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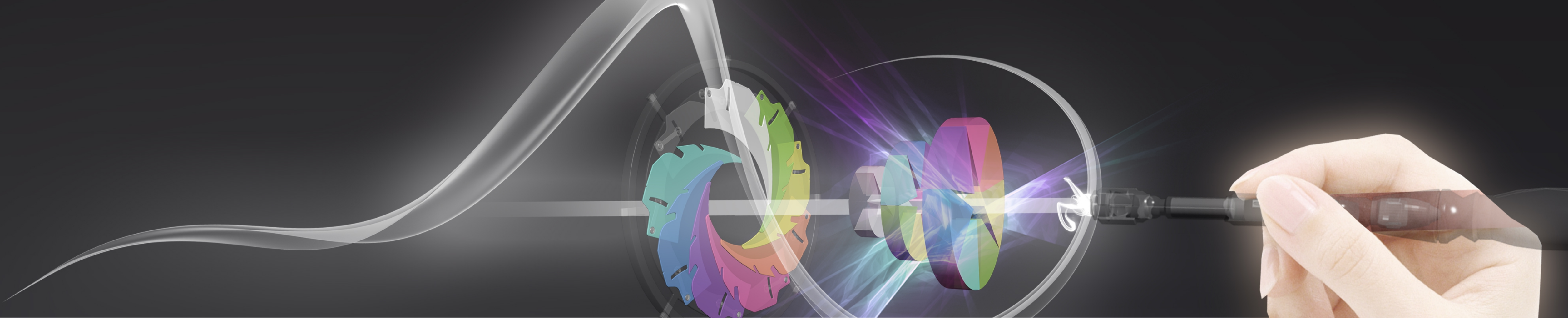

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Microbubble resonator simulation using FDTD

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Introduction

- **Microbubble resonators** have recently gathered interest as candidates for biosensors [1].
- Microbubbles are able to sustain **Whispering Gallery Modes** (WGMs), which are sensitive to changes inside and outside the resonator, and are capable of high quality(Q)-factors [2].
- In modelling the WGM spectra of microbubbles, we use the **Finite-Difference Time-Domain** (FDTD) method [3], which is readily customised to simulate a range of novel resonator shapes for a variety of mode excitation methods.
- The behaviour of the WGM spectra as a function of diameter and shell thickness can be used to fit the free spectral range (FSR) of silica microbubbles, and agreement between modelling and experiment can be found.

Aims

- To investigate the behaviour of the WGM spectra of microbubbles for a range of diameters and shell thicknesses.
- To predict the spectra of a given microbubble, by using modelling to estimate the geometric parameters for a known refractive index.

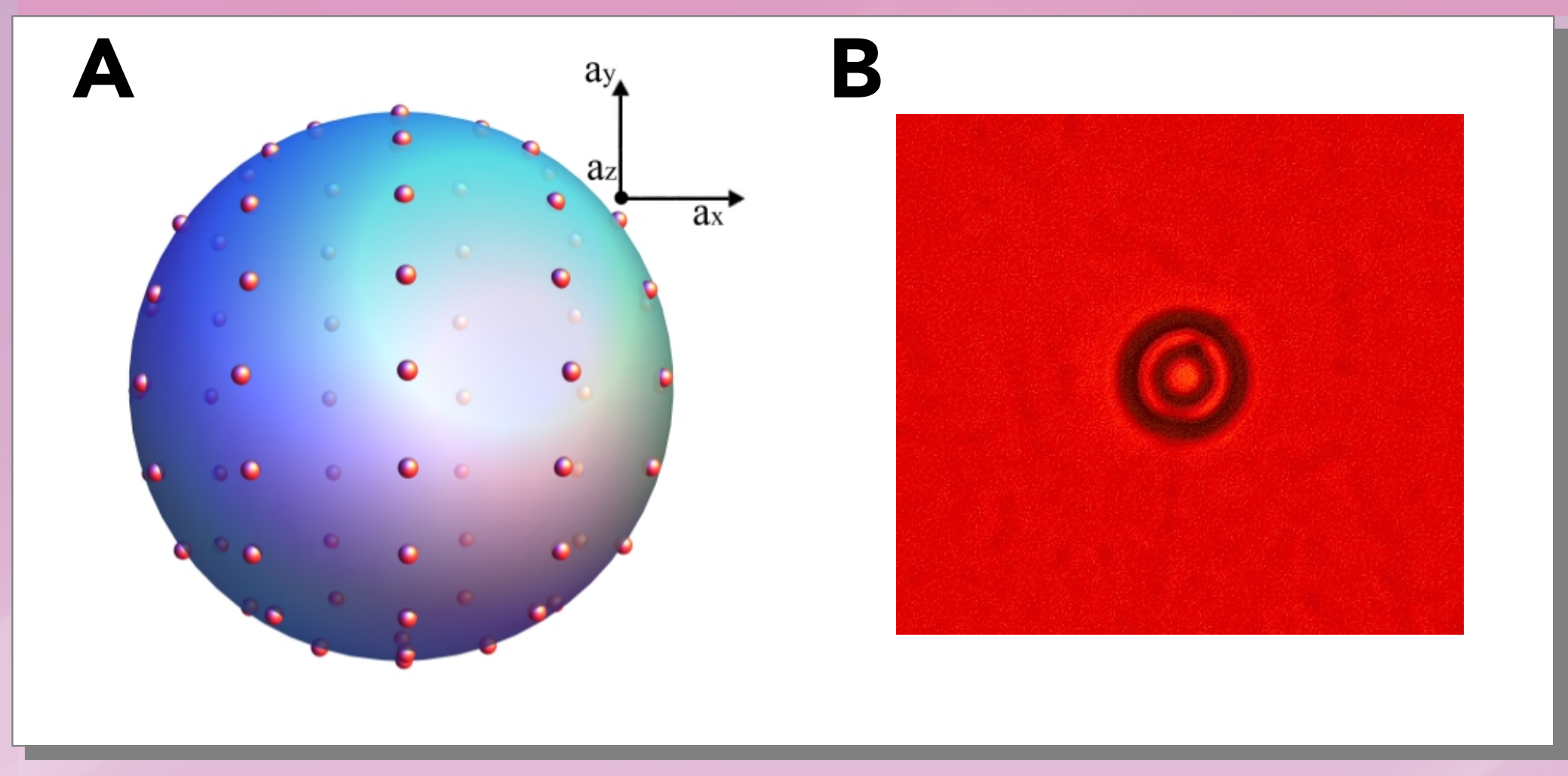

Figure 1 | Simulation (left) and experiment (right) of fluorophore-coated silica microbubble resonators. The red spheres shown on the surface of the simulated microbubble indicate a uniform distribution of electric dipole sources of random alignment.

- Silica glass microbubbles of diameter *D* and shell thickness *d* are used to test the FDTD simulation method.
- Microbubbles, surrounded by air both inside and outside, were coated with a carboxylic functionalised organic dye.

Microbubble simulation results

- Figure 1A illustrates the simulated microbubble with a coating of electric dipole sources placed on the surface.
- For a diameter of 8µm, the shell thickness is varied across a range: 0.5-2.0µm. The resulting WGM power spectra are shown in Fig. 2. The results for a diameter of 10 µm are shown in Fig. 3.

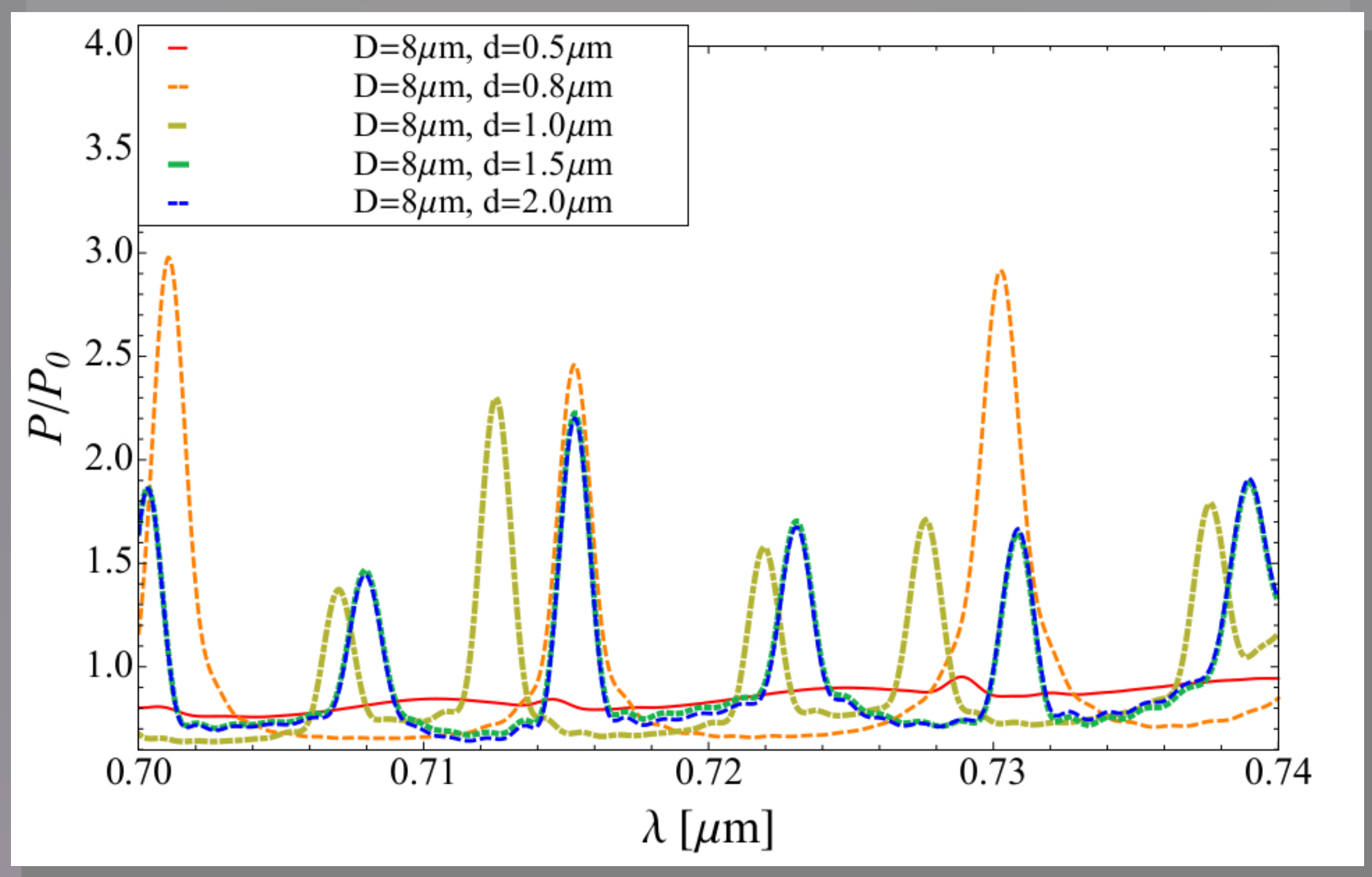

Figure 2 | The WGM power spectra for a diameter of 8µm for a range of shell thicknesses.

- The WGM power spectra in Fig. 2 exhibit little change for larger shell thicknesses. For d<1.5µm there is a significant shift in the peak positions and free spectral range. For d=0.5µm there is a rapid loss of Q-factor as the microbubble is less able to sustain WGMs.

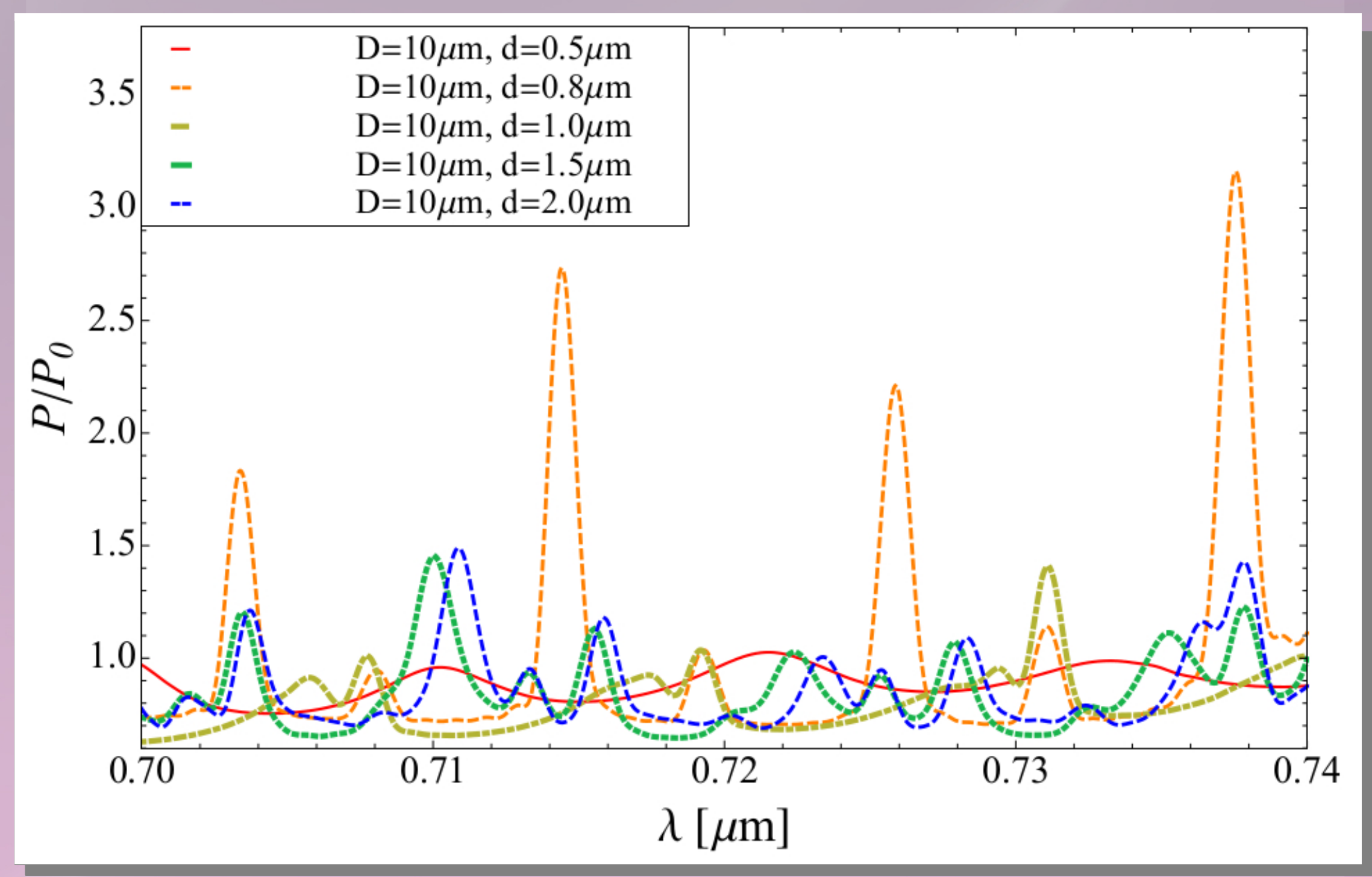

Figure 3 | The WGM power spectra for a diameter of 10µm for a range of shell thicknesses.

- For a larger diameter of 10µm (Fig. 3), the free spectral range is smaller, and the peak positions begin to shift at larger shell thicknesses. For d=0.5µm there is still loss of Q-factor.
- By examining a range of diameters and shell thicknesses, a WGM spectrum can be generated that exhibits the same free spectral range as the silica microbubble experimental results.

- The free spectral ranges for a range of shell thicknesses, *d,* are shown in Fig. 4 vs. diameter. For each value of *d*, a diameter can be found for which the experimental FSR is reproduced.
- Figure 5 shows the fitted simulation spectrum against the experimental WGM spectra. The positions of the dominant modes match, with the simulation predicting a larger Q-factor. This may be due to neglected scattering and absorption losses in the simulation, and deviation from perfect sphericty in experiment.

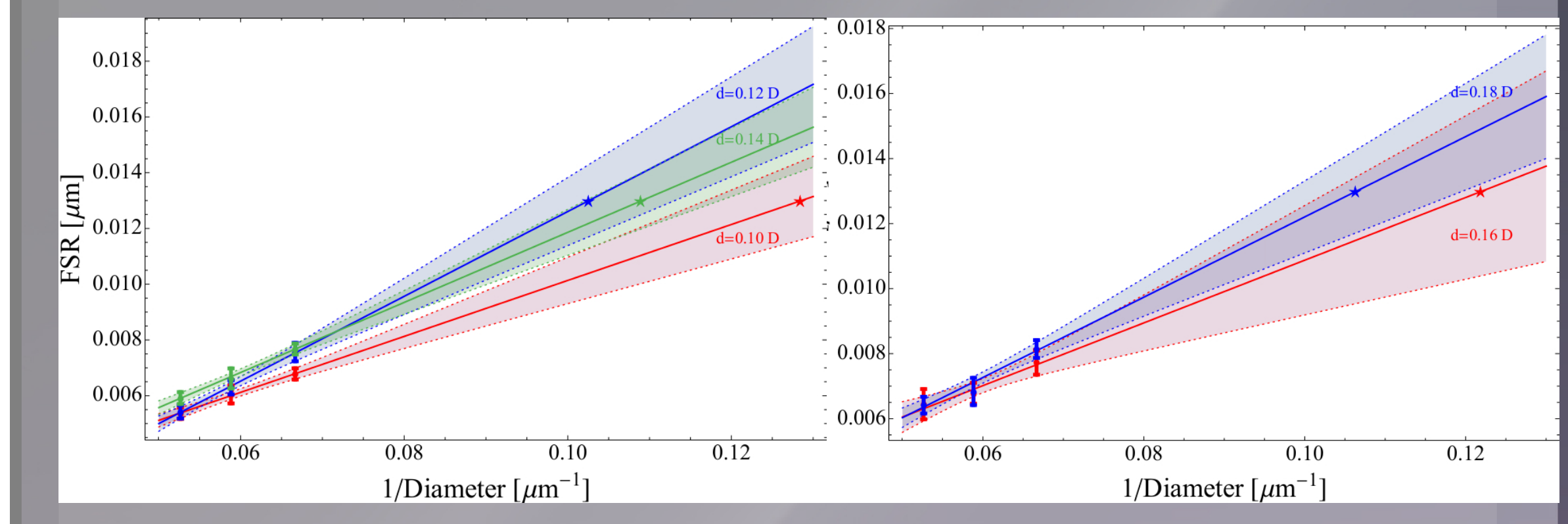

Figure 4 | The behaviour of the free spectral range as a function of 1/D for a variety of shell thicknesses. The stars indicate the experimental value.

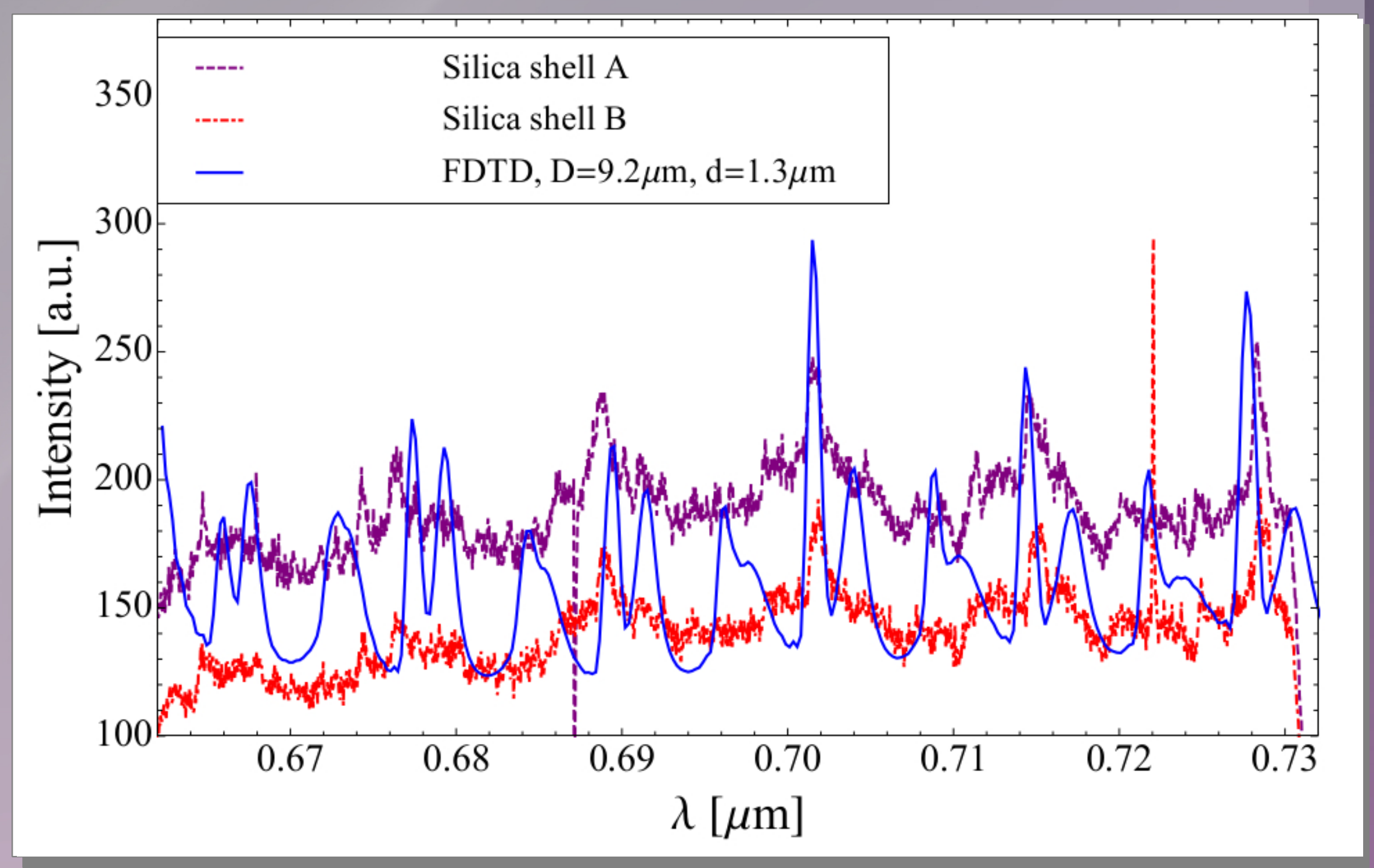

Figure 5 | The WGM simulation spectrum shown against experimental spectra of silica microbubbles.

Conclusion

- The WGM spectra of microbubbles exhibit deviations in mode positions, free spectral range and Q-factor for small shell thicknesses.
- The FDTD approach can be used obtain the geometric parameters (diameter and shell thickness) of a given microbubble of known refractive index, and reproduce its spectrum.

References

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