Plasmonic nanoparticles as contrast agent for enhancement of optoacoustic signal generation

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Photoacoustic imaging

Optoacoustics combine the high contrast of optics with the good resolution of ultrasound. Signal generation is based on the conversion of light into heat and pressure by means of the thermoelastic effect occuring when tissue is irradiated with ultrashort laser pulses in the range of nanoseconds.

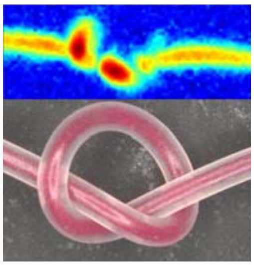


Fig. 1: Optoacoustic image of a vessel filled with dye embedded in a scattering phantom (10 MHz transducer, laser diode 905nm for signal excitation) and optical image for comparison

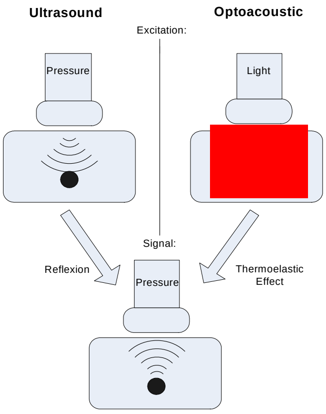


Fig.2: Comparison of signal generation process in conventional ultrasound an in the case of optoacoustic imaging

Nanogold as contrast agent for photoacoustics

Due to a strong plasmon resonance, nanoscaled gold particles exhibit strong absorption behavior for light in the visible and the NIR. The absorption properties depend strongly on the size and the shape of the particles. In biomedical optoacoustic imaging, the excitation wavelength is mostly located in the NIR (near infrared) where high penetration depth are achieved. In this wavelength domain, two particle types are available:

- Gold nanoshells made of a SiO_2 core and a gold shell
- Asymmetric gold nanoparticles (nanorods)

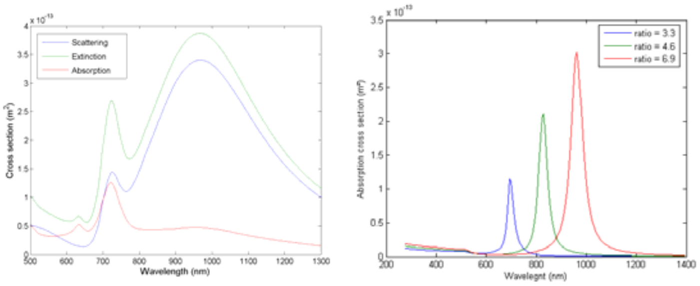


Fig.3: Calculated absorption spectra for nanoshells (100nm core radius and 10nm gold layer) and for nanorods of different aspect ratio

Different types of nanoparticles were evaluated regarding their suitability as optoacoustic contrast agent:
- Nanospheres
- Nanorods
- Nanoshells (commercial + IBMT)

Fig. 4: Different particle types (from the left to the right): Nanoshells (IBMT) - Nanorods - Nanospheres - Nanoshells (commercial)

Nanoshell synthesis

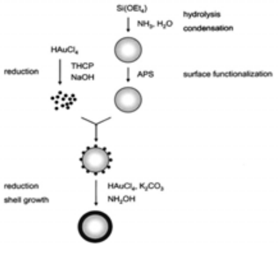
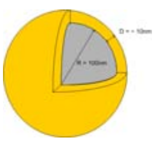


Fig. 6: Processes involved in nanoshell synthesis



Nanoshell synthesis was performed in 4 steps:
- silanisation of SiO_2 particles (100nm diameter)
- synthesis of gold colloid
- fixation of colloid on SiO_2 particle surface
- formation of compete shell by reduction of gold ions

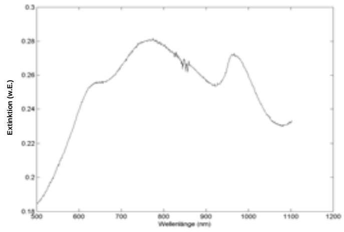
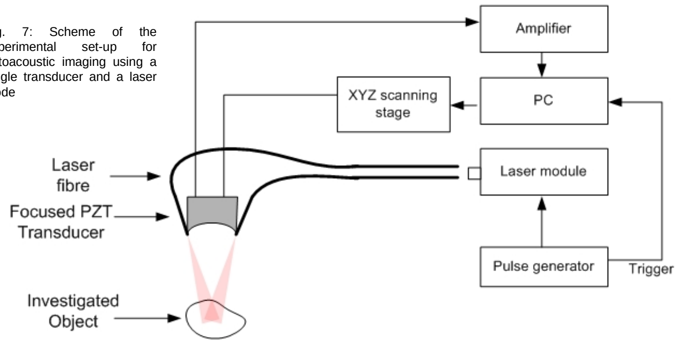


Fig. 5: Extinction spectrum of gold nanoshells (200nm core, 10nm shell)

Contrast enhanced optoacoustic signals

Optoacoustic images were acquired using both single- and multichannel systems. The single channel system consists of a focused PZT transducer combined with a high power laser diode (905nm, 70ns, 6µJ pulse energy).

Fig. 7: Scheme of the experimental set-up for optoacoustic imaging using a single transducer and a laser diode



Different particle types such as nanospheres, nanorods and nanoshells were used as signal source in the optoacoustic experiments based on data acquisition with the single channel set-up.

Fig. 8: 3D representation of optoacoustic signals of microvessels (0.5 mm diameter) filled with a gold nanosphere suspension (left)

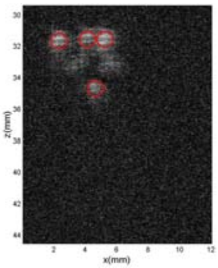


Fig. 9: Optoacoustic image of 4 microvessels filled with nanorods. Detection was made with a 10MHz focused transducer.

Due to the need for mechanical scanning, such systems present the inconveniency of long signal acquisition times. Additionally, the low energies delivered by diodes result in a need for averaging.

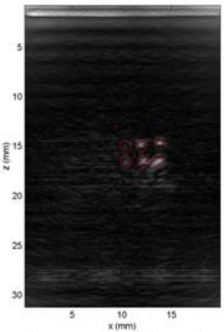


Fig. 10: Optoacoustic image of 6 vessels filled with a suspension of nanoshells (200nm silica core, 9nm gold shell, commercial) recorded with the real-time optoacoustic imaging platform

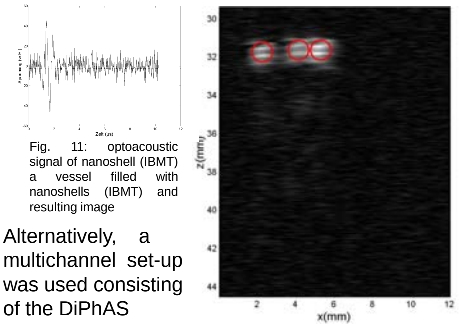


Fig. 11: optoacoustic signal of nanoshell (IBMT) a vessel filled with nanoshells (IBMT) and resulting image

Alternatively, a multichannel set-up was used consisting of the DiPhAS (Digital Phased Array System, Fraunhofer IBMT) and a Nd:YAG laser (1064nm, 40mJ). Signals of 64 elements of a linear array are recorded simultaneously and converted into a spatial representation of the local absorbed energy.

Conclusion

For all nanoparticle types, optoacoustic transients could be detected when the 905nm laser source was used for signal generation. With the set-up allowing real-time imaging using the Nd:YAG laser (1064 nm), only the nanoshell suspension gave rise to detectable signals. This particle type offers the advantage of showing strong absorption in spectral domains where light penetration depth is high and powerful laser sources are available. Nanoshells can therefore be regarded as a very promising particle type for contrast enhanced optoacoustic imaging. In addition, the surface chemistry of these particles is well understood which enables easy attachment of biomarkers and makes of them an ideal candidate for molecular imaging.

Acknowledgments

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Project Website: www.fp6-adonis.net