Improving the sensitivities and detection limits of fluorescence-based refractometric sensors

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Introduction

Refractometric sensors detect small changes in the refractive index (RI) of an analyte fluid. In microfluidics, they can be used for biosensing via chemical functionalization of the sensor surface.

My project goal is to improve the performance of our fluorescence-based microcapillary refractive index sensors.

An ideal sensor:

- **High sensitivity:** large response to changes in local RI
- **Excellent resolution:** can detect small spectral shifts

$$\text{Detection Limit (DL)} = \frac{\text{Resolution}}{\text{Sensitivity}}$$

Key results

Better resolution:
Full analysis of 2D spectral images improves resolution by a factor of 5.5.

Higher sensitivity:
Better control over device fabrication can improve the sensitivity by a factor of 5.

Microcapillary RI sensors

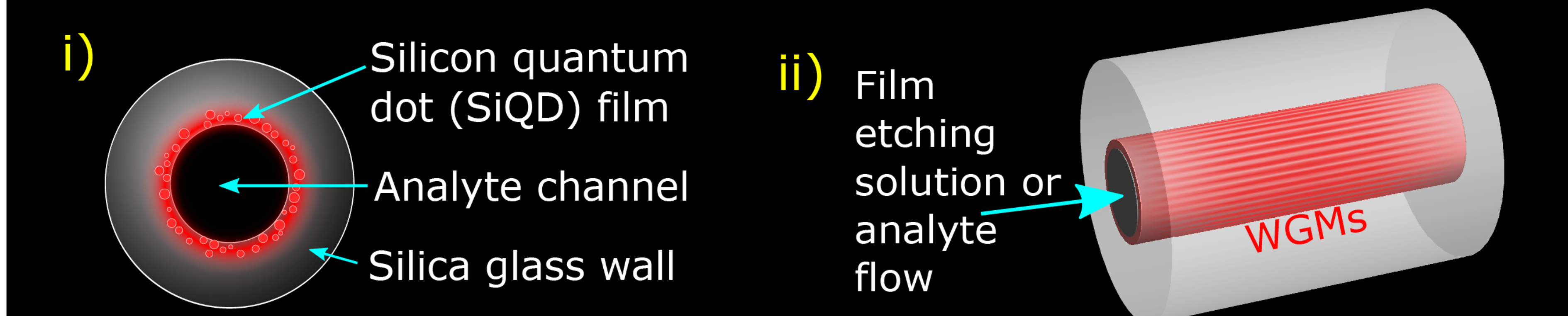
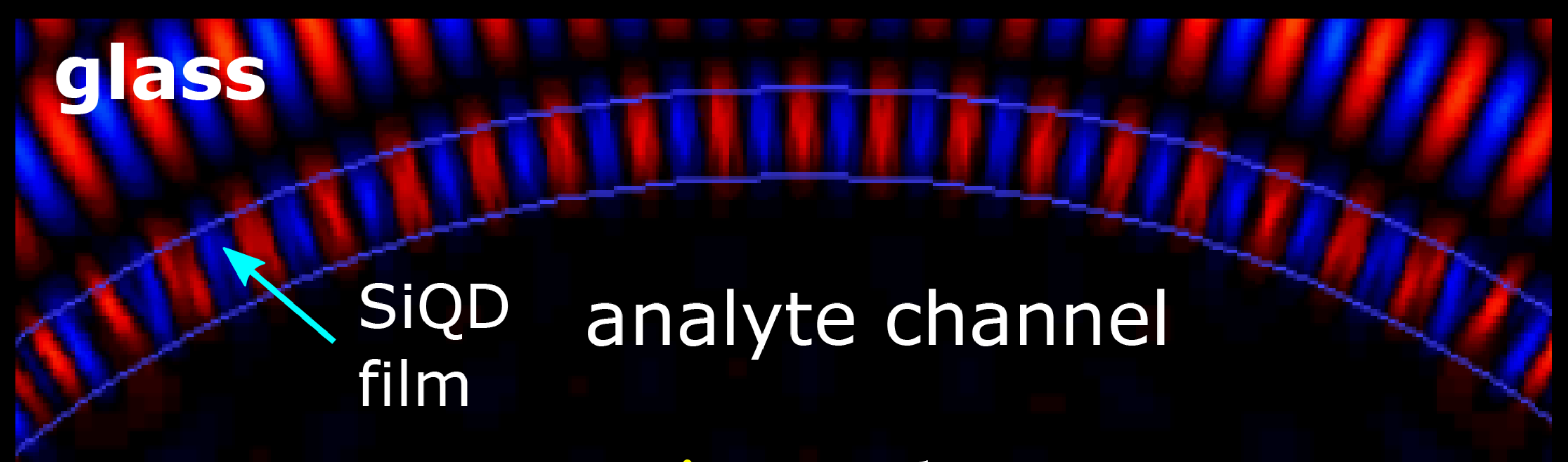


Fig. 1 End-on (i), side (ii) views of a fluorescent-core microcapillary. Sensitivity is measured for different SiQD film thicknesses.

Whispering gallery modes



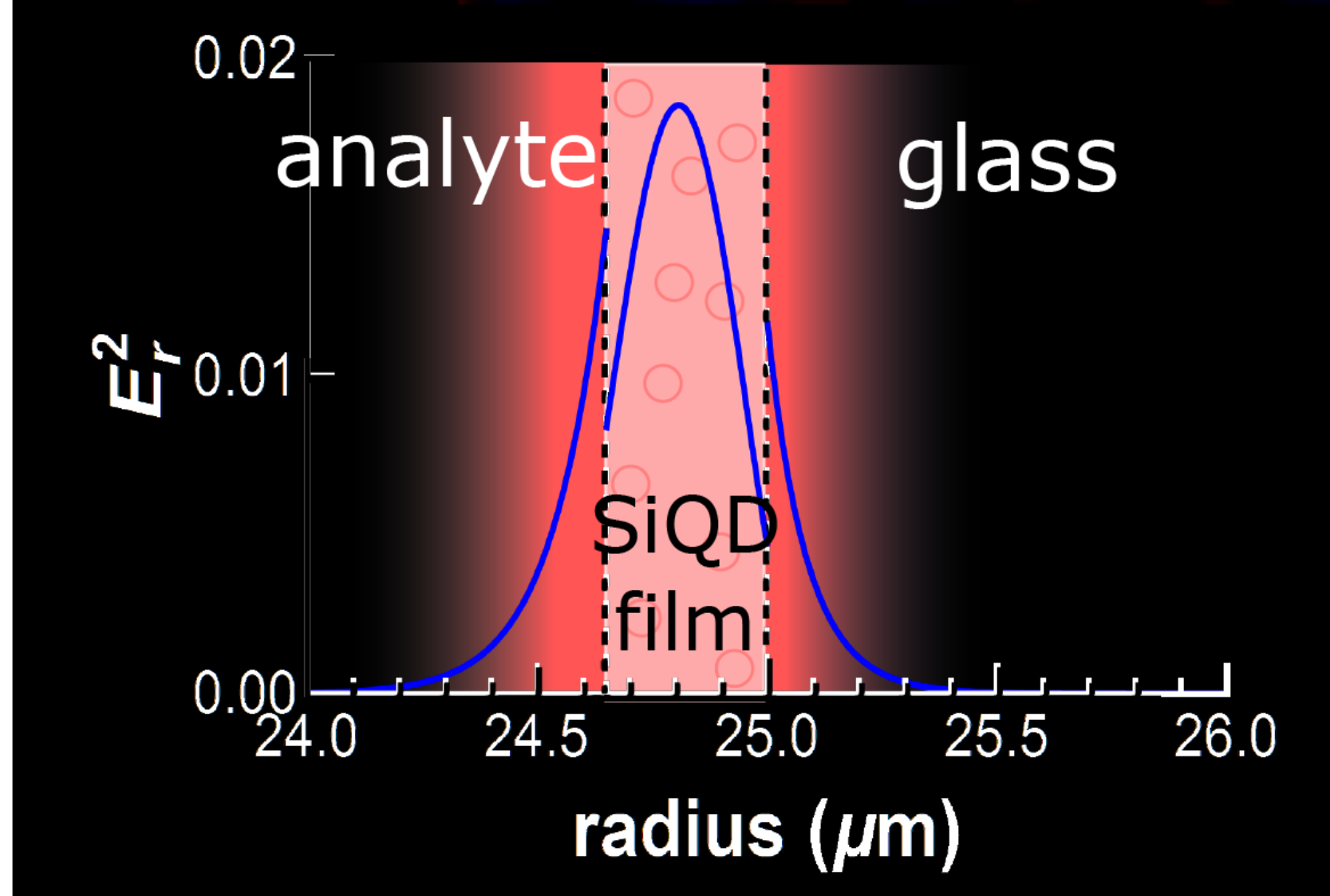


Fig. 2 Fluorsecence in a circular dielectric can resonate in whispering gallery modes (WGMs) . Above: Simulation of electric field, zoomed in. Left: WGMS are confined to the SiQD film. Some of the electric field extends into the analyte.

Data processing and analysis

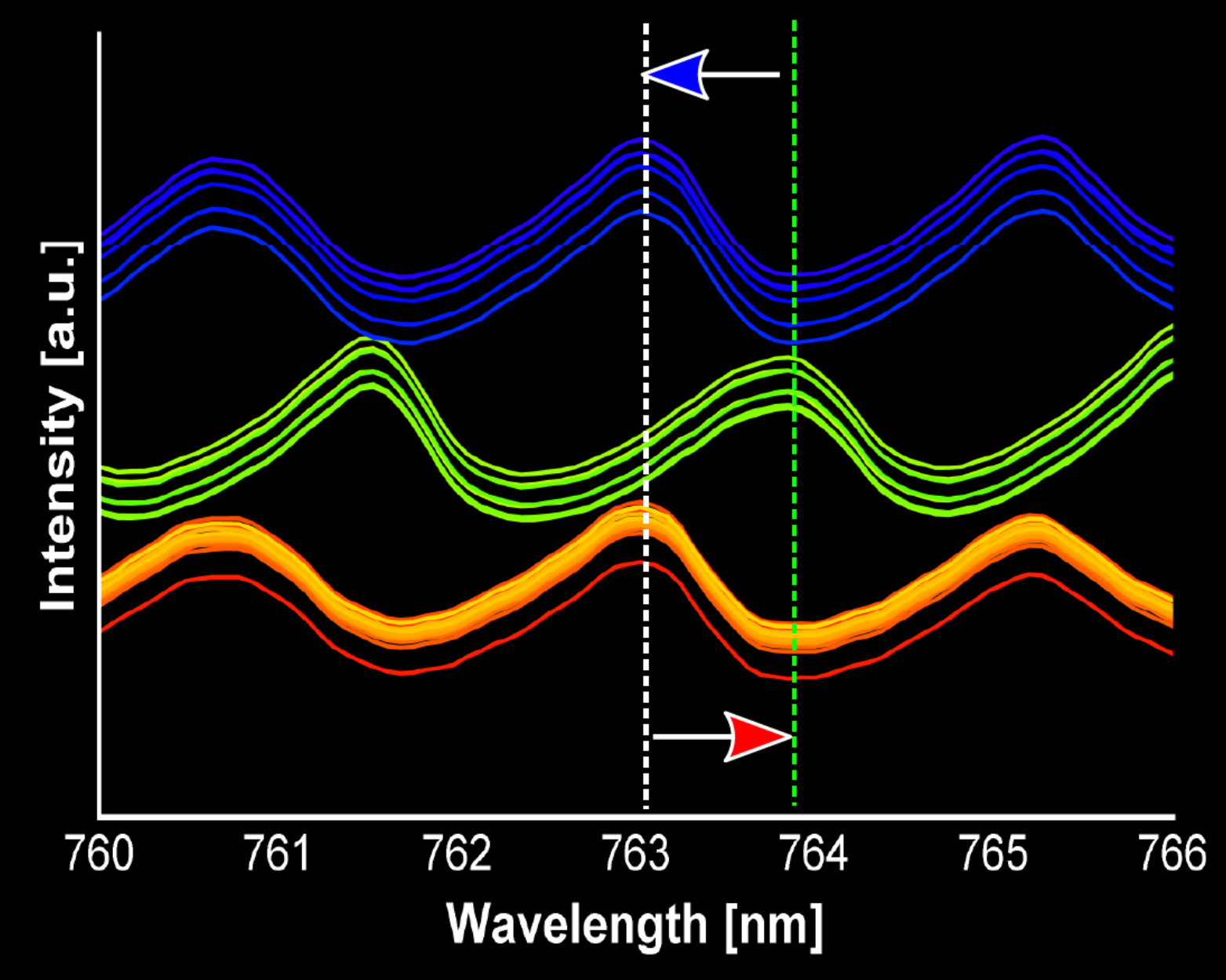
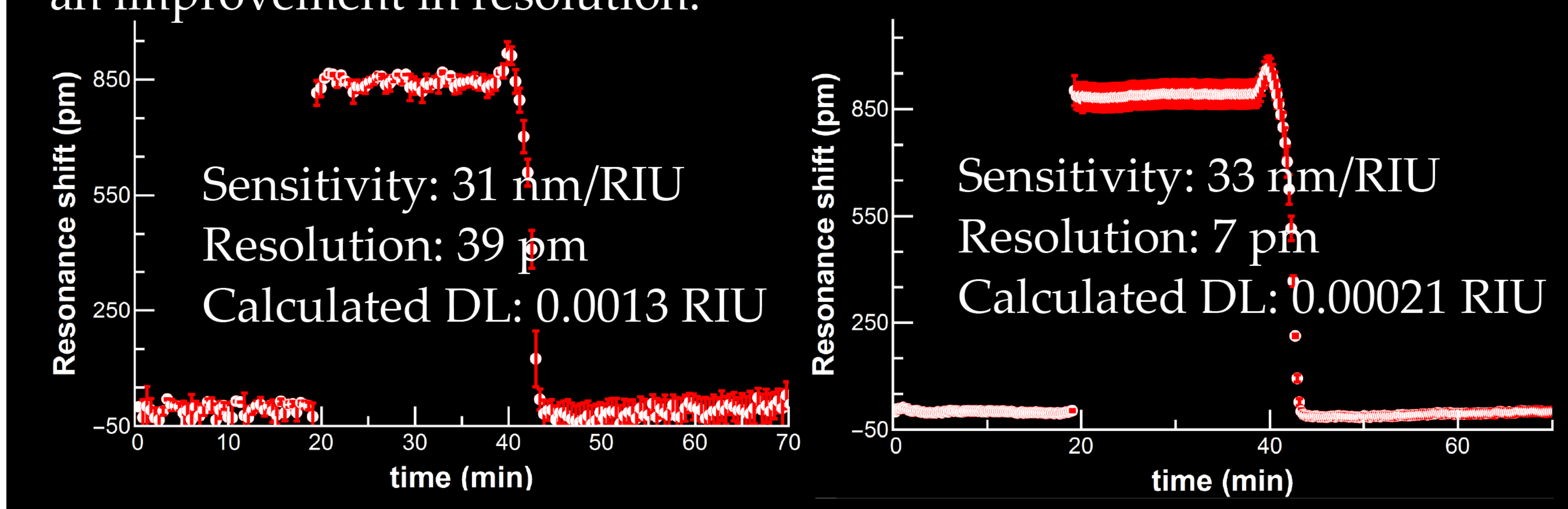


Fig. 3 The resonance wavelength shifts when the RI changes. These shifts can be monitored in sensorgram format (below). Time goes from red waveform up to blue.

Fig. 4 Data of the same 10^{-2} RIU change, processed two ways, yields an improvement in resolution.



Sensitivity: 31 nm/RIU
Resolution: 39 pm
Calculated DL: 0.0013 RIU

Sensitivity: 33 nm/RIU
Resolution: 7 pm
Calculated DL: 0.00021 RIU

i) Single row across CCD. Noisy.

ii) Sum of intensities of each resonance over whole CCD. 5.5 times less noisy.

Numerical predictions

Fig. 5 i) Below: Calculated device sensitivity for different analyte fluids. The optimum film thickness is 0.33 μm for water and ethanol.

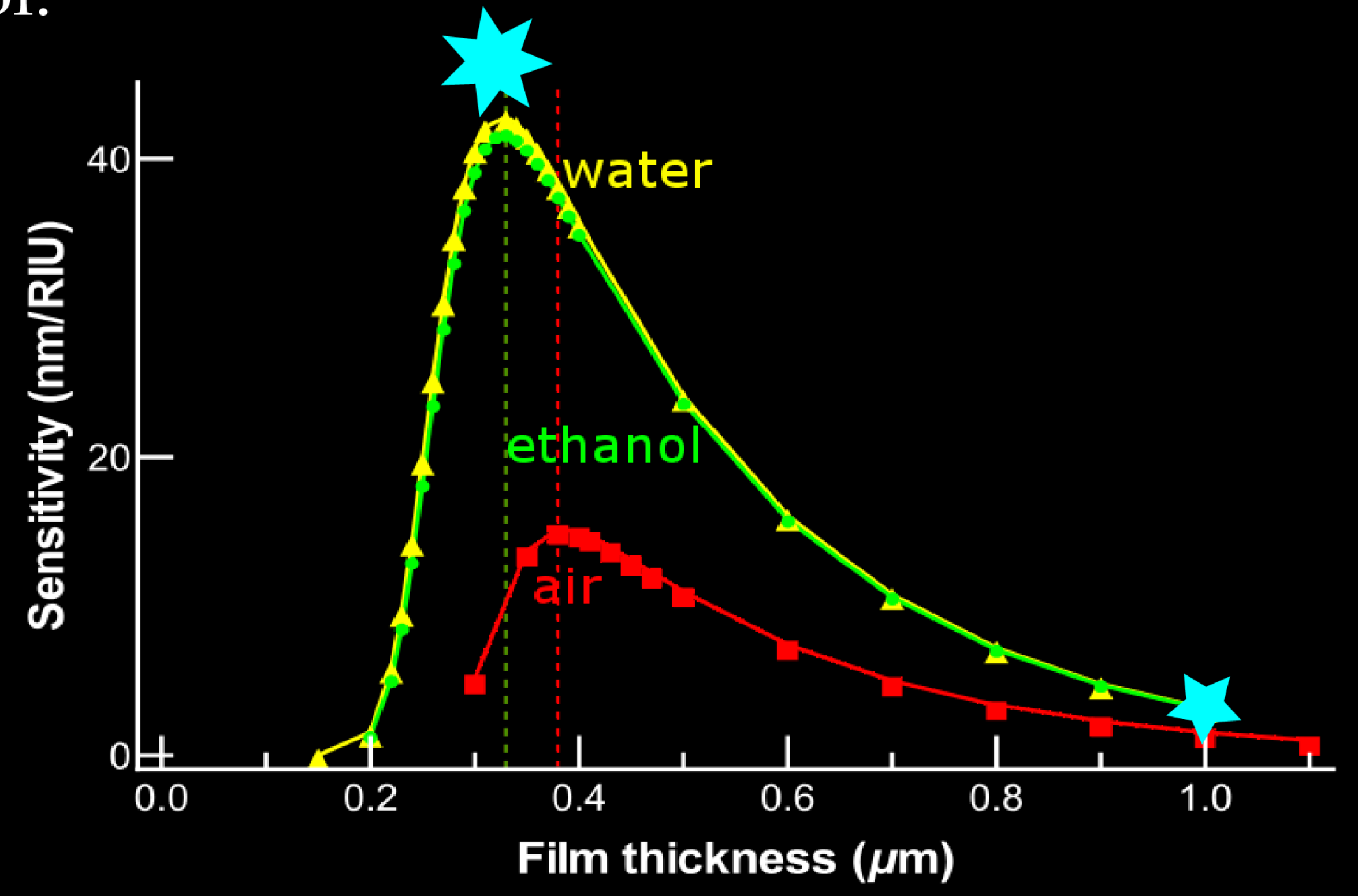
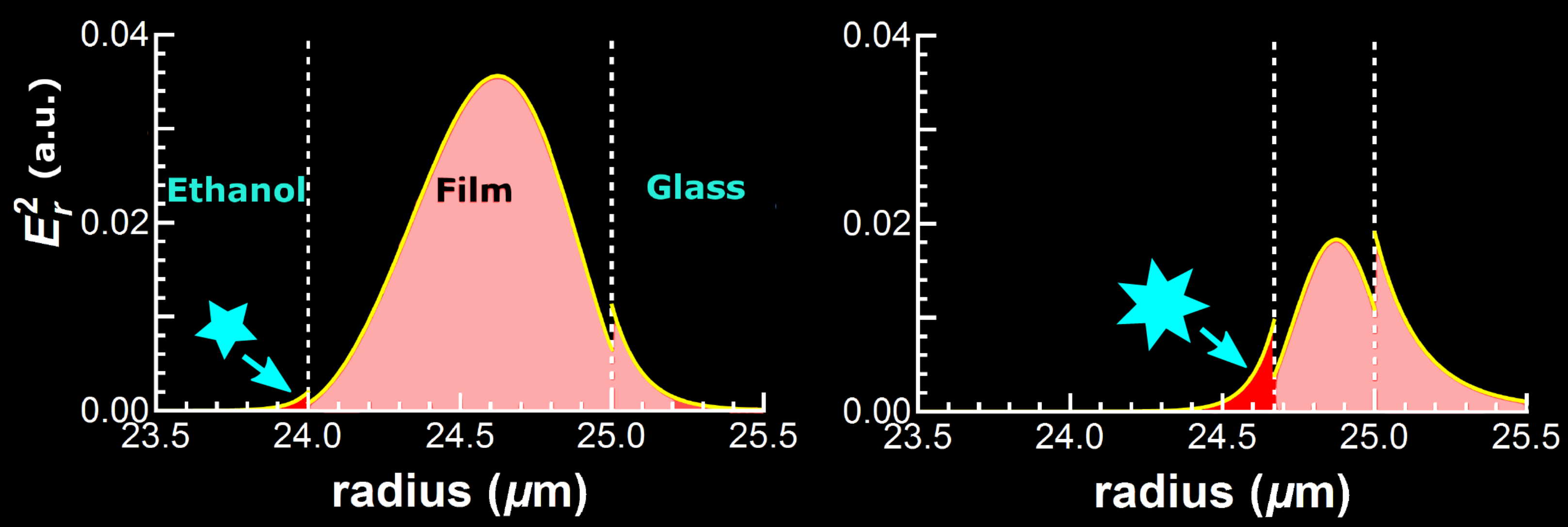


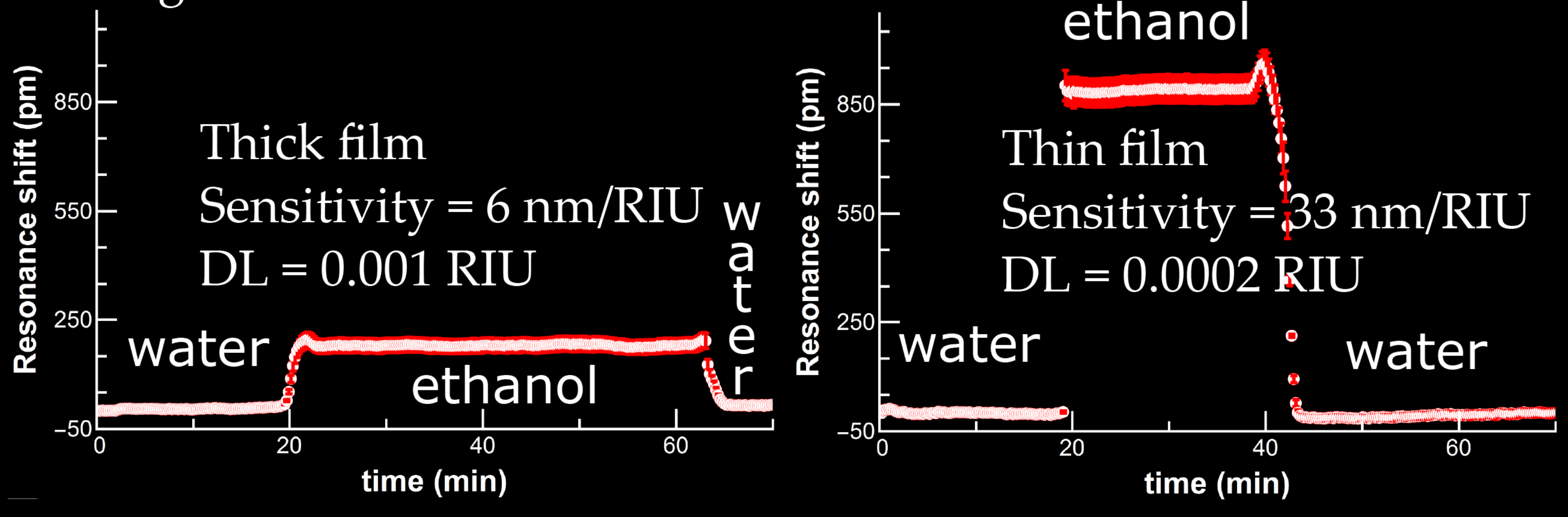
Fig. 5 ii) Below: Calculated electric field profile corresponding to different film thicknesses.



As the blue stars indicate, the portion of the electric field in the analyte grows larger for thinner films, but the cavity Q-factor drops after the peak sensitivity. This means that less of the light is confined and can imply worse perfomance. The optimum film thickness represents the balance between these two mechanisms.

Sensorgrams

Fig. 6 Sensorgrams of the same 10^{-2} RI change before and after etching.



Thick film
Sensitivity = 6 nm/RIU
DL = 0.001 RIU

Thin film
Sensitivity = 33 nm/RIU
DL = 0.0002 RIU

Future work

The next step is to optimize film thickness and pursue lower **measured** detection limits.

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