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High efficiency rare-earth emitter for thermophotovoltaic applications

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Applied Physics Letters 105, 111107 (2014)

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The paper

APPLIED PHYSICS LETTERS **105**, 111107 (2014)

High efficiency rare-earth emitter for thermophotovoltaic applications

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(Received 30 July 2014; accepted 4 September 2014; published online 16 September 2014)

In this work, we propose a rare-earth-based ceramic thermal emitter design that can boost thermophotovoltaic (TPV) efficiencies significantly without cold-side filters at a temperature of 1573 K (1300 °C). The proposed emitter enhances a naturally occurring rare earth transition using quality-factor matching, with a quarter-wave stack as a highly reflective back mirror, while suppressing parasitic losses via exponential chirping of a multilayer reflector transmitting only at short wavelengths. This allows the emissivity to approach the blackbody limit for wavelengths overlapping with the absorption peak of the rare-earth material, while effectively reducing the losses associated with undesirable long-wavelength emission. We obtain TPV efficiencies of 34% using this layered design, which only requires modest index contrast, making it particularly amenable to fabrication via a wide variety of techniques, including sputtering, spin-coating, and plasma-enhanced chemical vapor deposition. *© 2014 AIP Publishing LLC.* [http://dx.doi.org/10.1063/1.4895932]

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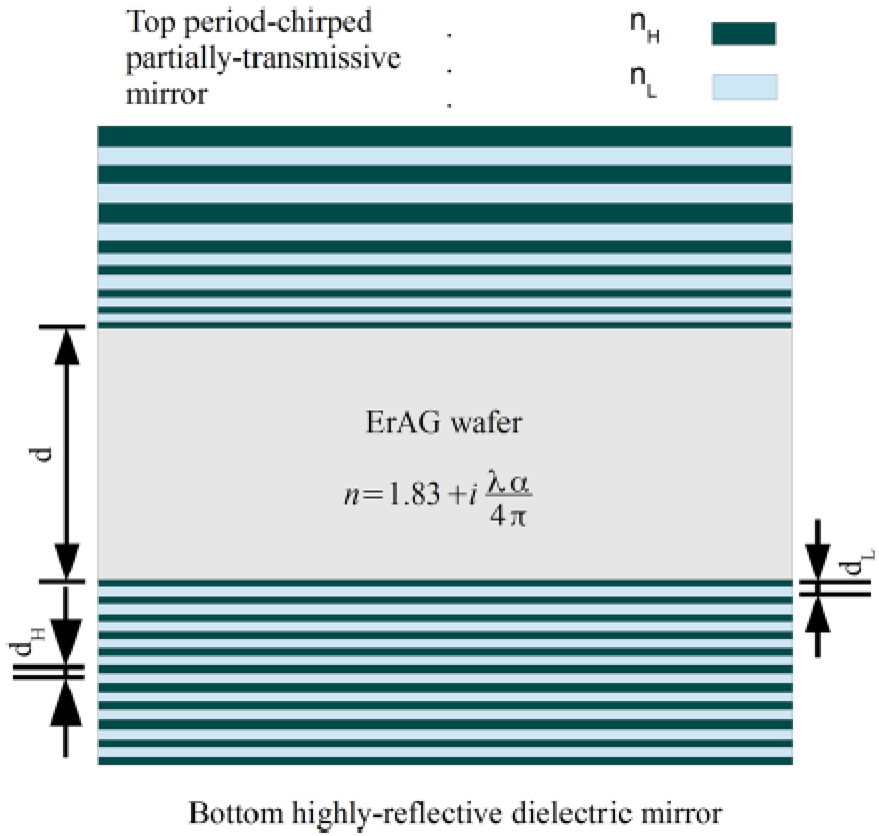
Key results

Studied spectral emissivity and TPV efficiency for a multi-layer rare-earth doped ceramic emitter, such as Erbium Aluminum Garnet (ErAG):

- Effect of adding dielectric mirror as a back reflector instead of refractory metals to reduce parasitic losses.
- Effect of using integrated chirped filter on top to reduce sub-bandgap parasitic losses



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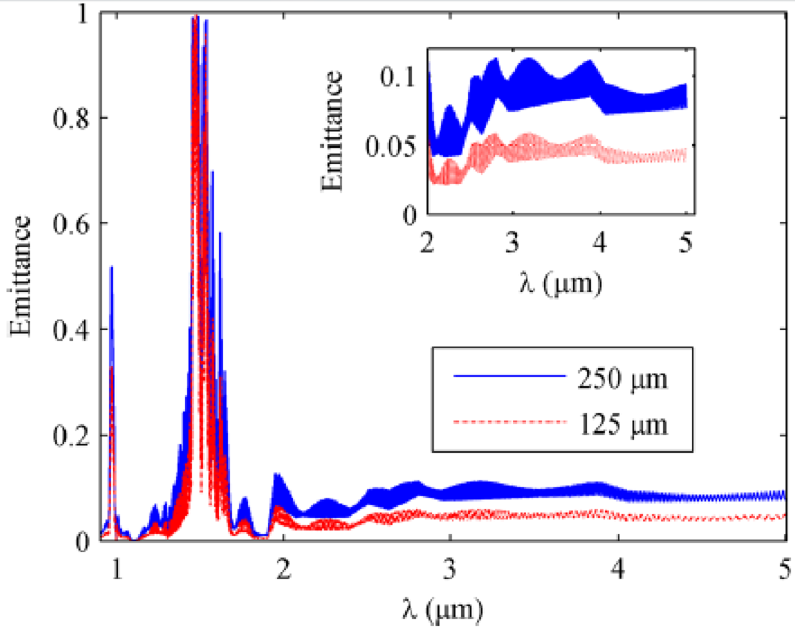
Key results



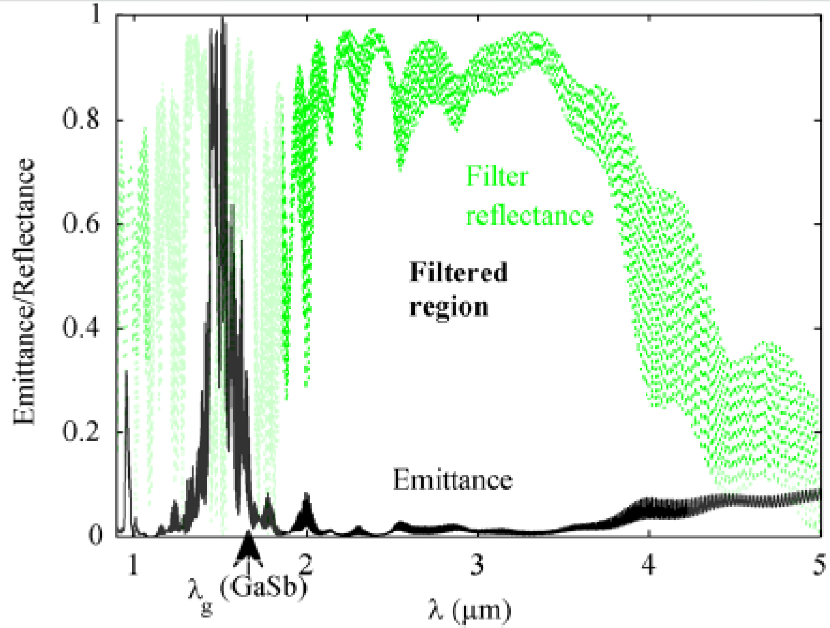
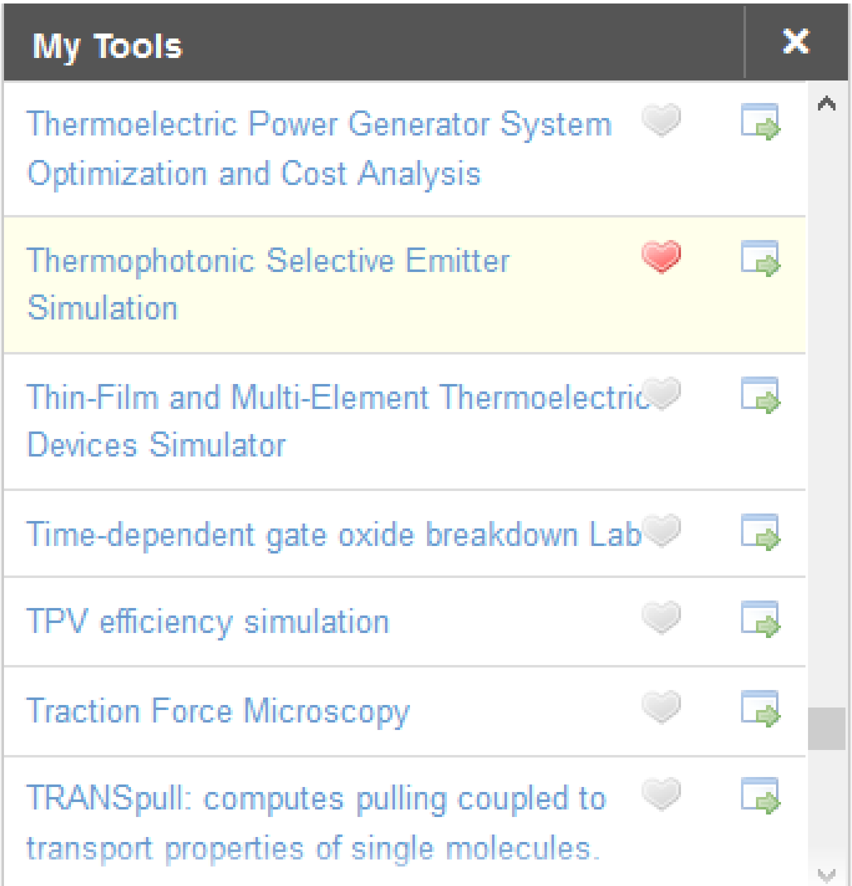


TABLE I. TPV efficiency for different ErAG emitter designs. Although all designs display overall efficiencies higher than seen for metal substrates, the best overall performance comes from the chirped filter + shifted rugate filter at 33.89%.

ErAG emitter	d (μm)	η (%) at 1323 K	η (%) at 1573 K	η_{rad} (%) at 1573 K	$\bar{\varepsilon}$ (%) at 1573 K	Top/bottom layers
AR + rugate filter	125	12.6	19.18	41.4	5.09	1/1
AR + rugate filter	250	12.05	18.63	37	9.26	1/1
Q-matched + rugate filter	125	17	24.32	51.4	6.12	3/21
Q-matched + rugate filter	250	15.34	22.58	44.53	10.44	3/21
Chirped filter + shifted rugate filter	250	25.55	33.89	70.85	6.11	Chirped 26/21
Chirped filter only	250	25.46	32.94	70.85	6.11	Chirped 26/21

The simulation tool



From the tools menu launch "Thermophotonics Selective Emitter Simulation", or simply click https://nanohub.org/tools/tpxsim

About the tool:

TPXsim is a GUI-based tool to calculate the emittance spectrum using the S-matrix approach and TPV system efficiency for a rare earth-based multi-layer structure emitter.

Learn more:

- Bermel, Peter, et al. "Design and global optimization of high-efficiency thermophotovoltaic systems." *Optics express* 18.103 (2010): A314-A334.
- S4: Stanford Stratified Structure Solver
- https://nanohub.org/tools/s4sim

What we will do

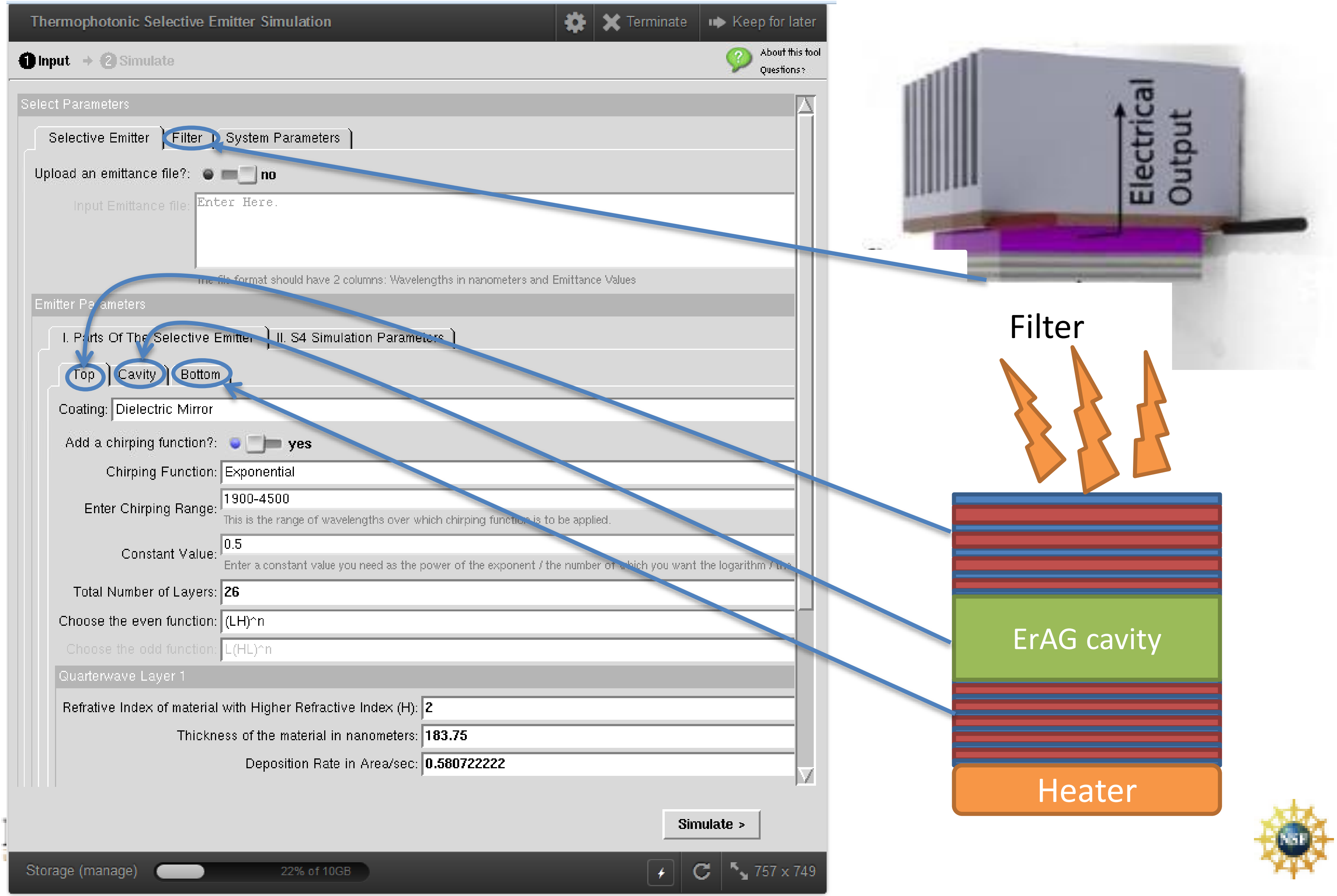
Objective

We will compute the emittance spectrum, the radiation efficiency and the TPV efficiency for the different structures mentioned in the paper.

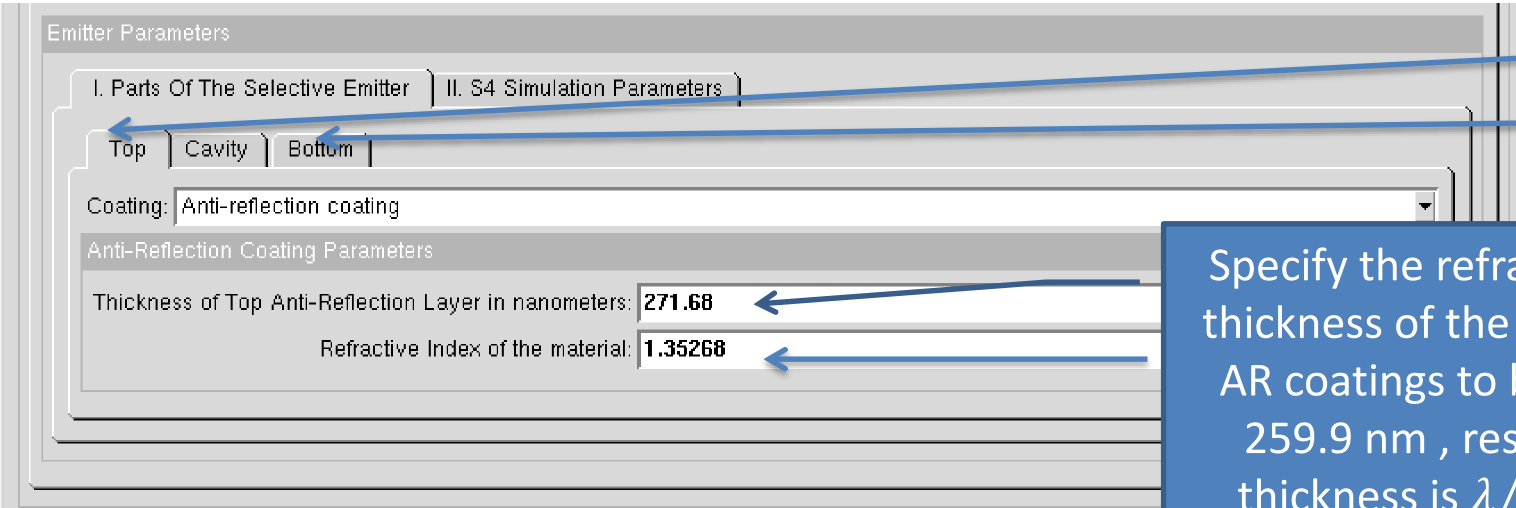
Approach

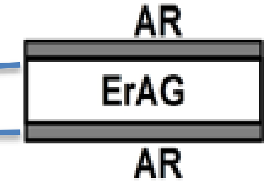
- We will describe the selected structure using the GUI.
- Perform an optical simulation to obtain the absorption spectrum which is the same as the emittance spectrum according to Kirchhoff's law of thermal radiation.
- Perform electrical simulation to obtain a theoretical estiamtion of the TPV system efficiency.

An overview of the tool

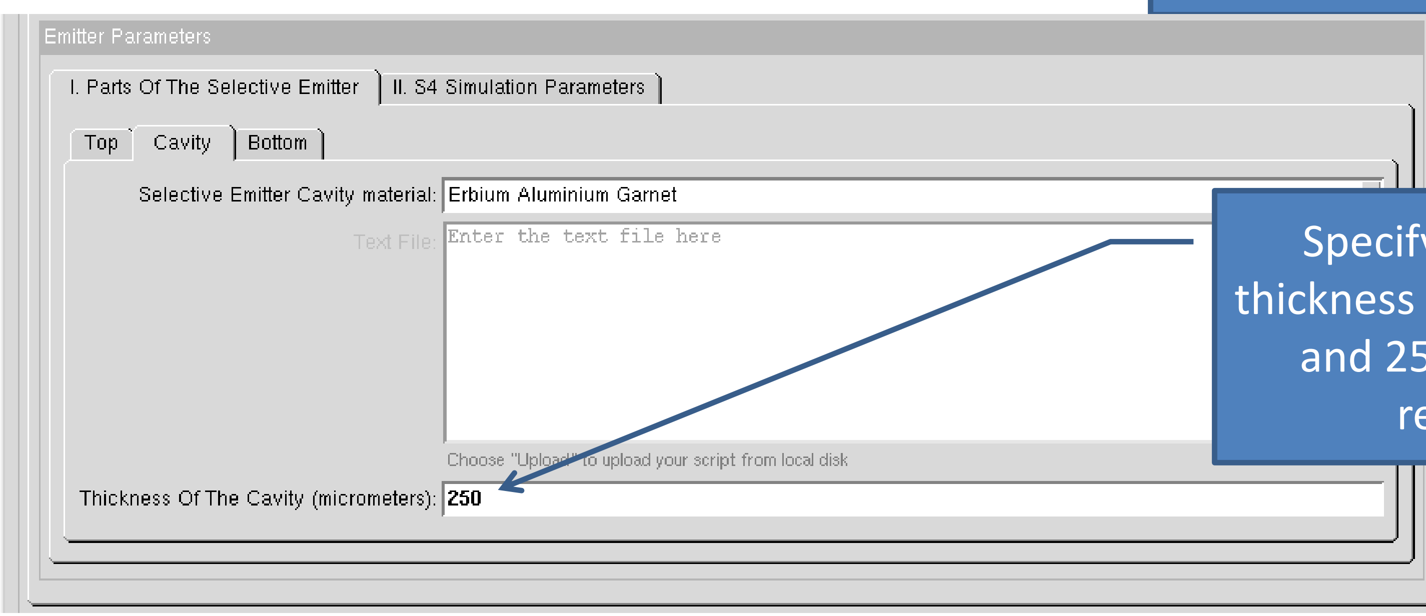


ErAG emitter with AR coatings



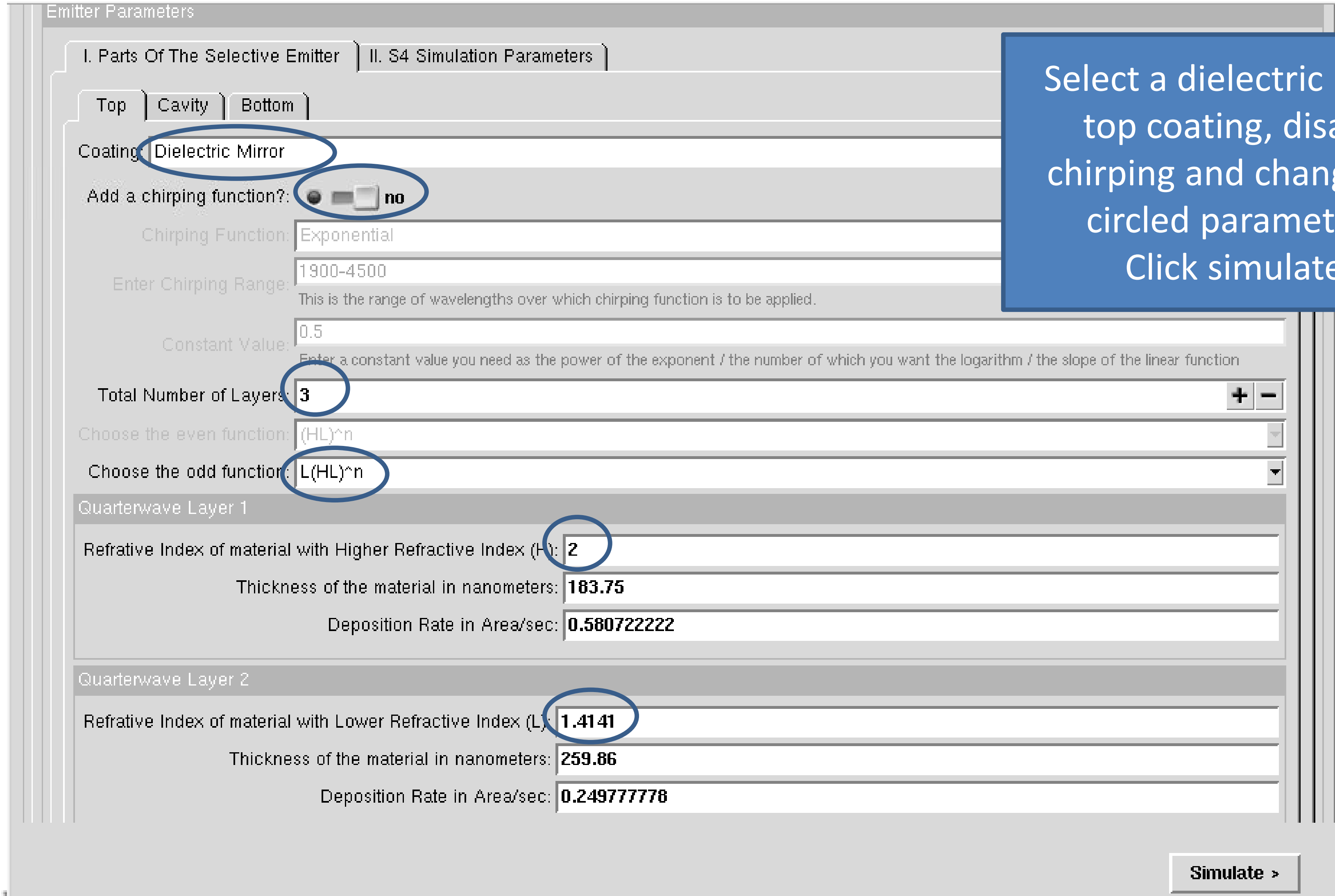


Specify the refractive index and thickness of the top and bottom AR coatings to be 1.35268 and 259.9 nm , respectively. The thickness is $\lambda/4$ at 1470 nm.



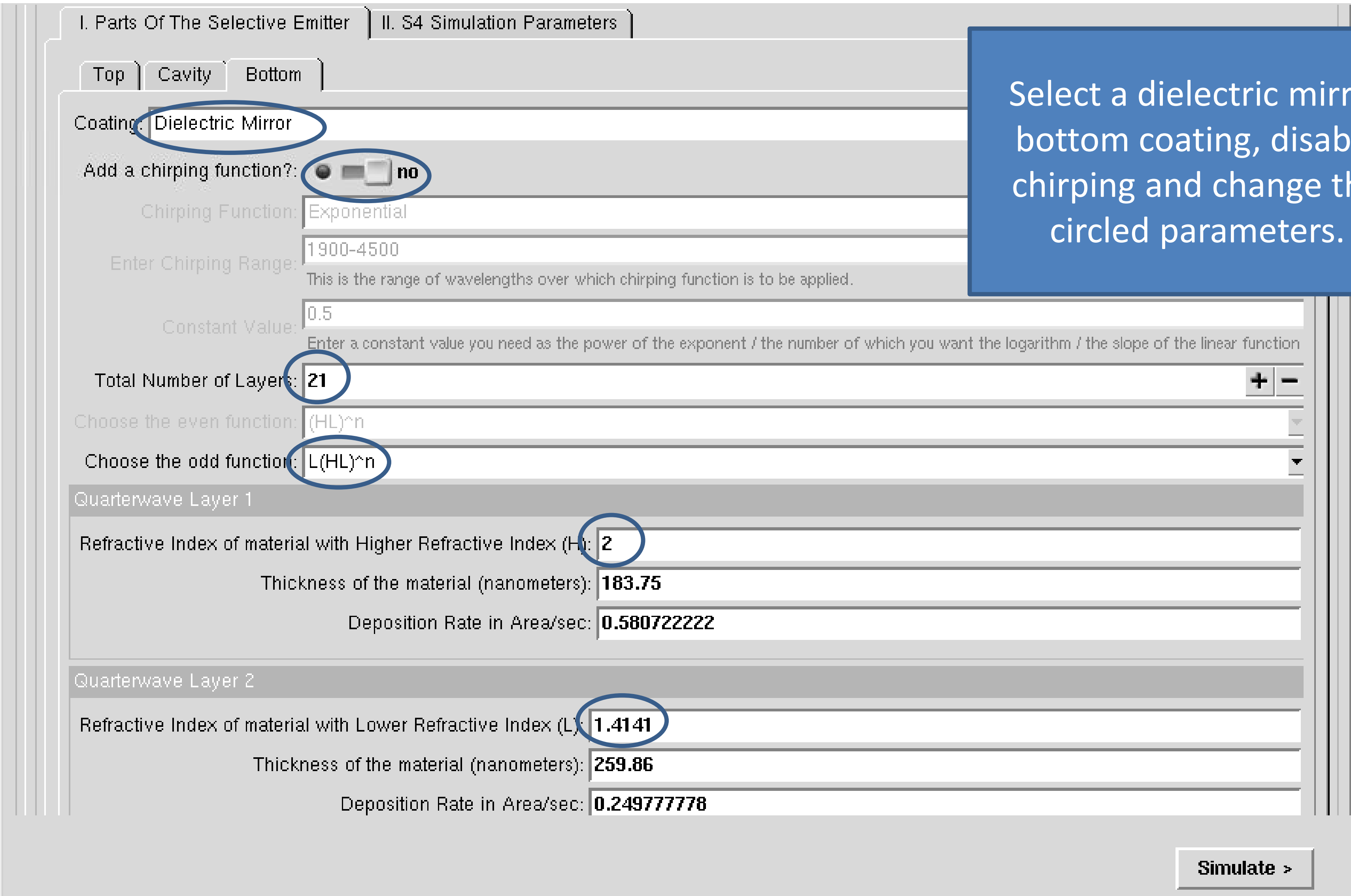
Specify the ErAG cavity thickness in micrometers (125 and 250 for cases 1 & 2 respectively).

Q-matched ErAG emitter



Select a dielectric mirror top coating, disable chirping and change the circled parameters. Click simulate.

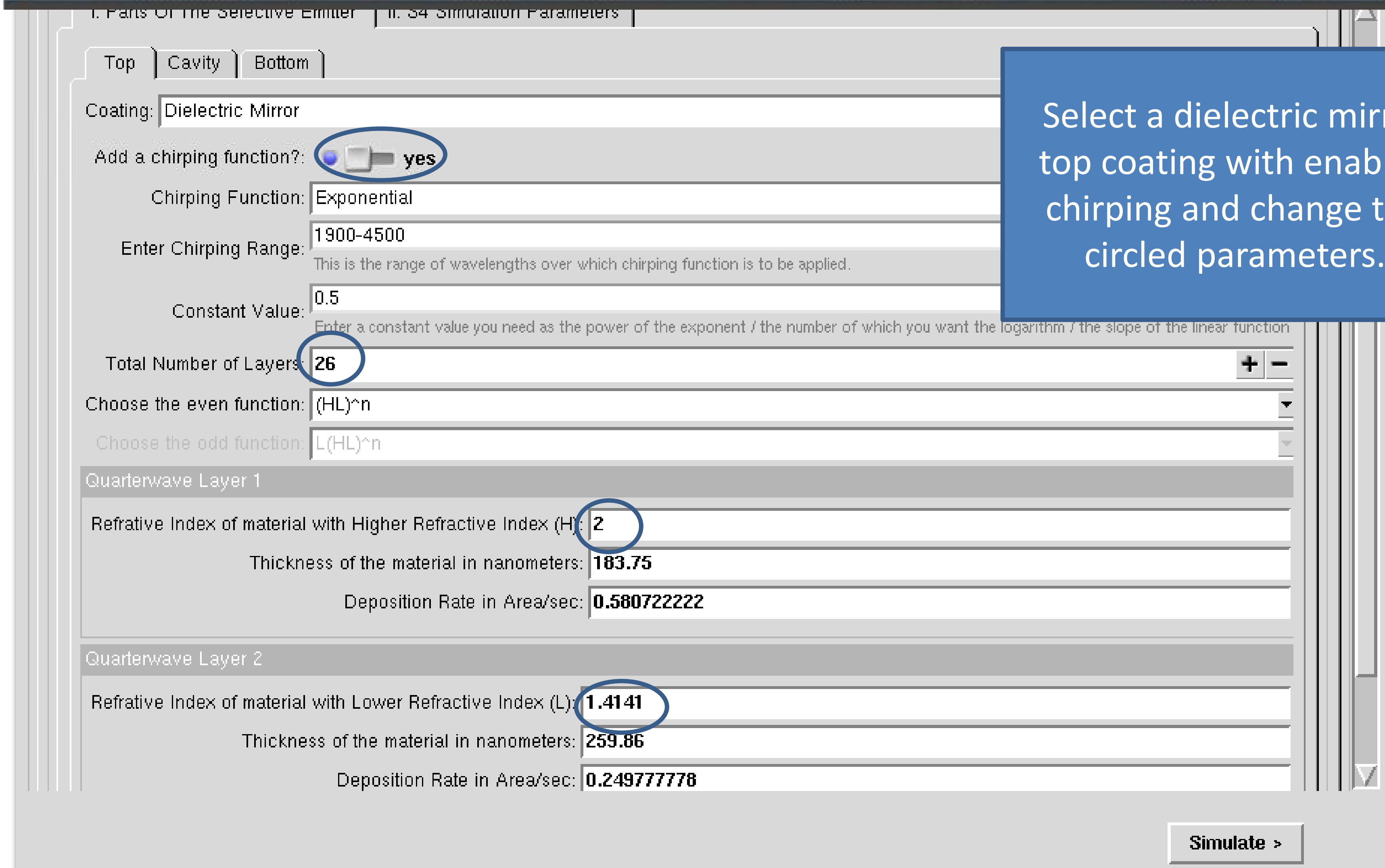
Q-matched ErAG emitter



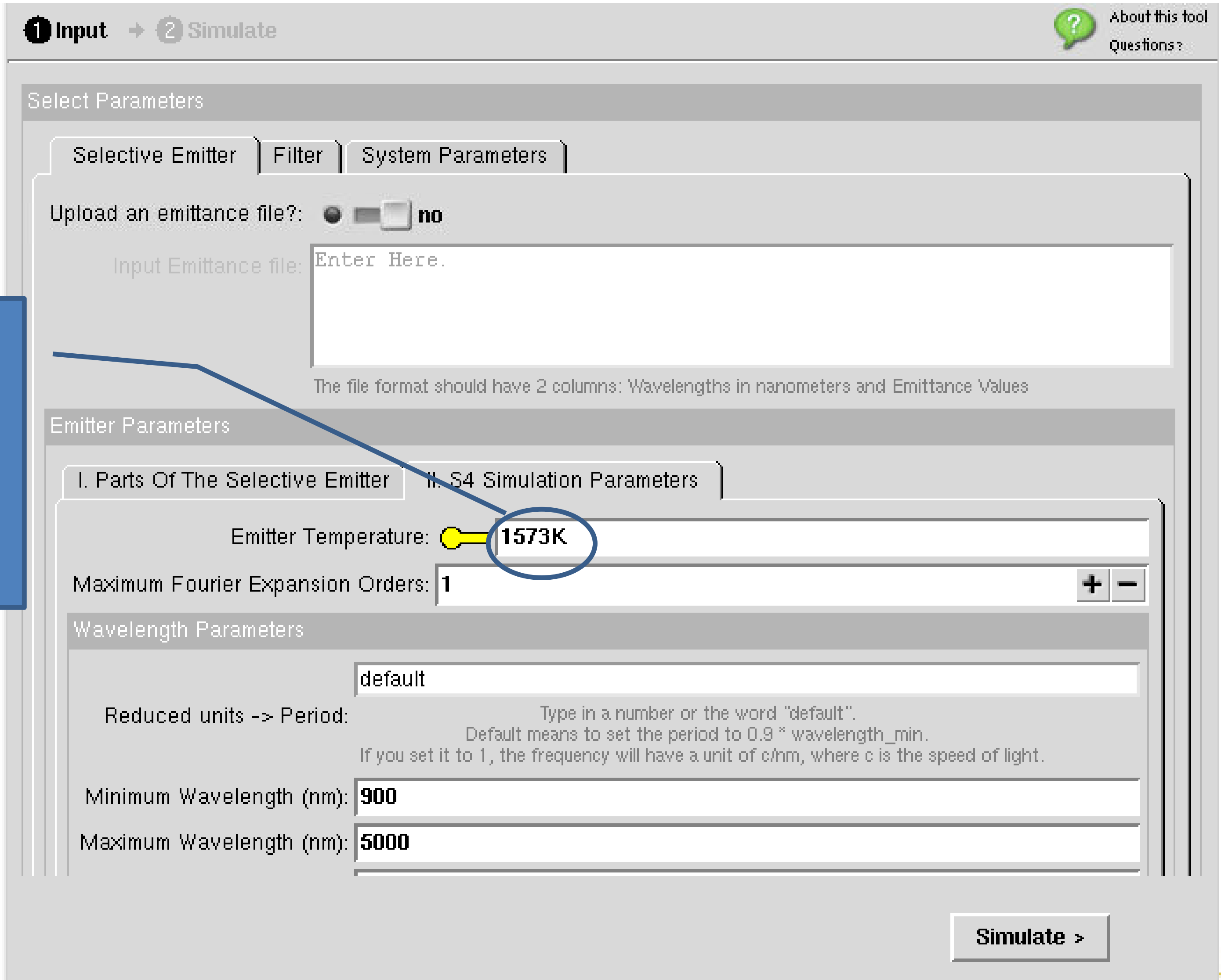
Select a dielectric mirror bottom coating, disable chirping and change the circled parameters.

Chirped ErAG emitter

Select a dielectric mirror top coating with enabled chirping and change the circled parameters.

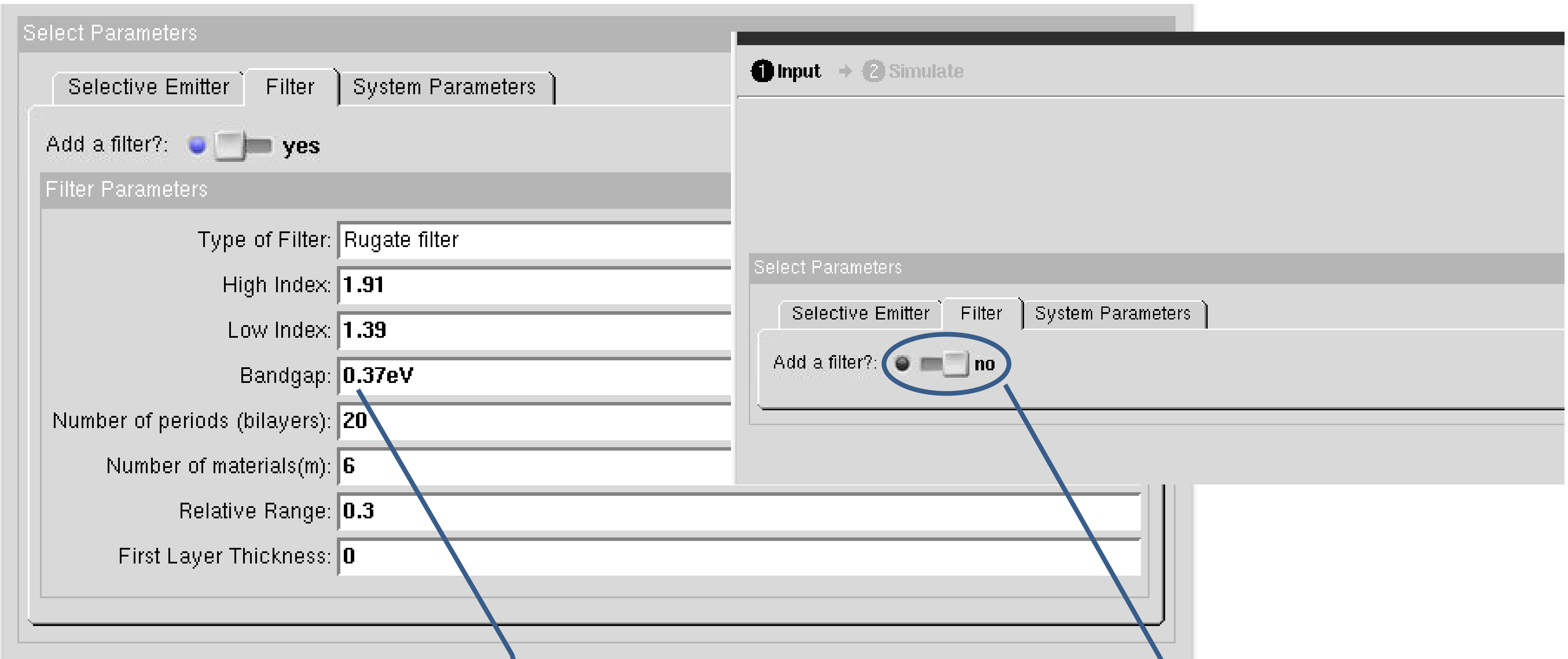


Specify the emitter temperature



Try different emitter temeratures e.g. 1573 K and 1323 K

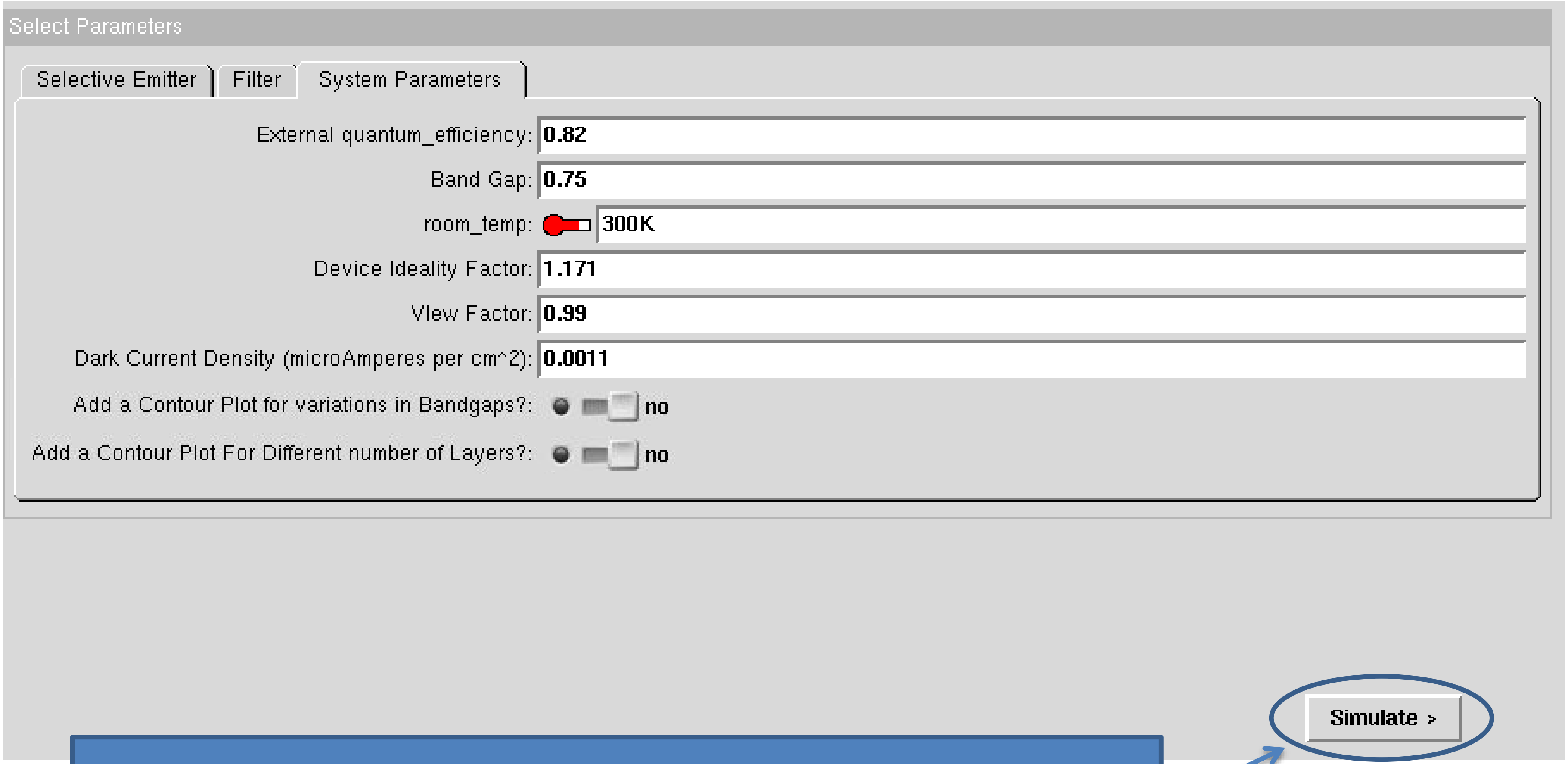
Remove or control the rugate filter



Shift the rugate filter bandgap to 0.37 eV and keep other parameters to their default values

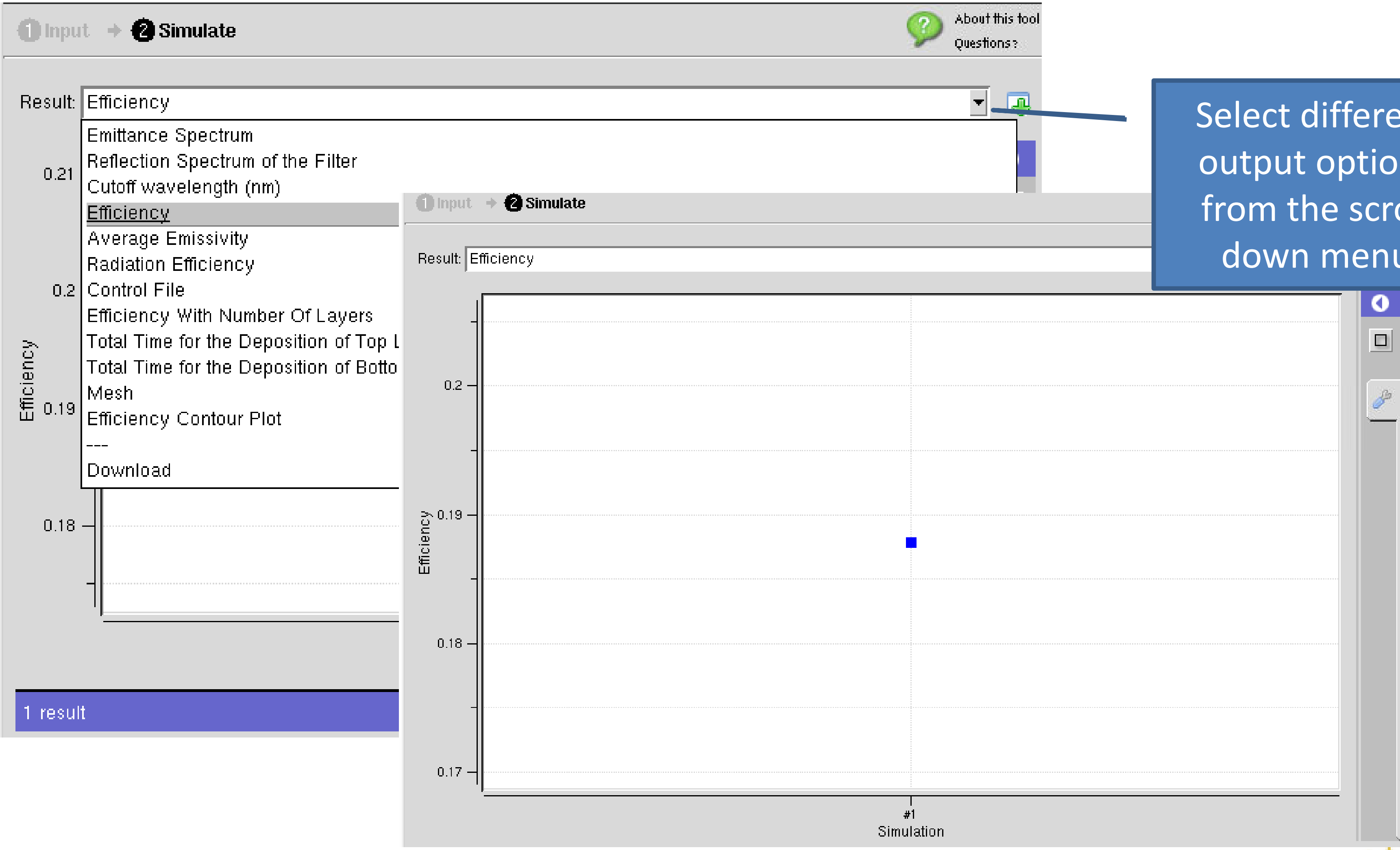
Enable /disable the rugate filter

Specify system parameters



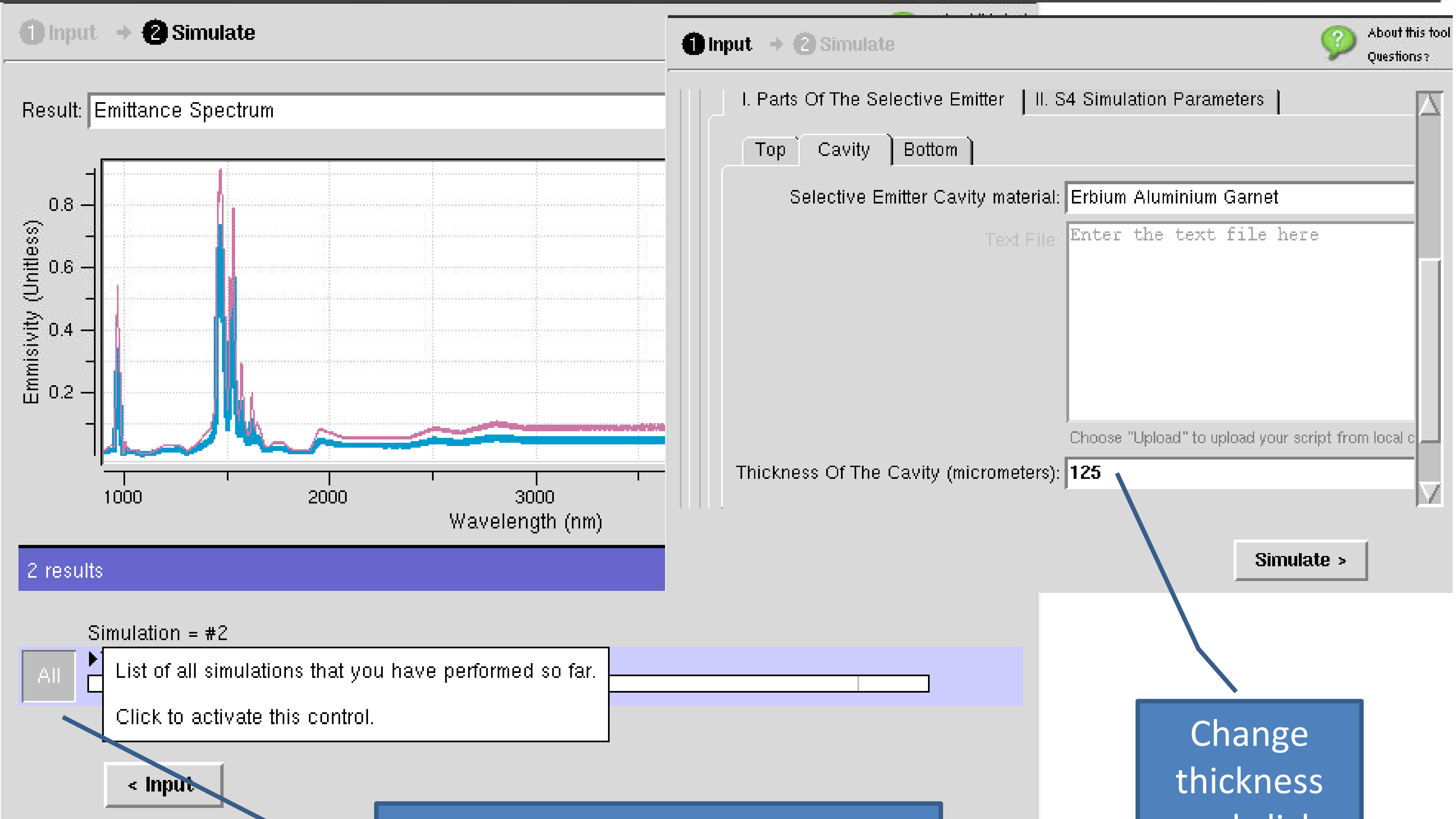
Use the default values of system parameters and click simulate

Simulation Results



Select different output options from the scroll down menu

Change ErAG thickness



Click all to view multiple outputs on a single graph

Change thickness and click simulate

Compare with predictions

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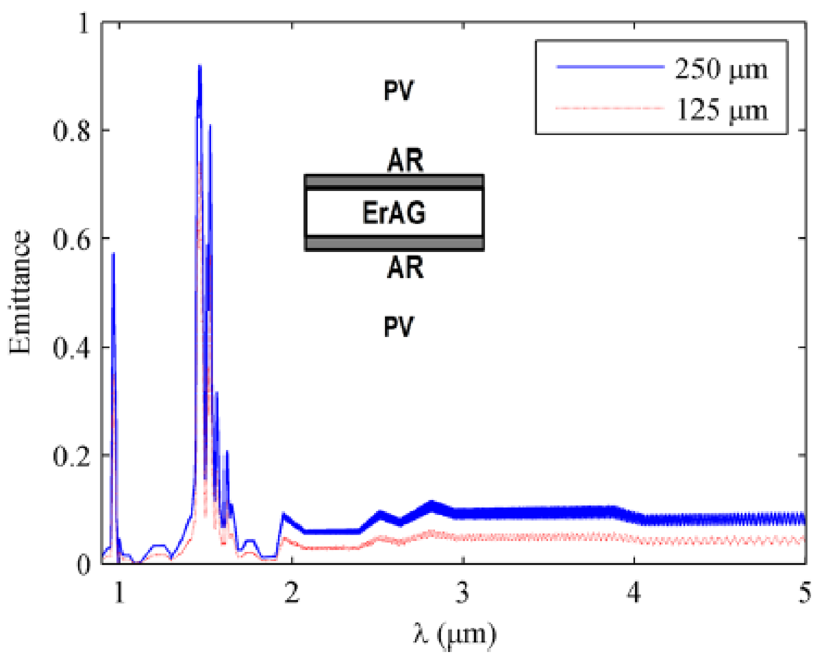
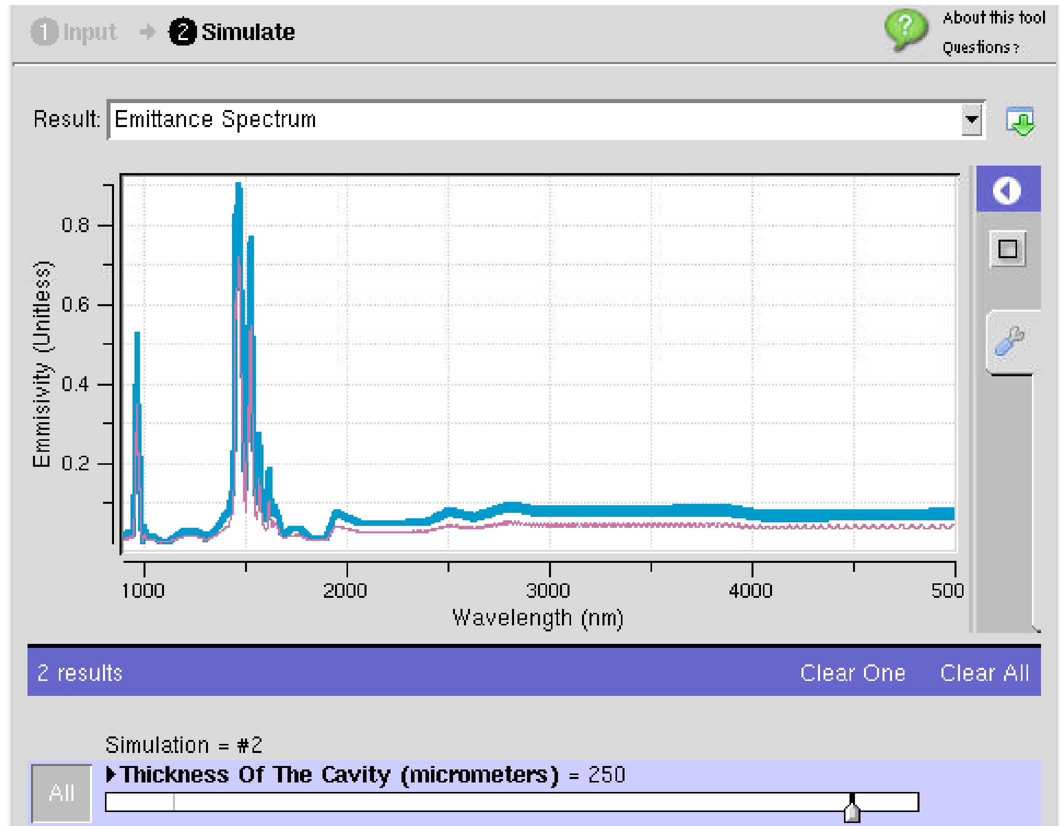
Emittance spectrum





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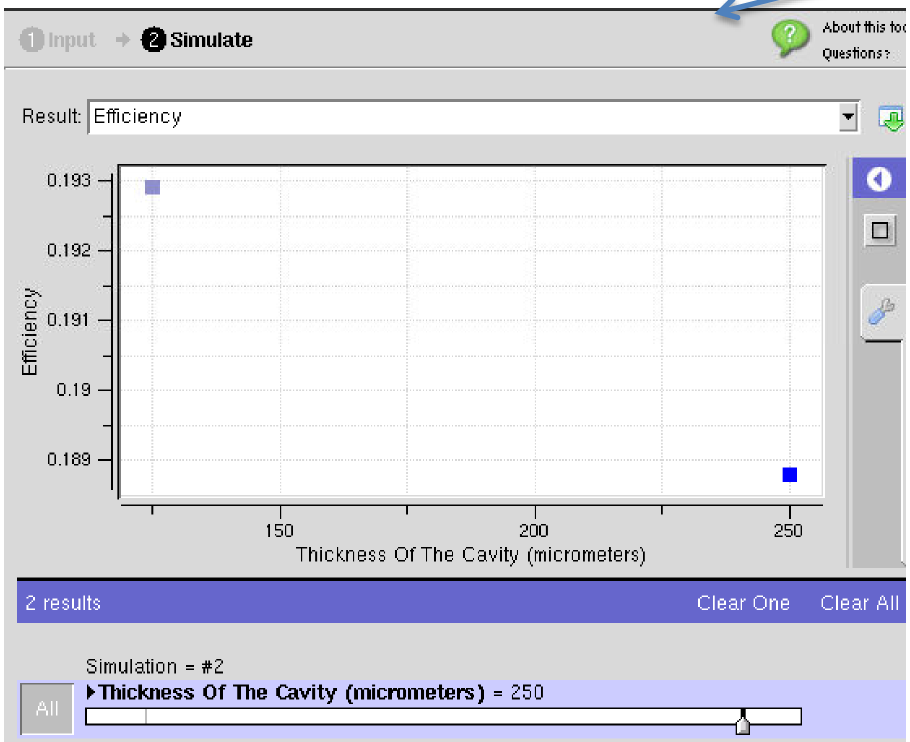

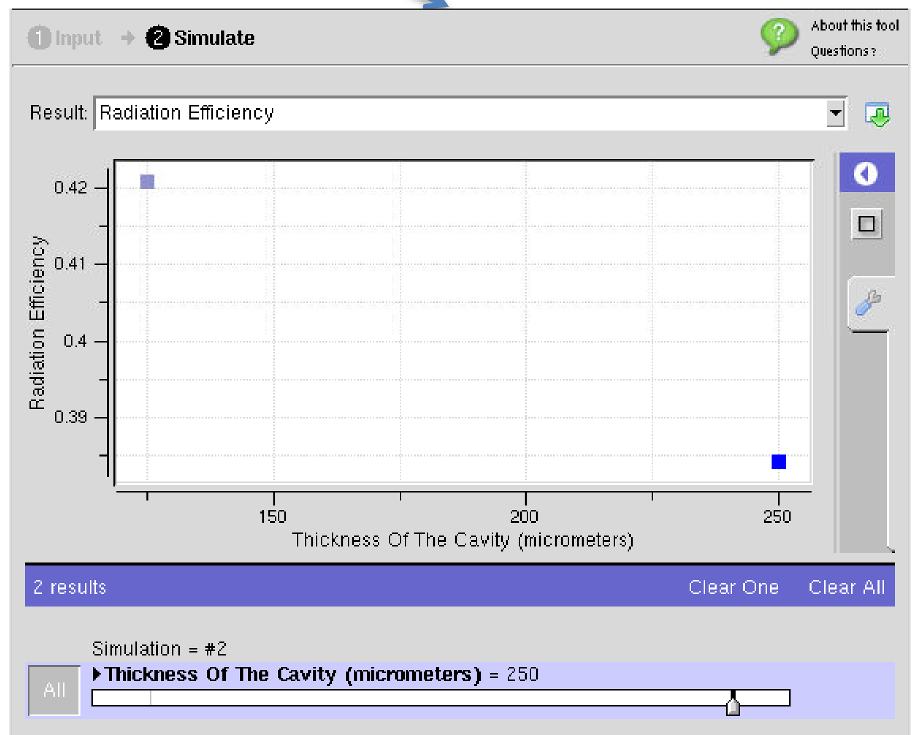

The small discrepancy is because the tool does implement a random change in the layers thicknesses as deduced from experimental evidence

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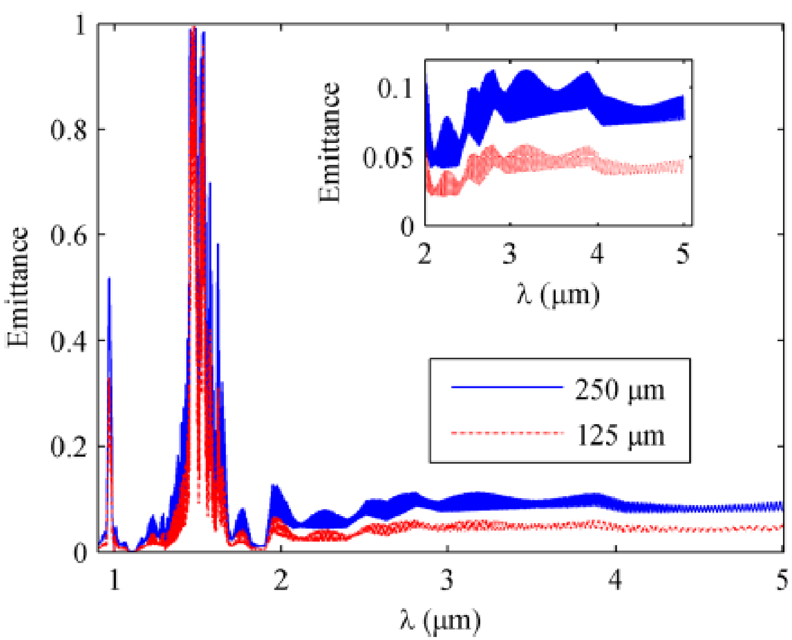

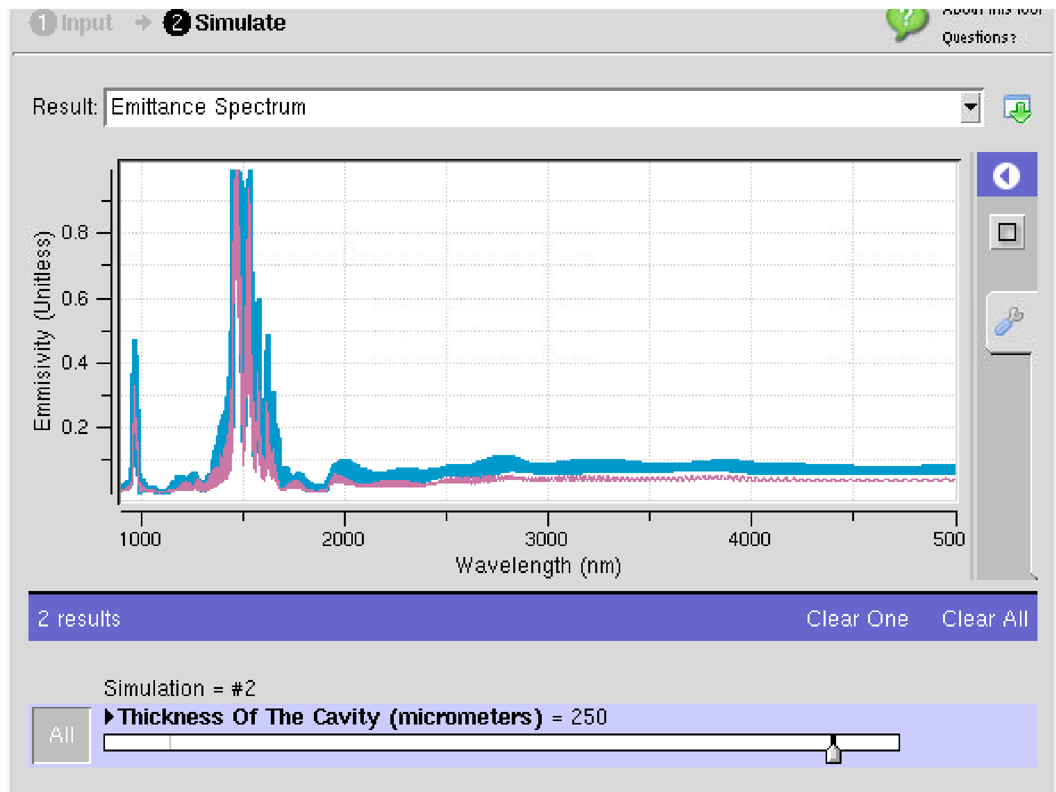

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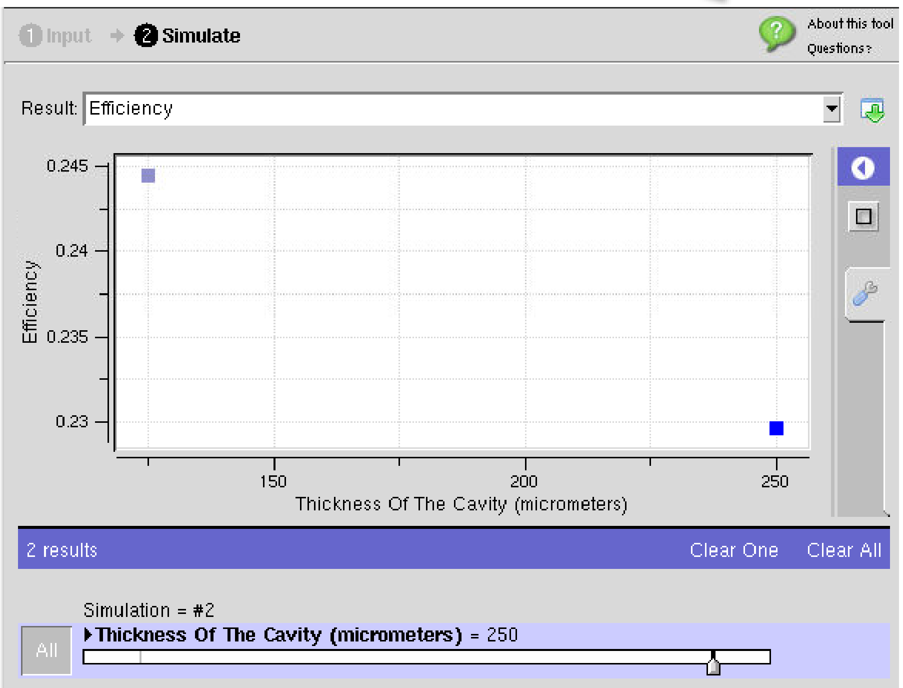

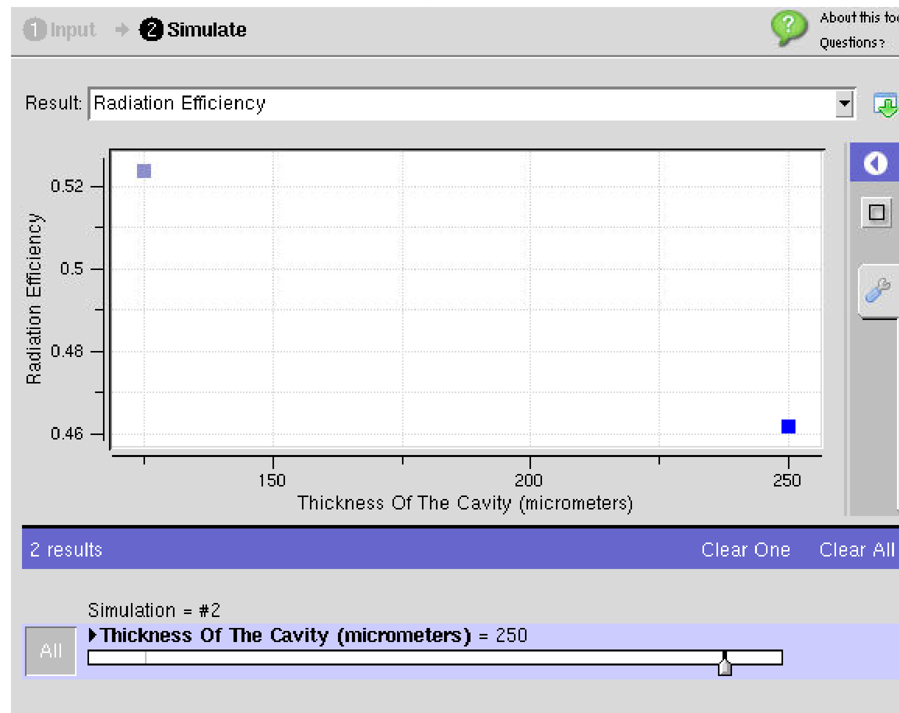

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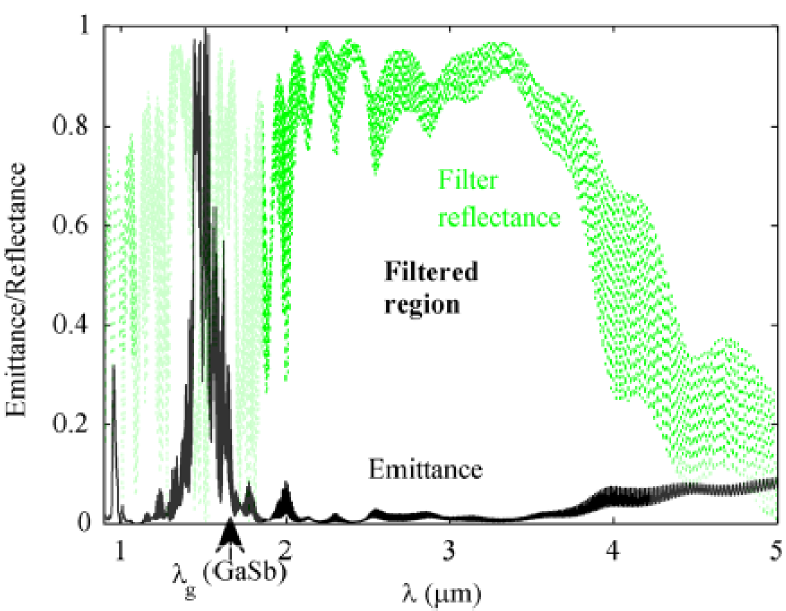

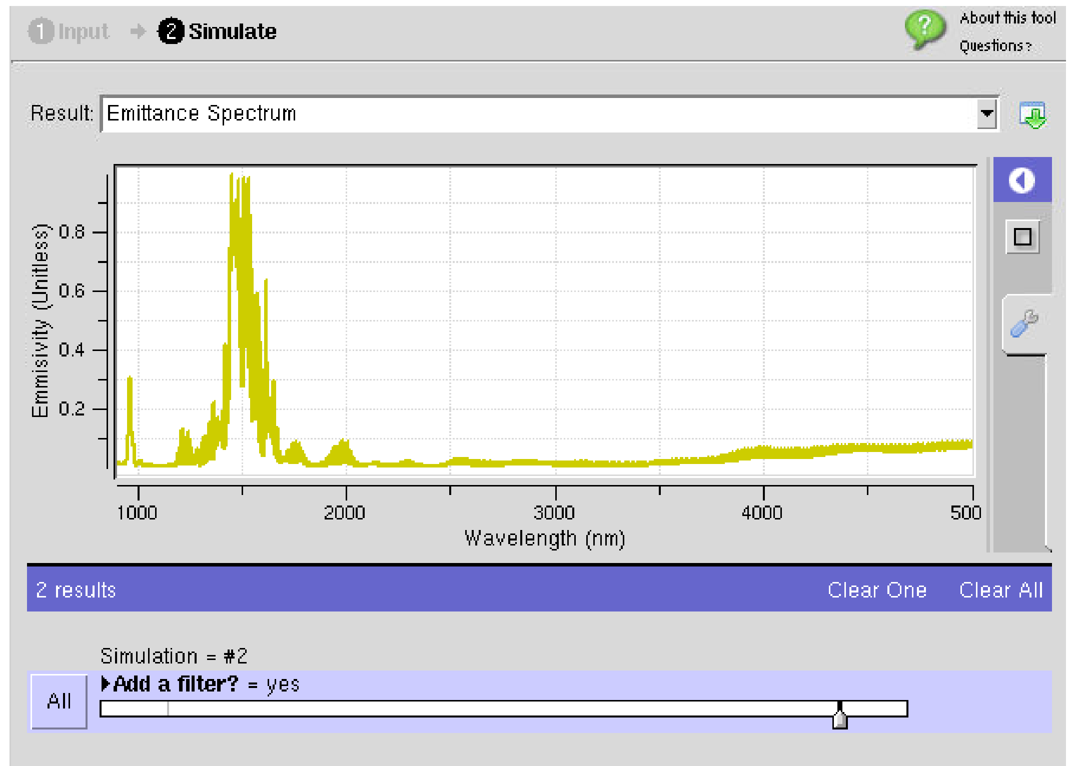

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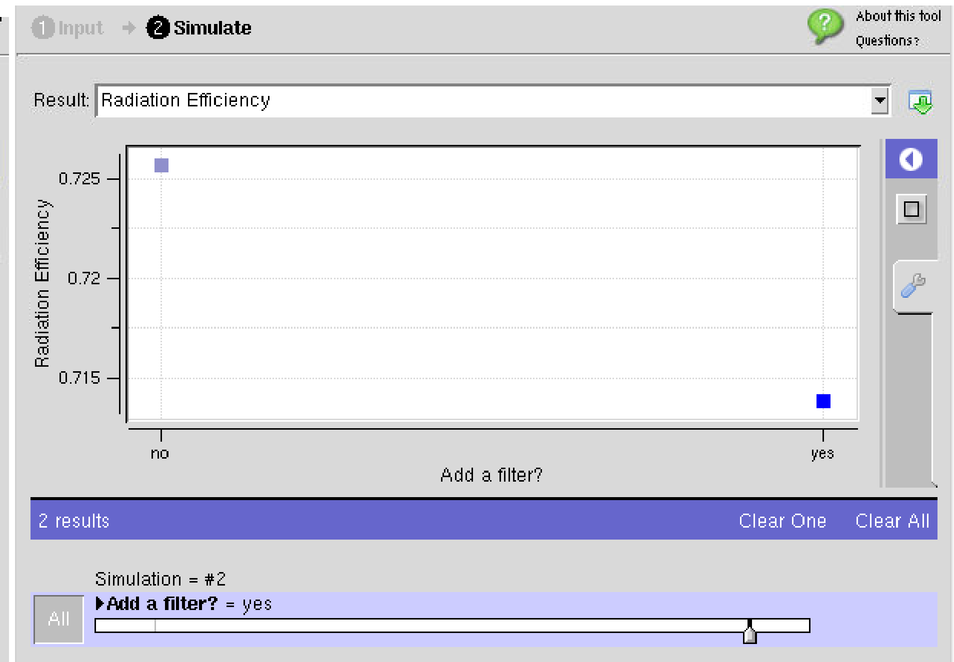

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Future work

- Simulate other naturally-selective rare earth materials.
- Optimize the number of layers for the maximum TPV efficiency.