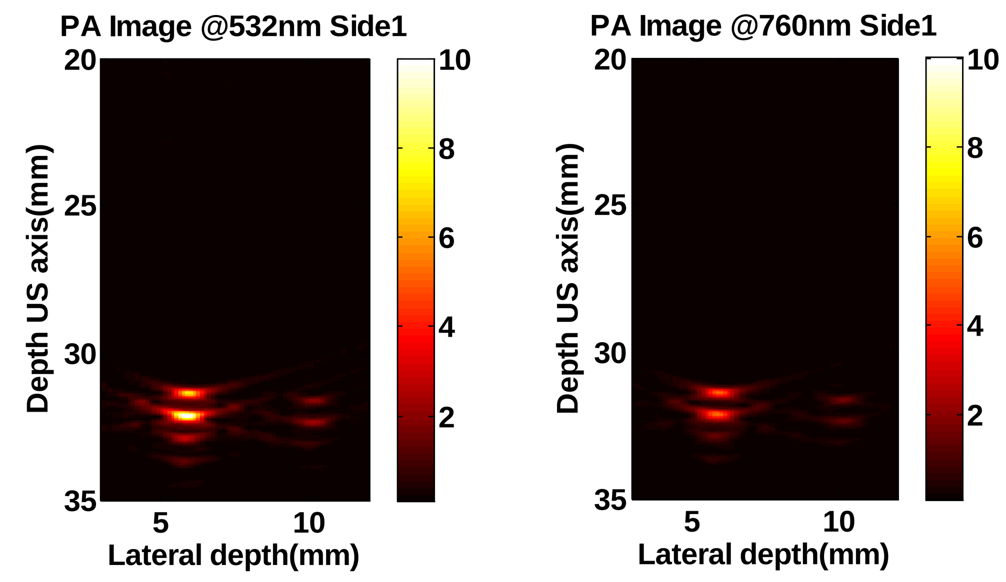


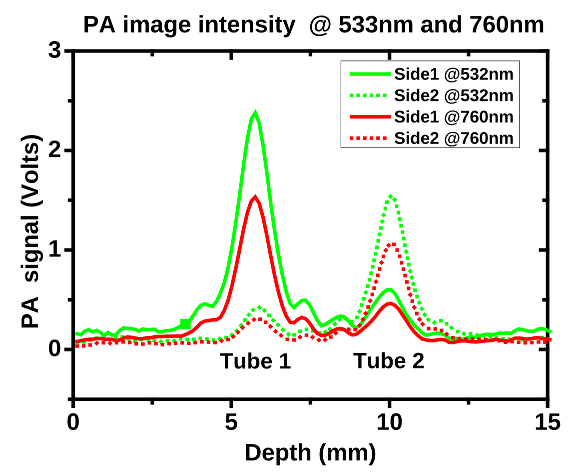


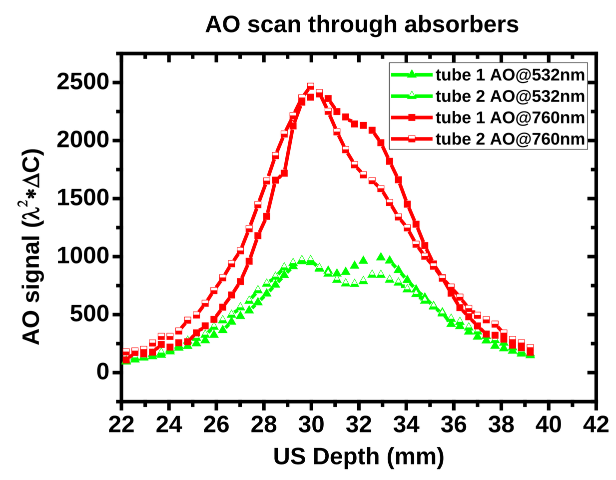
Results

Fluence compensation in PAS

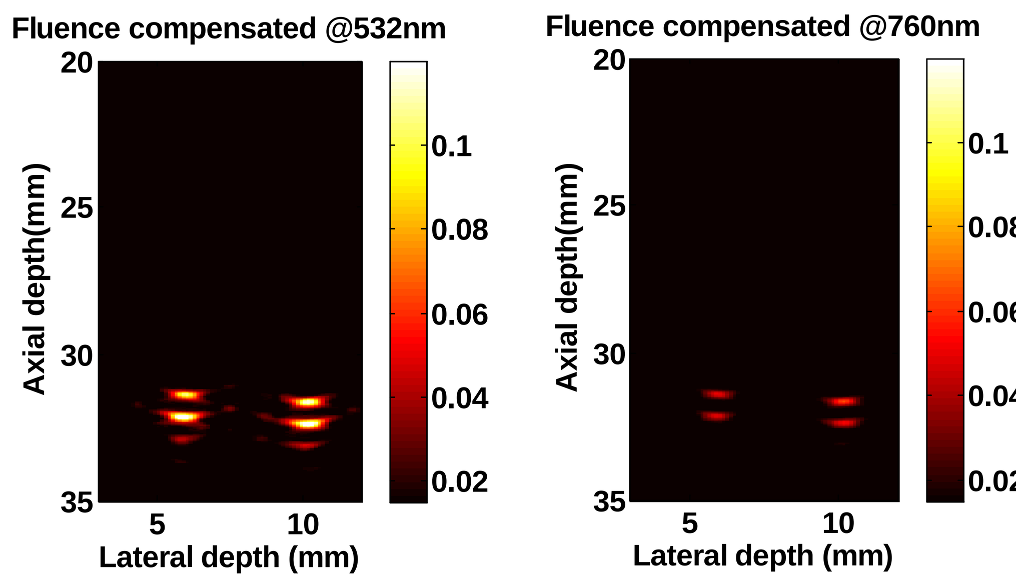
Before fluence compensation

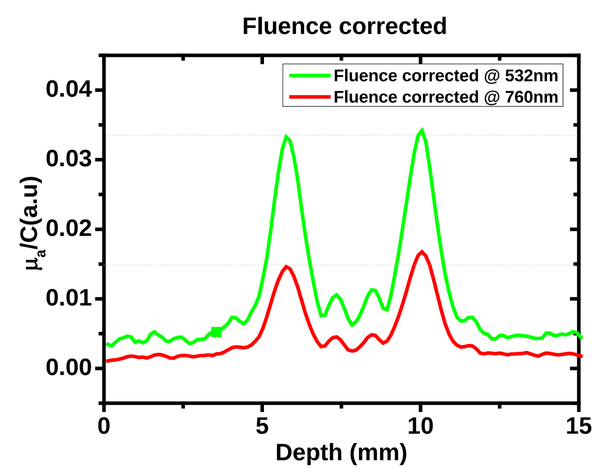






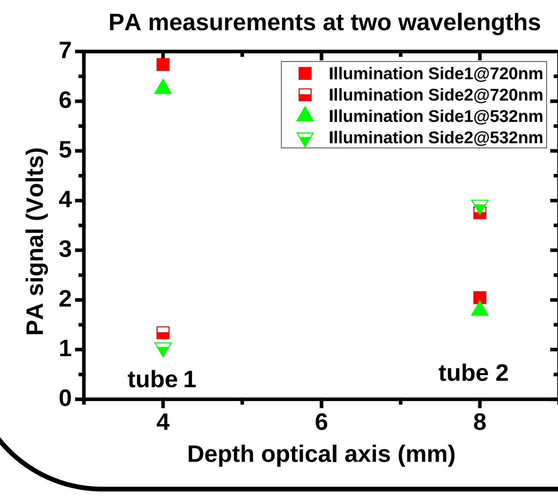
After fluence compensation

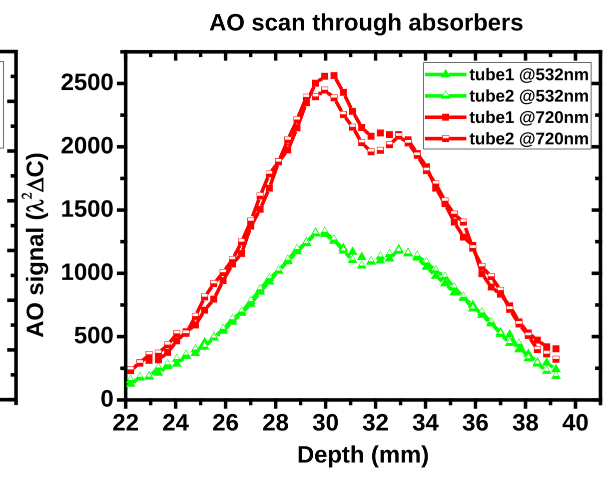


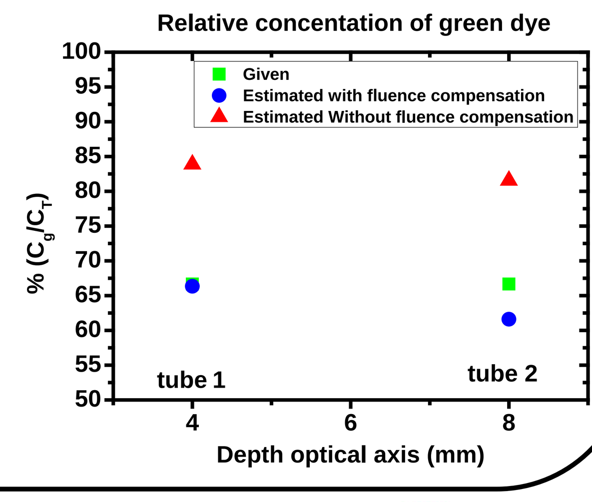


Quantification of simulated blood oxygen saturation (So2)

− Inclusions: two nylon tubes at depths 4 mm and 8 mm containing mixture of black ink (33.3 vol%) and green ink (66.7 vol%)







Conclusion

- AO modulated signals can be used to experimentally compensate for local fluence variations in PAS
- The measured ratio of absorbance of black ink at 532 nm to 760 nm is 2.11 for absorber at depth of 4 mm and 2.34 for absorber at depth of 8 mm which is in good agreement with ratio 2.15 measured with photospectrometer
- The technique potentially can provide quantitative measure of spatially resolved blood oxygen saturation noninvasively

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