Supplementary Information – Surface Plasmon Resonance Imaging of Excitable Cells

Carmel L. Howe[1,2,*], Kevin F. Webb[1,*], Sidahmed A. Abayzeed[1], David J. Anderson[3], Chris Denning[3], Noah A. Russell[1]
[1]Department of Electrical and Electronic Engineering, University of Nottingham, Nottingham, NG7 2RD, UK
[2]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK
[3]Department of Stem Cell Biology, Centre of Biomolecular Sciences, University of Nottingham, Nottingham, NG7 2RD, UK
[*]These authors contributed equally to this work

Email: noah.russell@nottingham.ac.uk

Supplementary Information

The Fresnel equations describe the behaviour of light at a single interface between two media. When incident light reaches an interface of two media with different refractive indices some of the light is reflected and some is refracted (or transmitted). Snell's Law describes the relationship between the angle of the incident light (θ_1) and the resulting reflected and refracted light (θ_2) given by $\tilde{n}_1 \sin\theta_1 = \tilde{n}_2 \sin\theta_2$. $\tilde{n}_i$ is the complex refractive index for each medium given by $\tilde{n} = n + ik$ where n and k are the real and imaginary parts of the refractive index, respectively. The refractive index relates to the permittivity of the material using Equations (1) – (4).

$$\varepsilon_1 = n^2 - k^2 \tag{1}$$

$$\varepsilon_2 = 2nk \tag{2}$$

$$n^2 = \frac{\varepsilon_1}{2} + \frac{1}{2}\sqrt{\varepsilon_1^2 + \varepsilon_2^2} \tag{3}$$

$$k = \frac{\varepsilon_2}{2n} \tag{4}$$

where n is the real part of the complex refractive index and k is the extinction coefficient.[1]

The Fresnel equations represent the ratio of reflected (r) and refracted (t) light at a single interface between two media of different refractive indices. For p- and s- polarised light the Fresnel coefficients for the reflected light are given by (5) and (6), respectively.

$$r_p = \frac{-n_1 \cos\theta_2 + n_2 \cos\theta_1}{n_1 \cos\theta_2 + n_2 \cos\theta_1} \tag{5}$$

$$r_s = \frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2} \tag{6}$$

$$\tag{7}$$

where θ_1 and θ_2 are the angles of the incident light and the resulting reflected and refracted light, respectively.

The Fresnel coefficients for the transmitted light are

$$t_p = \frac{2n_1 \cos\theta_1}{n_1 \cos\theta_2 + n_2 \cos\theta_1} \tag{8}$$

$$t_s = \frac{2n_1 \cos\theta_1}{n_1 \cos\theta_1 + n_2 \cos\theta_2} \tag{9}$$

The reflectance (R) is related to (5) and (6) by $R_i = |r_i|^2$.[1] The transmittance (T) however, is related by

$$T_i = \frac{n_2 \cos\theta_2}{n_1 \cos\theta_1}|t_i|^2 \tag{10}$$

Figure 1b and 3b were plotted using the Fresnel equations above. Figure 5a was determined by scanning the illumination angle and finding the angle of the minimum reflection for each pixel also using the Fresnel equations.

Stem cell derived cardiomyocyte

Video 1: Surface plasmon resonance response from stem cell derived cardiomyocyte video. Each frame has had the first frame subtracted from it. Playback is at 7 frames per second. Two stripes of increased light intensity are seen at around 15 seconds corresponding to electrical activity.

References

1 E. Hecht, *Optics*, Pearson Education (2016).