Developing robust and sensitive detectors for high resolution medical photoacoustic imaging

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1. Photoacoustic imaging

Photoacoustic imaging is a **non-invasive** imaging technique.

It relies on the **photoacoustic effect**, where light is used to excite biological tissue, producing **ultrasound waves**.

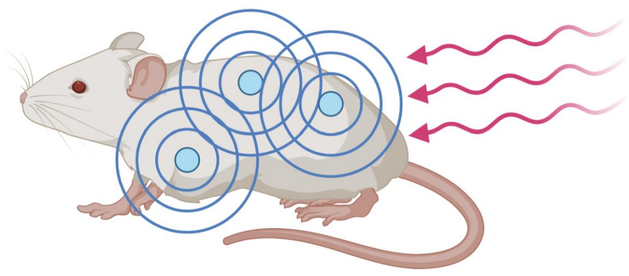


Figure 1: An illustration of the photoacoustic effect: light in, sound out.

Photoacoustic imaging is well suited to imaging **vasculature** due to the high optical absorption of **haemoglobin**.

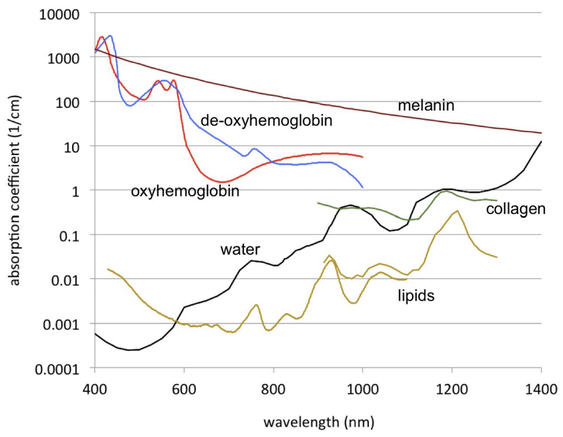


Figure 2: Absorption coefficients of various biological molecules against wavelength. Haemoglobin has high absorption in the region where water has low absorption. Weber 2016.

Photoacoustic imaging is very effective for **small animal imaging**.

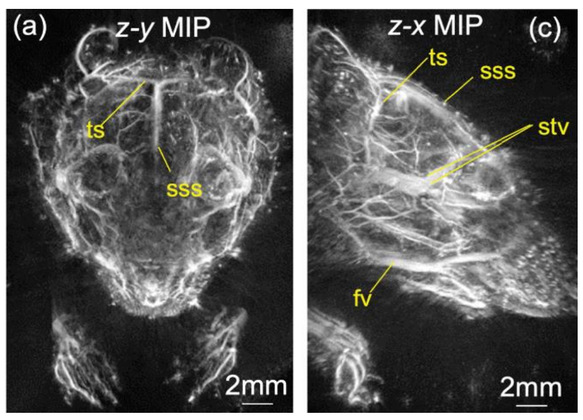


Figure 3: PA images of a mouse head with major blood vessels visible. Ogunlade 2025.

2. Clinical applications

Clinical applications of photoacoustic imaging include:

- Detection of **breast cancers**
- Determination of **tumour boundaries** in skin cancer
- Assessment of **skin conditions**
- **Endoscopic** surgery guiding

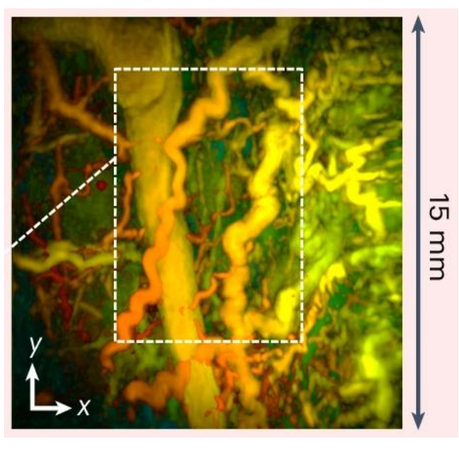


Figure 4: A PA image of vasculature in the foot of a patient with severe type II diabetes. Huynh 2025.

3. Detecting ultrasound: Fabry Perot sensors

Ultrasound can be detected with a Fabry Perot sensor: two mirrors separated by a spacer. The **thickness** of the spacer is **modulated** by acoustic waves.

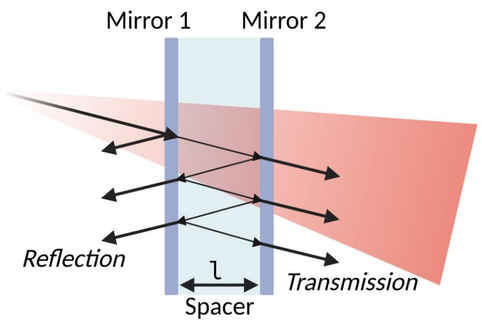


Figure 5: Certain wavelengths of light travelling through an FP sensor experience constructive interference, depending on the spacer thickness.

The **thickness** of the spacer can be calculated by measuring **reflected light intensity** from the sensor.

Total sensitivity = Optical sensitivity * Compressibility

Typically, **polymer** is used as the **spacer material,** but **glass** may be a better option...

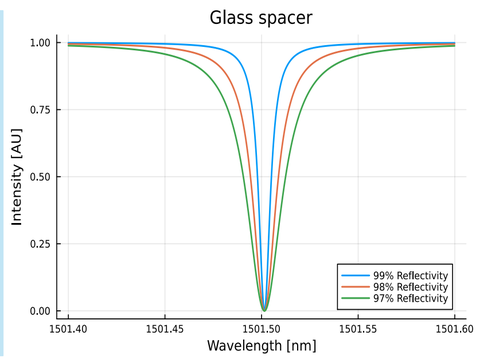
Polymer	Glass
High compressibility	Low compressibility
High optical absorption	Low optical absorption
Expands with heat	High temperature stability
Custom made	Off-the-shelf potential

4. Optical sensitivity

The **optical sensitivity** of an FP sensor depends on the **sharpness** of the fringes produced when reflected light intensity against wavelength is measured.

Due to **low optical losses** in glass, making changes to the sensor design which cause light to remain in the spacer for longer improves the optical performance.

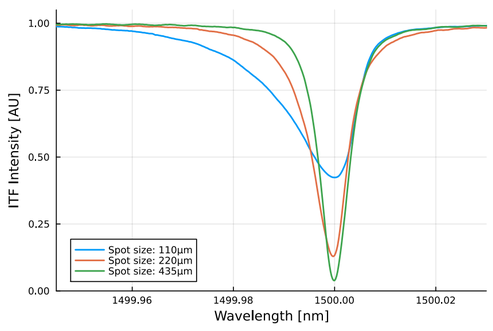
Figure 6: Modelled reflected light intensity for a glass FP sensor with increasing reflectivity, showing improved optical sensitivity.



The FP sensor is illuminated with a **Gaussian beam**, which has a certain **spot size**, depending on the **beam width**.

If the spot size used is too small, the fringes become asymmetrical and less sharp.

Figure 7: A comparison of reflected light intensity measured from the same sensor, with a range of beam sizes used.

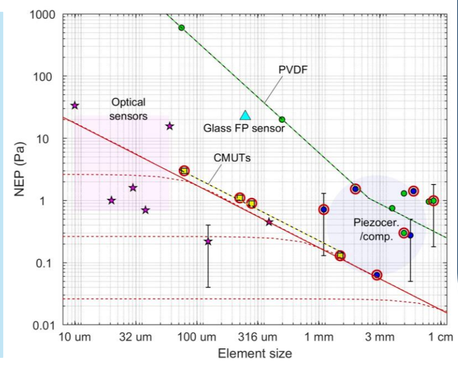


The spot size is the effective **optical element size**, which should be kept small to ensure the sensor response is **multi-directional**.

5. Acoustic performance

Acoustic sensitivity of glass FP sensors can be characterised by **noise equivalent pressure** (NEP), which indicates the minimum detectable signal over noise.

Figure 8: NEP against element size for different detectors. Polymer and glass FPs shown by pink stars and blue triangle, respectively. The NEP of the glass sensor is comparable to the existing polymer standard.



Key takeaways:

- Glass sensors have been successfully used to measure **ultrasound signals**
- Initial results show glass sensors have **comparable sensitivity** to polymer ones
- Changing **sensor design** may further improve sensitivity
- Glass sensors have the potential to be much more **accessible** than polymer

6. Areas for further research

Fabricate new sensors to improve sensitivity, and test standard of off-the-shelf products → Address **delivery of light** to and from sensor using **multi-mode fibres** → Build **prototype** and test using **phantoms** and tissue samples → Develop **handheld imaging system**, focussing on accessibility and sensitivity

References

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