Optimizing Fluorescence of Diamond Color Centers Encapsulated Into Core-shell Nano-resonators

Mária Csete, Lóránt Zsolt Szabó, András Szenes, Balázs Bánhelyi, Tibor Csendes, Gábor Szabó

Department of Optics and Quantum Electronics
Department of Computational Optimization
University of Szeged, Hungary

mcsete@physx.u-szeged.hu

UNIVERSITAS SCIENTIARUM SZEGEDIENSIS · SZEGEDI TUDOMÁNYEGYETEM · VERITAS VIRTUS LIBERTAS

Dr. Mária Csete

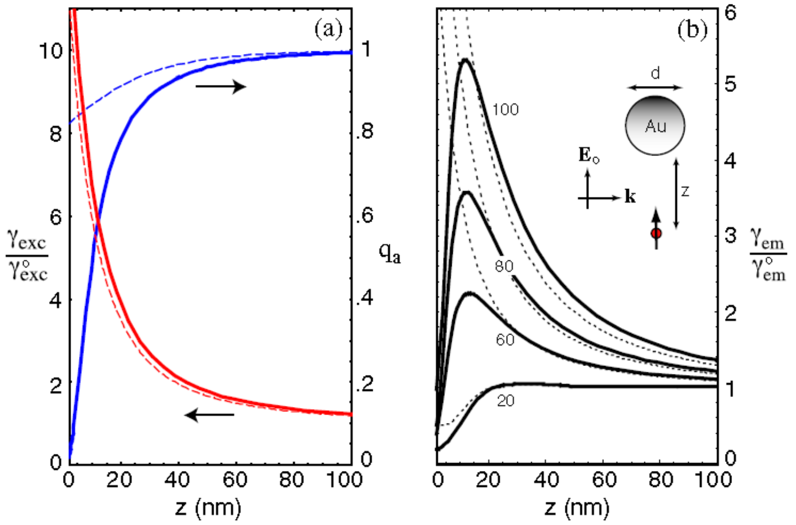
COMSOL Conference

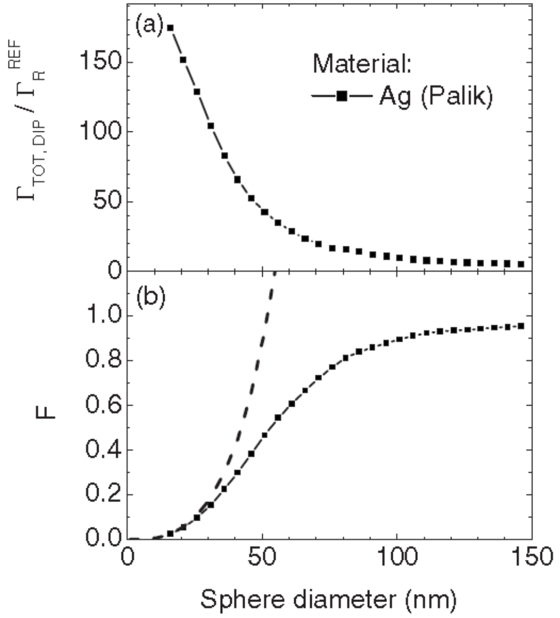
Boston, 2016

COMSOL CONFERENCE 2016 BOSTON

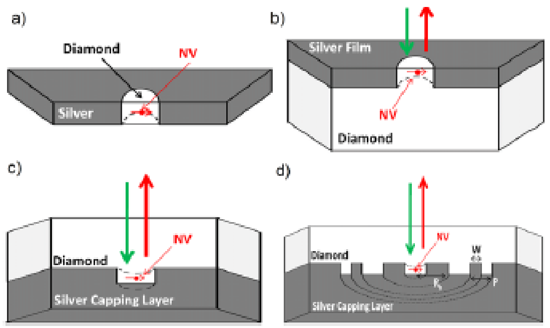
Plasmonic enhancement of light emission

- Modification of fluorescence intensity, decay rate
  - E. M. Purcell et. al.: Phys Rev 69 (194) 37
- Trade-off between Purcell factor and QE
  - P. C. Das et. al.: Phys. Rev. B 65 (2002) 155416
  - P. Anger et. al.: Phys. Rev. Lett. 96 (2006)
- Intrinsic limits defined by losses
  - F. Wang et al.: Phys. Rev. Lett. 97 (2006) 206806
  - H. Mertens et al.: Phys. Rev. B 76 (2007) 115123



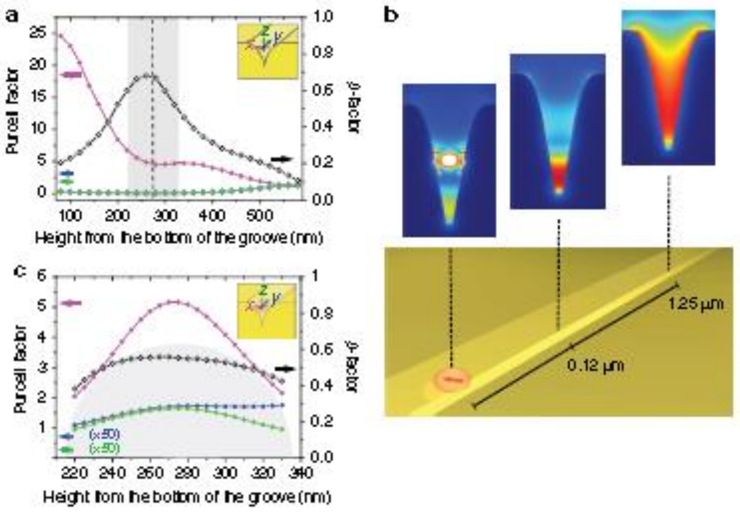


Enhancement of diamond color centers



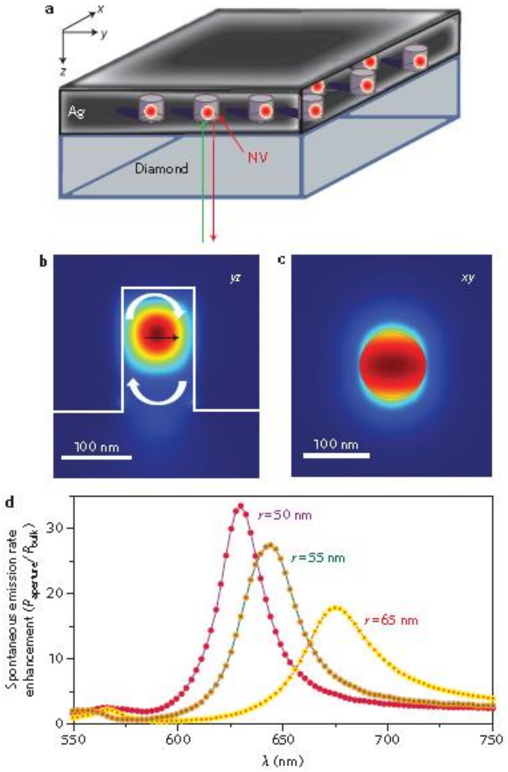
Nano-cavities and apertures to enhance emission

I. Bulu, T. Babinec, B. Hausmann, J. T. Choy,
II. and M. Loncar, Optics Express 19 (6), 5268-5276 (2011)



Positioning close to nano-channels

E. Bermúdez-Ureña, C. Gonzalez-Ballestero, M. Geiselmann, R. Marty, P. Radko, T. Holmgaard, Y. Alaverdyan, E. Moreno, F. J. García-Vidal, S. I. Bozhevolnyi and R. Quidant, Nature Communications 6, 7883

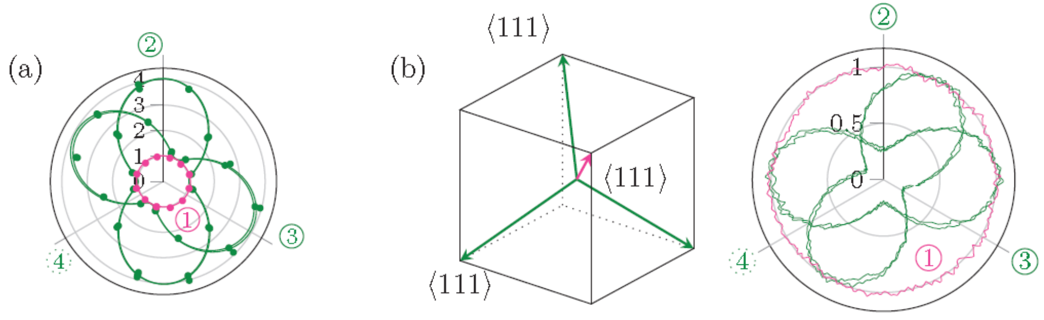


Array of nano-cavities to enhance emission and out-coupling

J. T. Choy, B. J. M. Hausmann, T. M. Babinec, Bulu, M. Khan, P. Maletinsky, A. Yacoby and M. Loncar, Nature Photonics 5, 738-743 (2011)

Perpendicularity of dipoles corresponding to excitation and emission

L. J. Rogers, K. D. Jahnke, M. W. Doherty, A. Dietrich, L. P. McGuinness, C. Müller, T. Teraji, H. Sumiya, J. Isoya, N. B. Manson, and F. Jelezko, Phys. Rev. B 89, 235101 (2014)



Principles to maximize radiative rate via spectral engineering

- **Excitation enhancement**: $\gamma^{excitation} / \gamma_0^{excitation} = |p \cdot E| / |p_0 \cdot E_0|$
- According to reciprocity radiative rate enhancement at excitation:

$$\left.\frac{\gamma^{radiative}}{\gamma_0^{radiative}}\right|_{emission} = \left.\frac{QE}{QE_0}\right|_{emission} \cdot \left.\frac{\gamma^{radiative}}{\gamma_0^{radiative}}\right|_{excitation} .$$

- **Emission enhancement**, total decay rate enhancement - > Purcell factor

$$F^{total} = \frac{\gamma^{radiative}_{uncoupled\,emitter} + \gamma^{radiative}_{coupled\,resonator} + \gamma^{non\text{-}radiative}_{emitter\,intrinsic} + \gamma^{non\text{-}radiative}_{coupled\,resonator} + \gamma^{non\text{-}radiative}_{quenching}}{\gamma^{radiative}_{uncoupled\,emitter,0} + \gamma^{non\text{-}radiative}_{emitter\,intrinsic,0}}$$

$$Purcell = F^{total}\Big|_{\gamma^{non\text{-}radiative}_{emitter\ intrinsic}=0,\ \gamma^{non\text{-}radiative}_{quenching}=0}$$

$$Purcell\Big|_{read-out} = \frac{P^{radiative} + P^{non-radiative}}{P_0^{radiative}}$$

- Quantum efficiency

$$QE\Big|_{\gamma^{non\text{-}radiative}_{emitter\ intrinsic}=0,\ \gamma^{non\text{-}radiative}_{quenching}=0} = \frac{\gamma^{radiative}_{uncoupled\,emitter} + \gamma^{radiative}_{coupled\,resonator}}{\gamma^{radiative}_{uncoupled\,emitter} + \gamma^{radiative}_{coupled\,resonator} + \gamma^{non\text{-}radiative}_{coupled\,resonator}}$$

$$QE\Big|_{read\text{-}out} = \frac{P^{radiative}}{P^{radiative} + P^{non\text{-}radiative}}$$

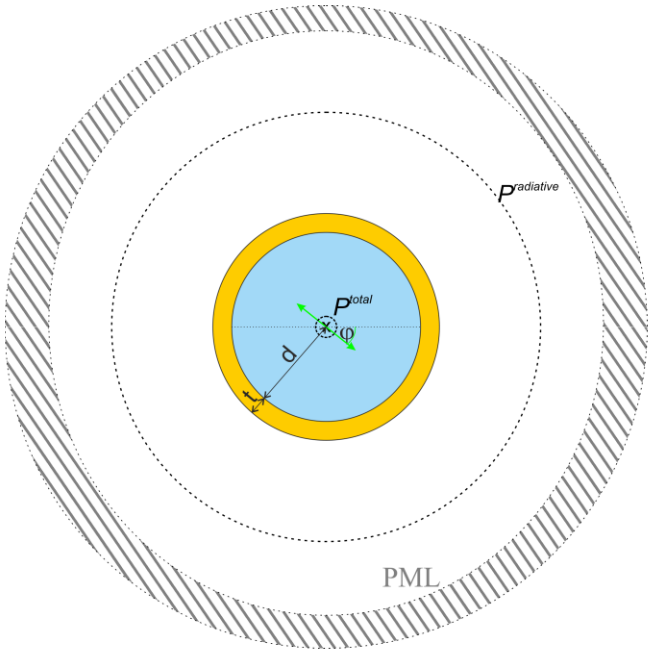
- Product of Purcell*QE - > radiative rate enhancement

$$F^{total} \cdot QE = \frac{\dfrac{\gamma^{radiative}_{uncoupled\,emitter} + \gamma^{radiative}_{coupled\,resonator}}{\gamma^{radiative}_{uncoupled\,emitter,0}}}{1 + \dfrac{1-QE_0}{QE_0}} = \frac{F^{radiative}}{1 + \dfrac{1-QE_0}{QE_0}}$$

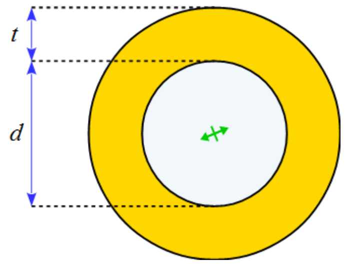
$$F^{radiative}\Big|_{read\text{-}out} = Purcell \cdot QE\Big|_{read\text{-}out} = \frac{P^{radiative}}{P_0^{radiative}}$$

- Corrected QE of the emitter

$$QE^{corrected} = \frac{P^{radiative}}{P^{radiative} + P^{non\text{-}radiative} + \dfrac{1-QE_0}{QE_0}}$$



Implementation into numerical methods & GLOBAL



Tuning dipole
position and orientation

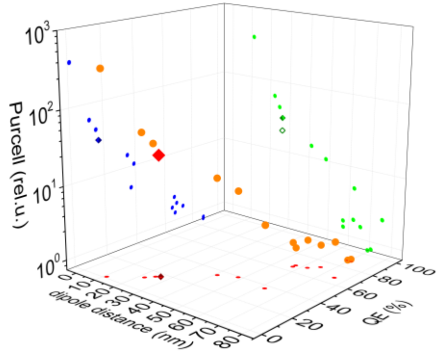
Conditional optimization

QE / Purcell factor optimization by stepping criterion regarding the Purcell factor / QE

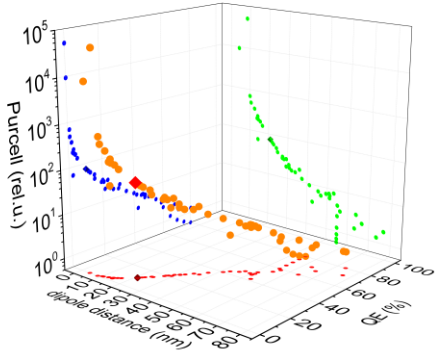
GLOBAL implemented via LiveLink for MATLAB: Sampling (Monte Carlo), Clustering (Single-link), Local searching (UNIRANDI, Random walk, BFGS)

T. Csendes et al.: The GLOBAL Optimization Method Revisited, Optimization Letters 2(2008) 445-454

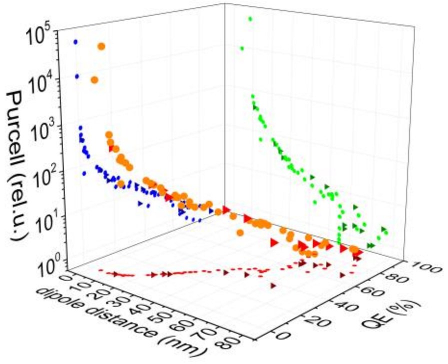
QE maximization with Purcell criterion



Purcell maximization with QE criterion



Integrated parameter cube

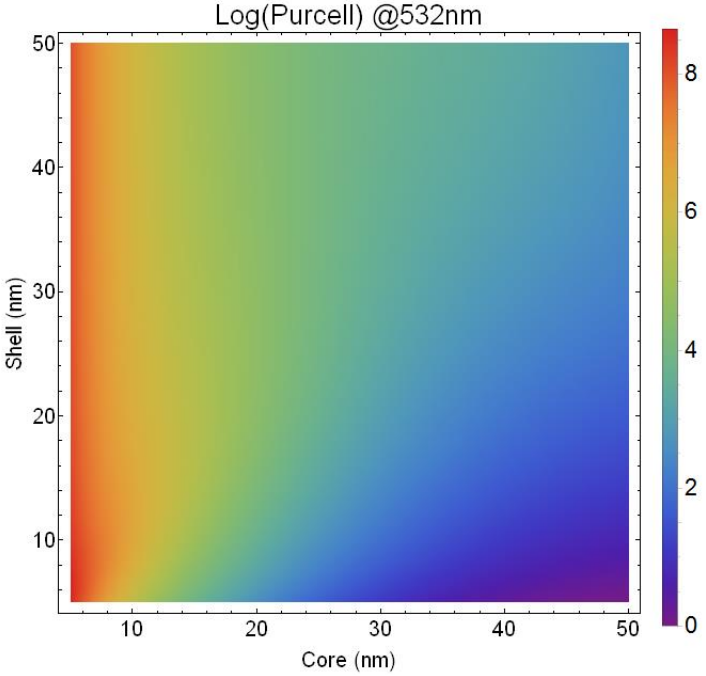


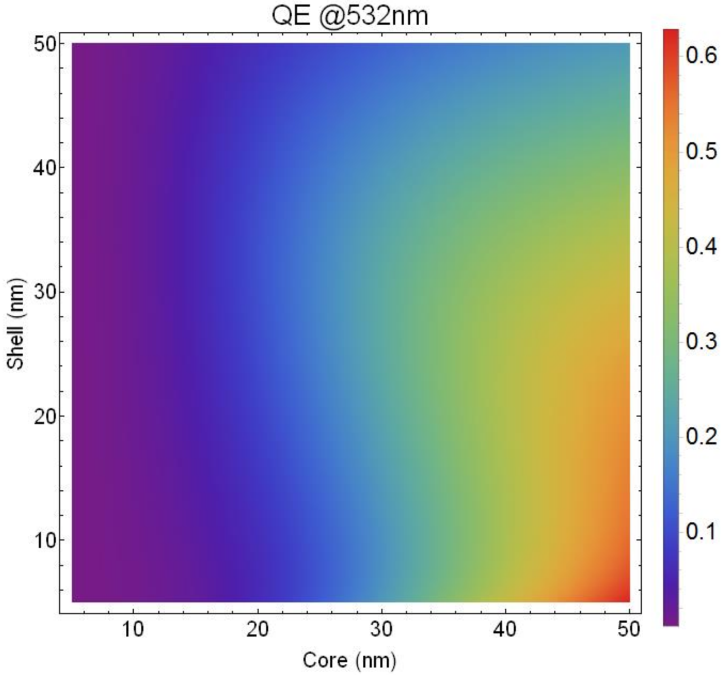
Extraction of wavelength dependent optical response
-radiated and absorbed power =>
-Purcell factor, QE
-radiative rate: Purcell*QE

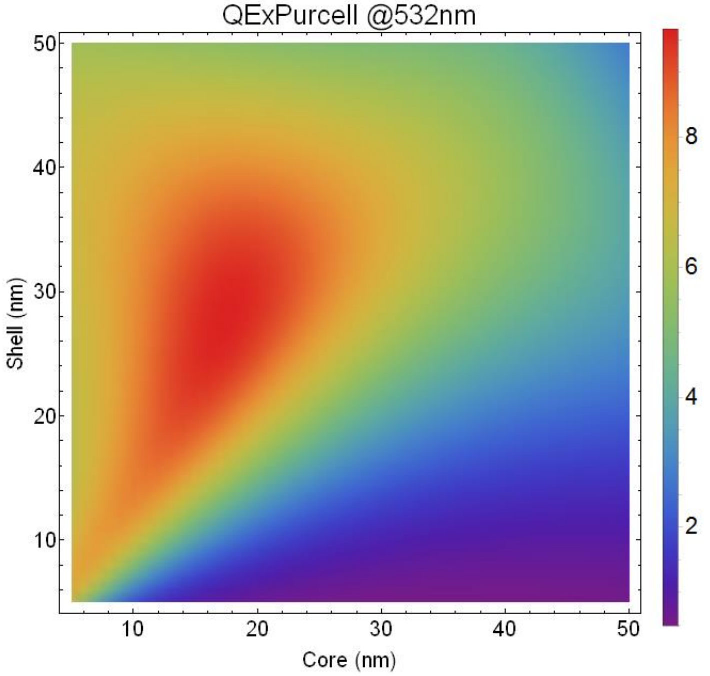
Inspection of near-field at extrema
Enorm,
powerflow,
charge distribution

Different metals
Centralized dipole
De-centralized dipole
Different criteria
Different objective function

Parametric sweep before optimization







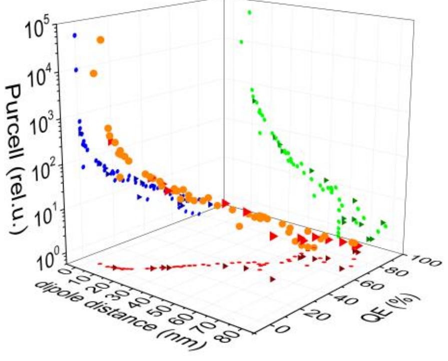
small cores are advantageous
to achieve large total decay rate
independently of shell thickness

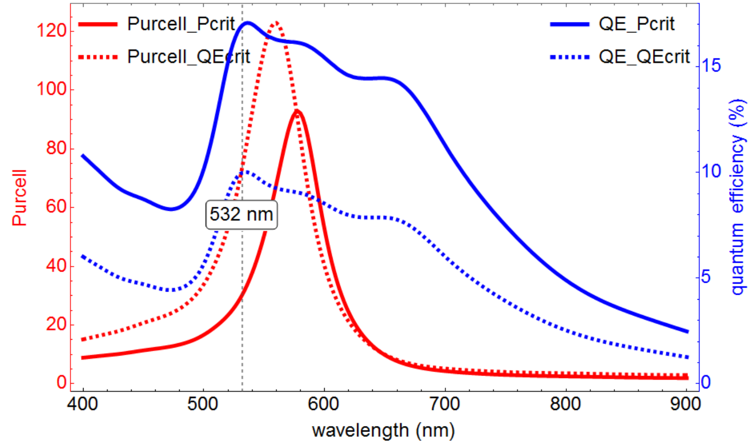
large cores with thin shells
are advantageous
to improve the QE

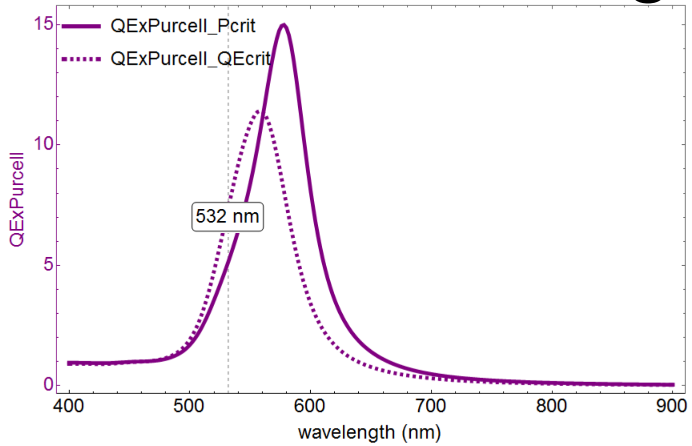
an optimal core-shell
combination exist

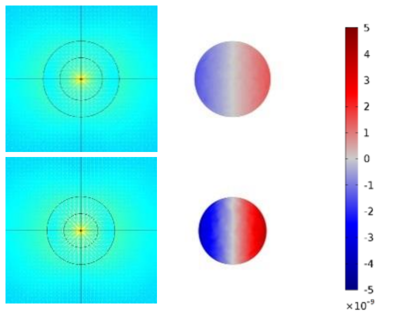
NV and SiV color center excitation enhancement: Au/Ag core-shell

Integrated parameter cube





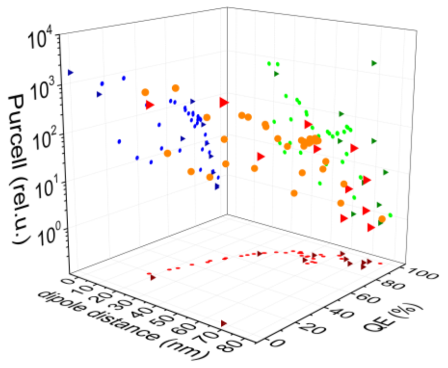


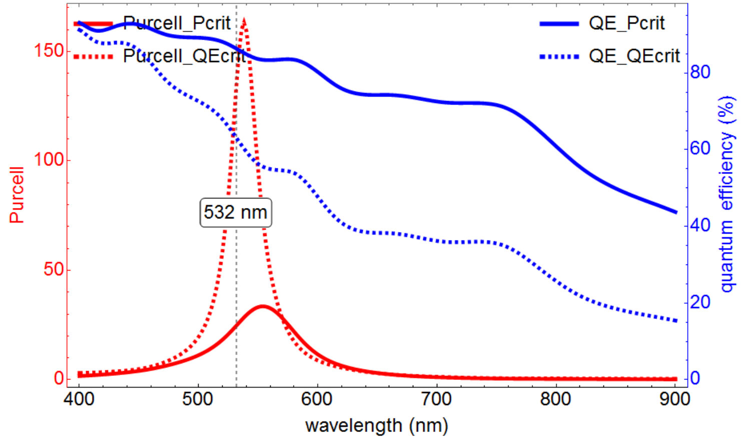


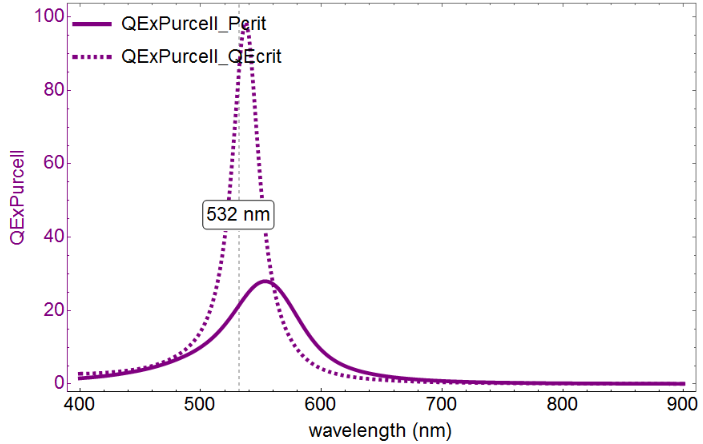
~10/10 radiative rate enhancement, Purcell / QE criterion: peaks at λ >> / > 532 nm

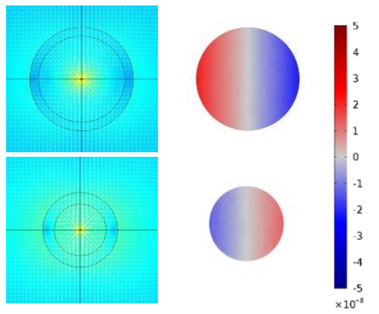
QE criterion: radiative rate larger, detuning smaller

Integrated parameter cube









~10 / 100 radiative rate enhancement, Purcell / QE criterion: peak at λ > / ~ 532 nm

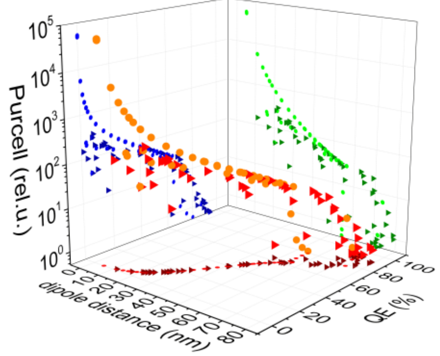
QE criterion: radiative rate larger, detuning smaller

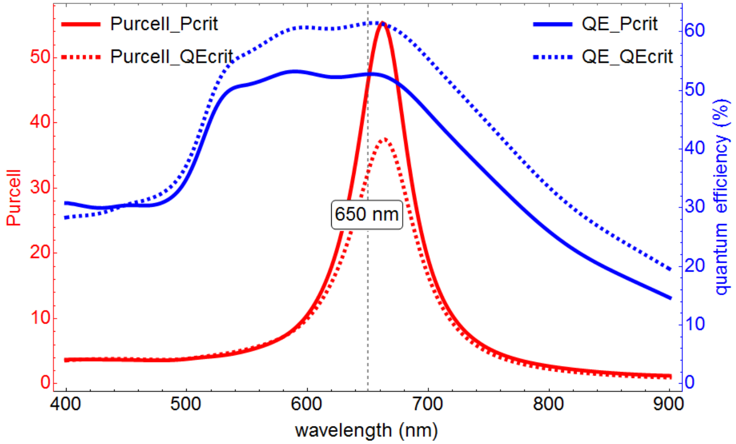
silver better:
larger QE and radiative rate, smaller detuning
larger core, larger distance

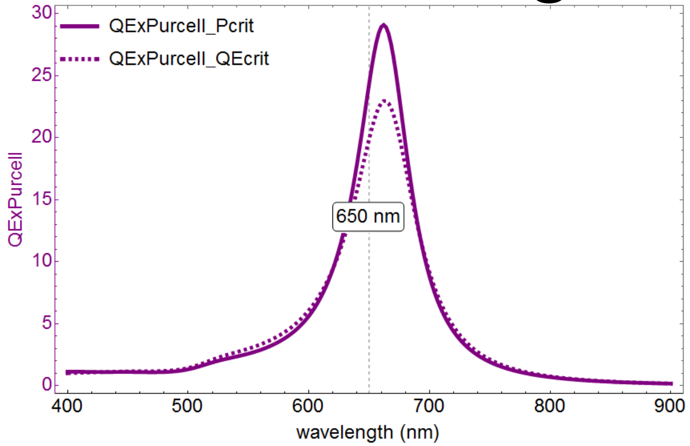
	criterion	P	Q(%)	QxP	Δλ(nm)	2r(nm)	t(nm)	r/t	d(nm)	φ(°)
Purcell	10	24.93	86.32	21.52	22	105.66	25.66	2.06	52.83	0.00
	Ag/Au	0.82	5.08	4.16	0.48	2.01	1.25	1.61	2.01	
QE	50	136.36	63.06	85.98	6	63.63	14.02	2.27	31.81	0.00
	Ag/Au	1.84	6.30	11.58	0.23	1.52	0.67	2.27	1.52	

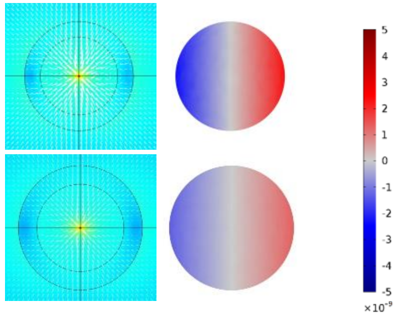
NV color center emission enhancement: Au/Ag core-shell

Integrated parameter cube





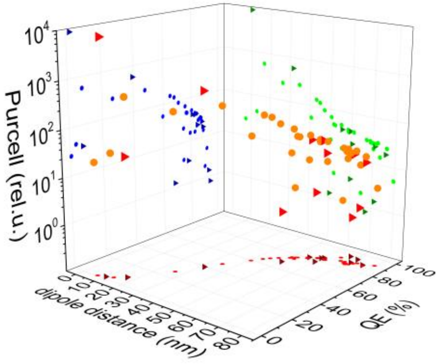


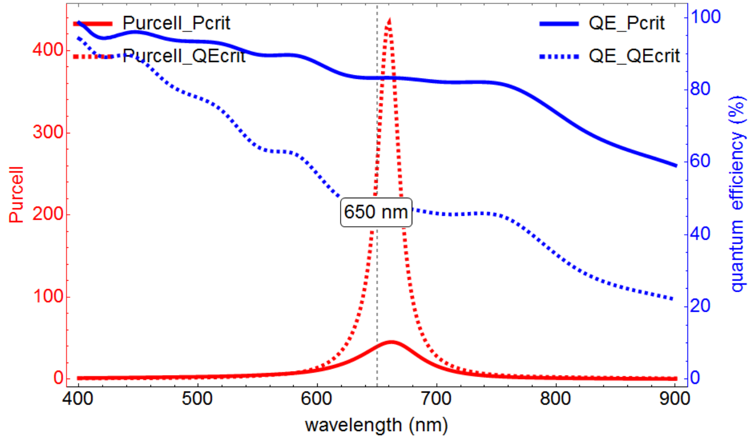


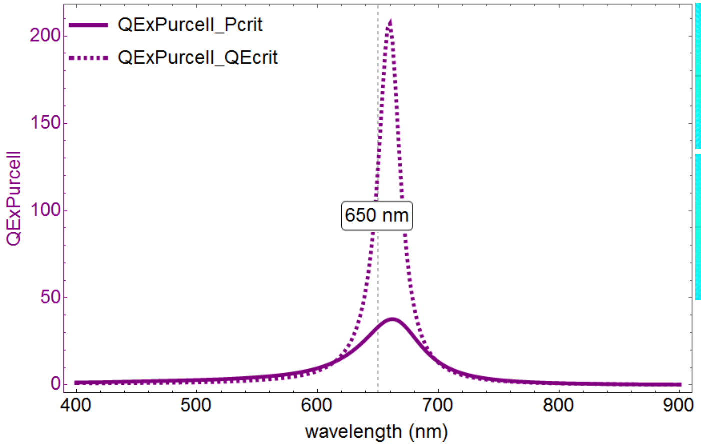
~10 / 10 radiative rate enhancement, **Purcell** / QE criterion: peaks at λ >~ 650 nm

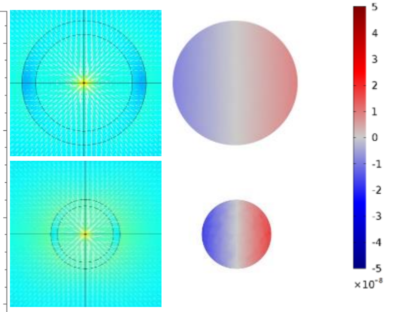
Purcell larger radiative rate, same detuning

Integrated parameter cube









~10 / 100 radiative rate enhancement, Purcell / **QE** criterion: peak at λ>~ 650 nm

QE larger radiative rate, smaller detuning

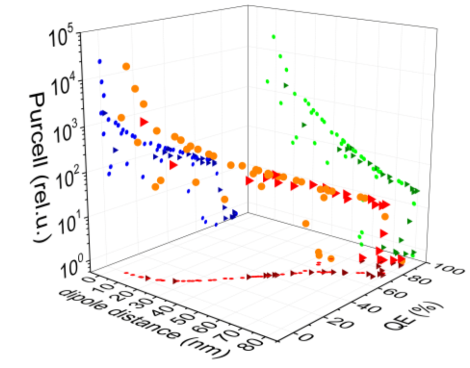
silver better: slightly larger QE and radiative rate, same/smaller detuning

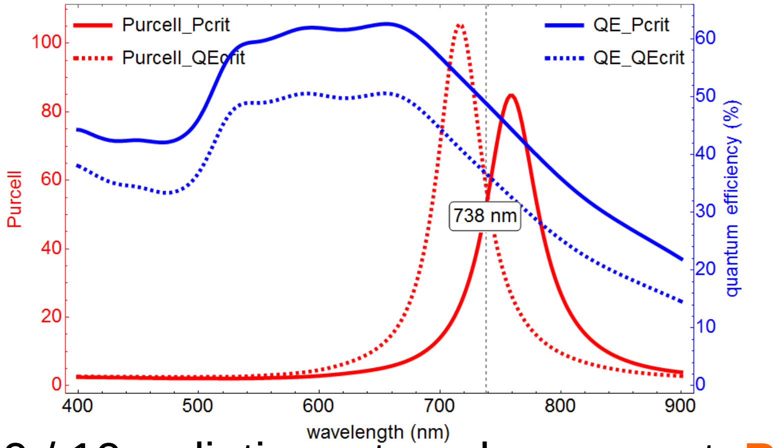
larger/smaller core, larger/smaller distance

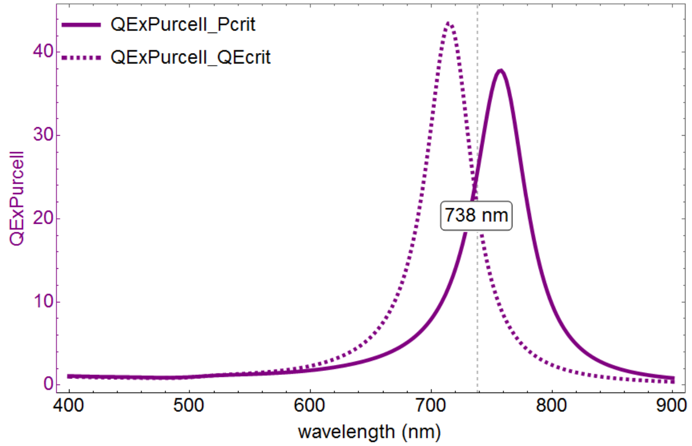
	criterion	P	Q(%)	QxP	Δλ(nm)	2r(nm)	t(nm)	r/t	d(nm)	φ(°)
Purcell	*25*	*39.73*	***83.43***	*33.14*	*12*	*119.21*	*16.96*	*3.52*	*59.60*	*0.00*
	Ag/Au	*0.86*	*1.58*	*1.36*	*1.00*	*1.25*	*0.88*	*1.43*	*1.25*	
QE	*20*	***142.29***	*64.85*	***92.28***	***10***	*86.13*	*10.77*	*4.00*	*43.06*	*0.00*
	Ag/Au	*4.40*	*1.06*	*4.64*	*0.83*	*0.80*	*0.47*	*1.70*	*0.80*	

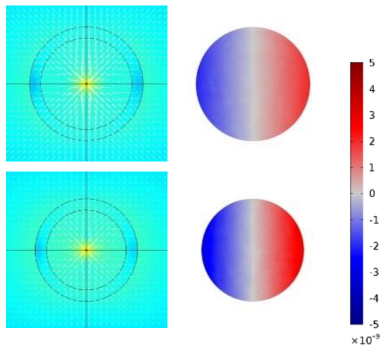
SiV color center emission enhancement: Au/Ag core-shell

Integrated parameter cube





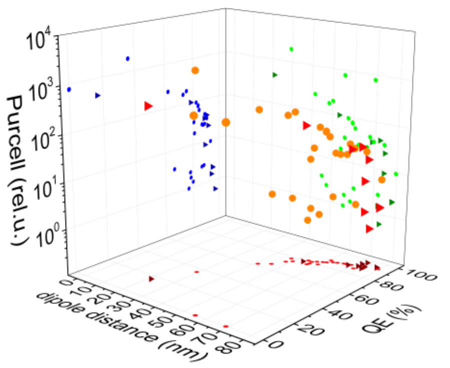


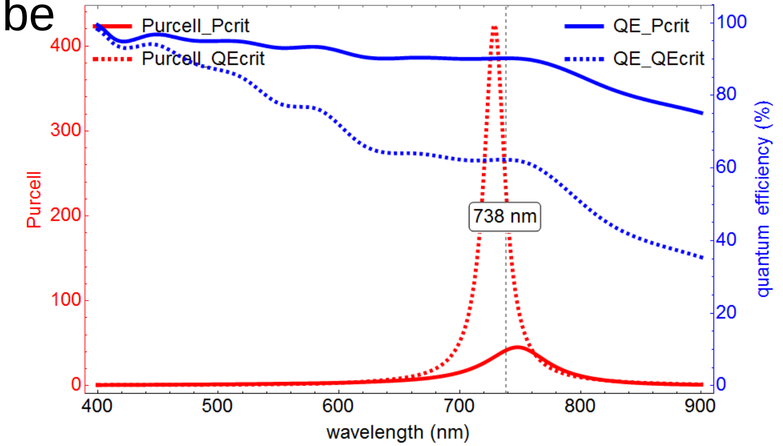


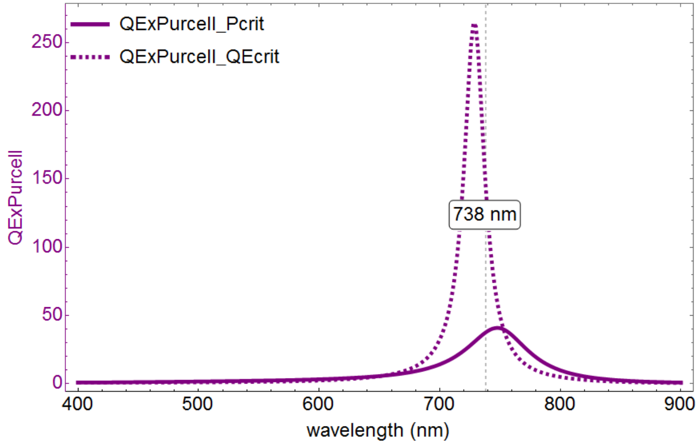
~10 / 10 radiative rate enhancement, **Purcell** / QE criterion: peaks at λ > / < 738 nm

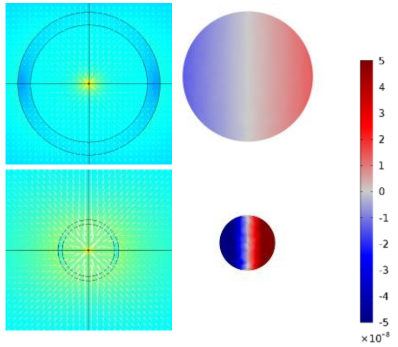
Purcell larger radiative rate, smaller detuning

Integrated parameter cube









~10 / 100 radiative rate enhancement, Purcell / **QE** criterion peak at λ > / ~ 650 nm

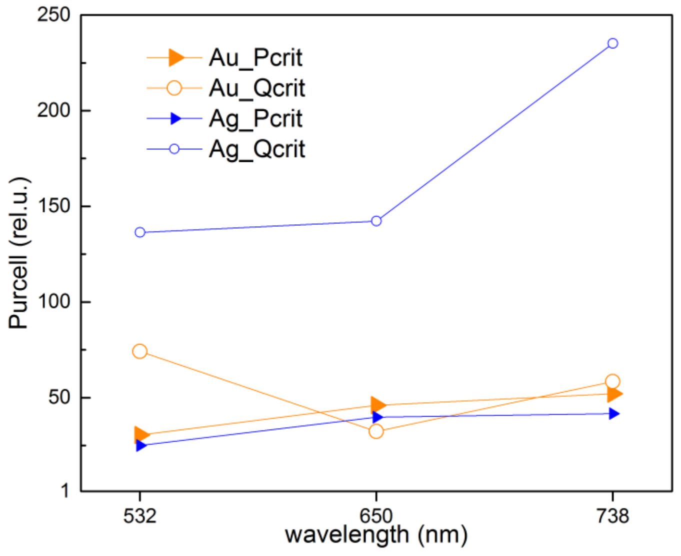
QE larger radiative rate and smaller detuning

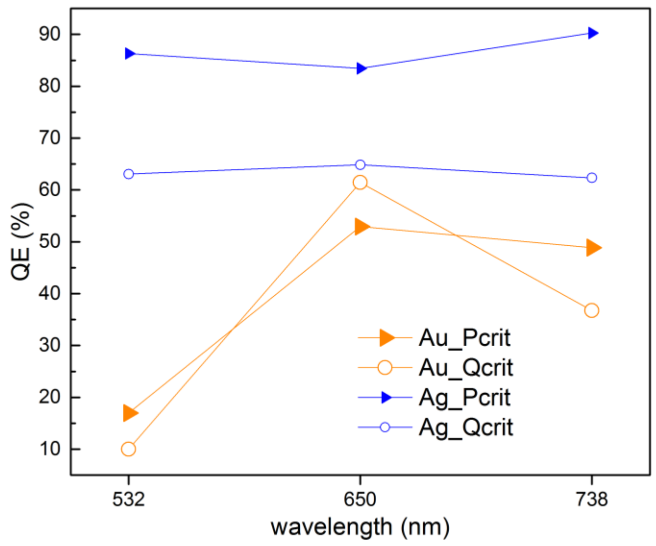
silver better: enhanced QE and radiative rate, smaller detuning

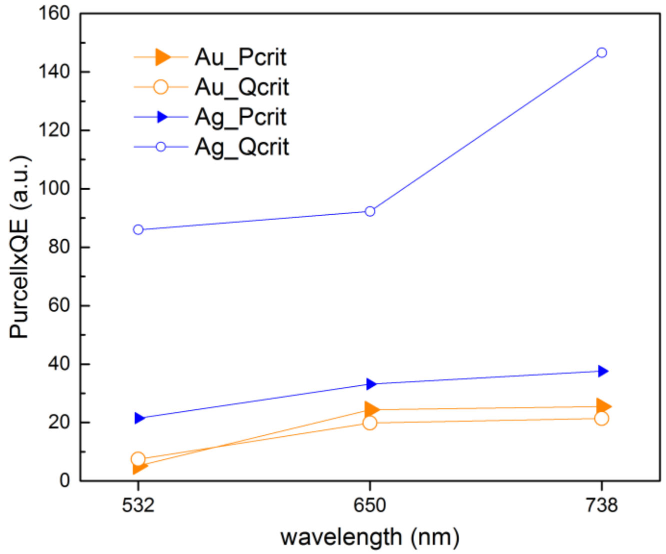
larger/smaller core, larger/smaller distance

	criterion	P	Q(%)	Qcorr(%)	QxP	Δλ(nm)	2r(nm)	t(nm)	r/t	d(nm)	φ(°)
Purcell	10	41.62	90.26	74.21	37.57	10	144.00	15.39	4.68	72.00	0.00
	Ag/Au	0.80	1.85	1.78	1.48	0.50	1.36	1.20	1.13	1.36	
QE	20	235.12	62.33	60.03	146.54	-2	82.76	7.55	5.48	41.38	0.00
	Ag/Au	4.03	1.70	1.89	6.84	0.09	0.90	0.58	1.56	0.90	

Centralized dipoles: single wavelength tendency







Total decay rate:
increase with wavelength
except in configuration_Au_Q_{crit}

Silver better
except configuation_Ag_P_{crit}

QE:
peaks at 650 nm
except in configuration_Ag_P_{crit}

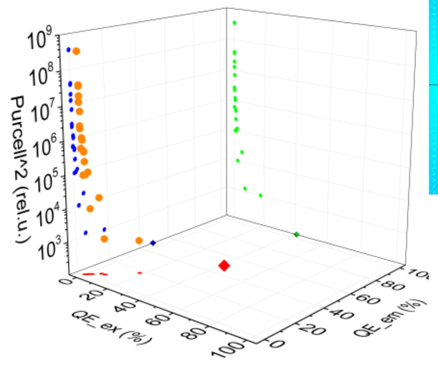
Silver better

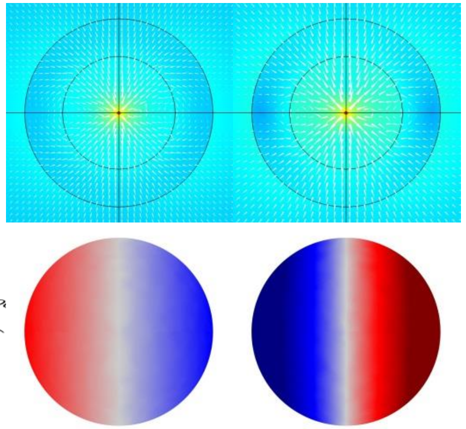
Radiative rate enhancement:
increases with wavelength
according to wavelength dependency
of material limits

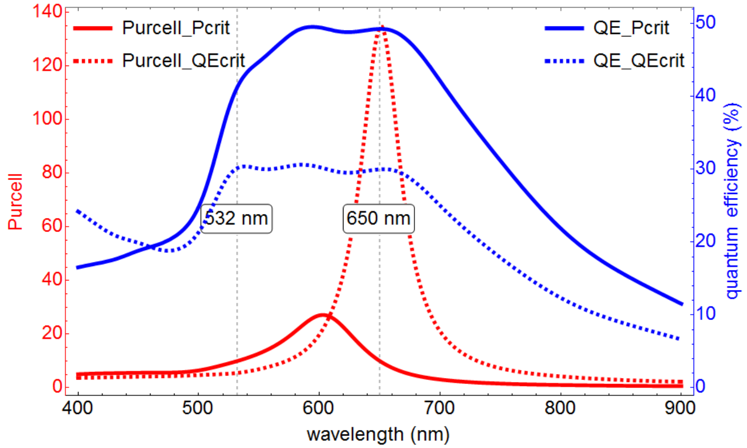
Silver better

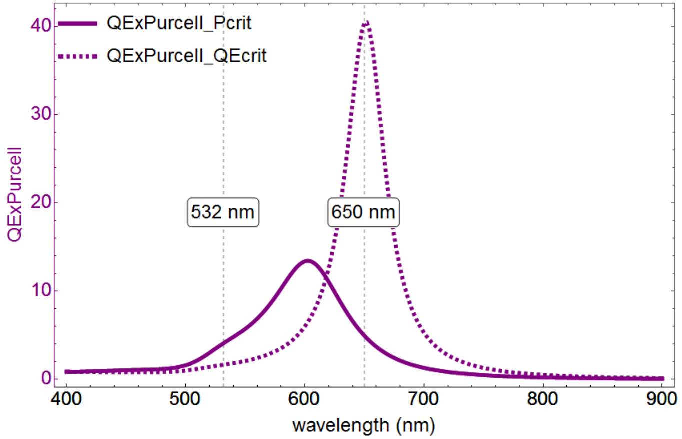
NV center simultaneous enhancement via Au

QE maximization with Purcell criterion

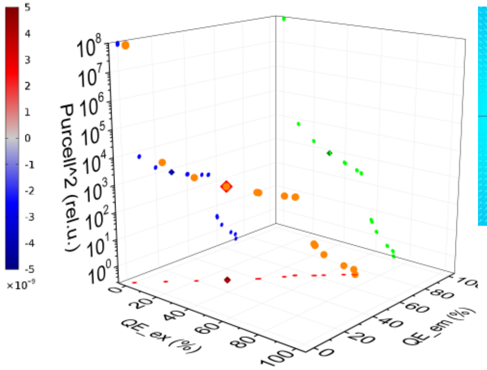


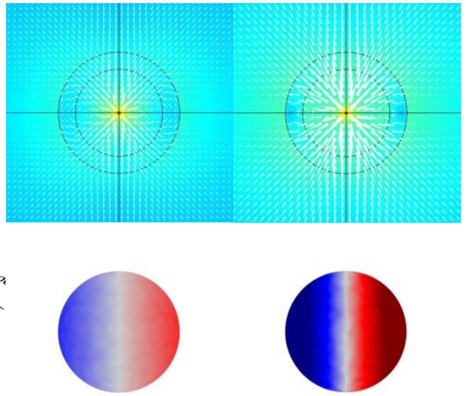






Purcell maximization with QE criterion





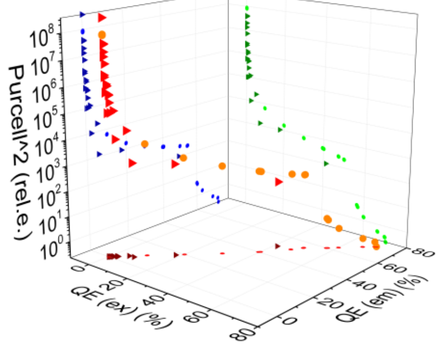
Purcell / QE criterion excitation / emission

~1 – 10/1-10 excitation - emission enhancement,

single peaks at 532 nm<λ<650 nm / 650 nm

Dual: both improves QE at excitation
with QE_{crit} better in emission enhancement, smaller detuning

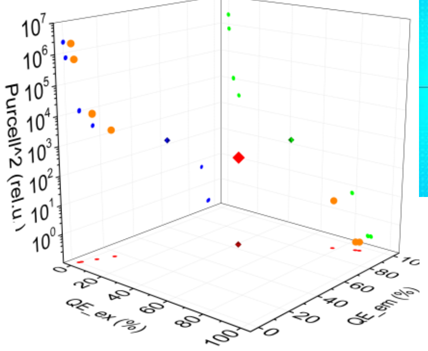
Integrated parameter cube

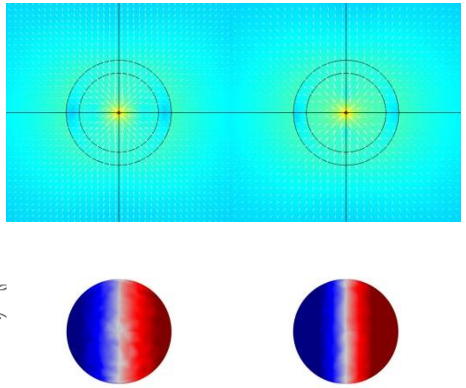


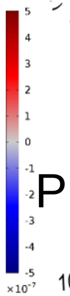
excitation						emission										
	criterion	P	Q(%)	QxP	Δλ(nm)	criterion	P	Q(%)	QxP	Δλ(nm)	QxP^2	2r(nm)	t(nm)	r/t	d(nm)	φ(°)
Purcell	10	10.03	41.29	4.14	70	10	10.00	49.28	4.93	-48	20.42	92.58	30.87	1.50	46.29	0.00
	Dual/Solo	0.33	2.43	0.80	1.52		0.22	0.93	0.20	-4.00						
QE	30	5.57	30.16	1.68	120	30	134.50	30.00	40.35	2	67.75	71.53	14.03	2.55	35.77	0.00
	Dual/Solo	0.07	3.02	0.23	4.62		4.16	0.49	2.03	0.17						

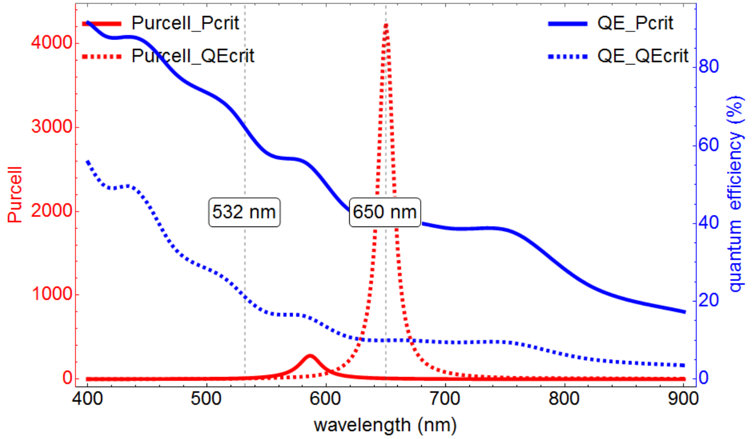
NV center simultaneous enhancement via Ag

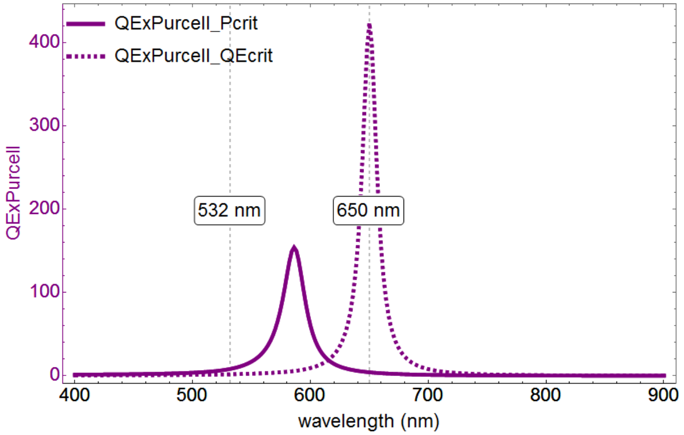
QE maximization with Purcell criterion



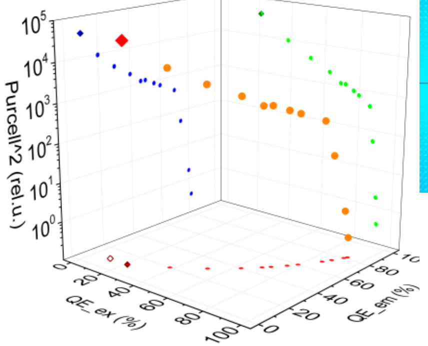


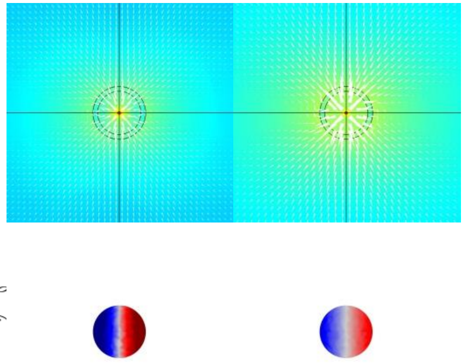






Purcell maximization with QE criterion





Purcell / QE criterion excitation / emission

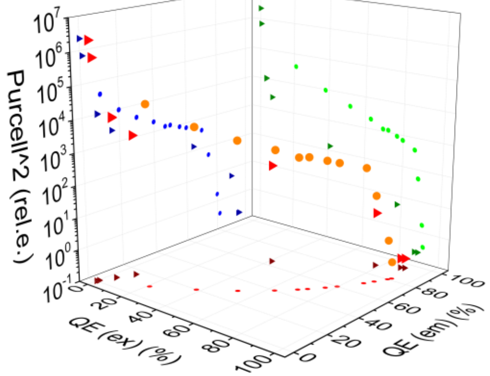
~1 - 10/1-100 excitation - emission enhancement

single peaks at 532 nm<λ<650 nm / 650 nm

silver is better in excitation and emission enhancement

smaller core with thinner shell, smaller dipole distance

Integrated parameter cube



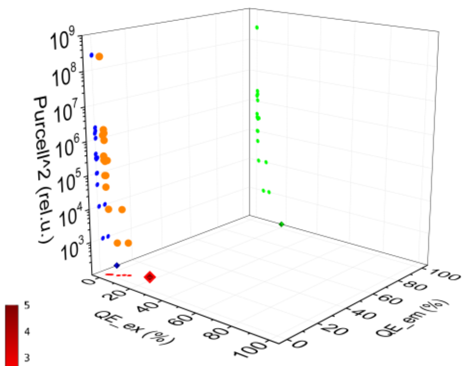
Dual: at excitation all quantities are smaller

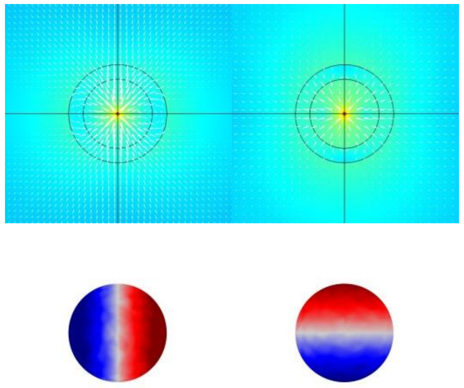
with QE_{crit} better in emission enhancement, smaller detuning

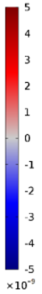
	excitation					emission										
	criterion	P	Q(%)	QxP	Δλ(nm)	criterion	P	Q(%)	QxP	Δλ(nm)	QxP^2	2r(nm)	t(nm)	r/t	d(nm)	φ(°)
Purcell	10	10.56	40.80	4.31	54	10	13.02	64.49	8.40	-64	36.17	65.04	10.63	3.06	32.52	0.00
	Ag/Au	1.05	0.99	1.04	0.77		1.30	1.31	1.70	1.33	1.77					
	Dual/Solo	0.42	0.47	0.20	2.45		0.33	0.77	0.25	-5.33						
QE	10	9.09	21.09	1.92	118	10	4.25E+3	10.00	424.54	0	814.08	35.51	3.92	4.53	17.75	0.00
	Ag/Au	1.63	0.70	1.14	0.98		31.56	0.33	10.52	0.00	12.02					
	Dual/Solo	0.07	0.33	0.02	19.67		29.84	0.15	4.60	0.00						

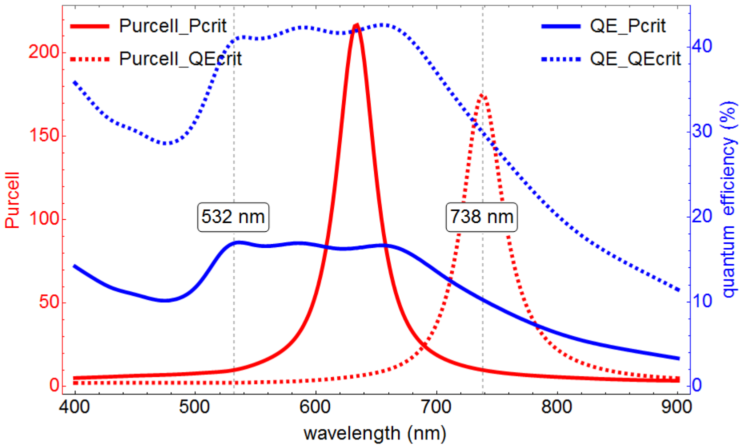
SiV center simultaneous enhancement via Au

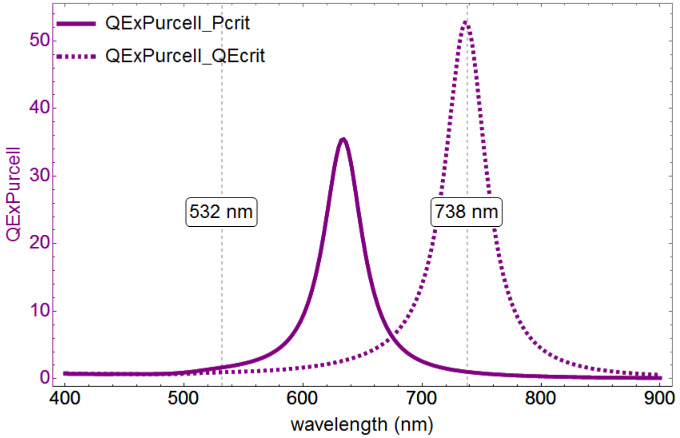
QE maximization with Purcell criterion



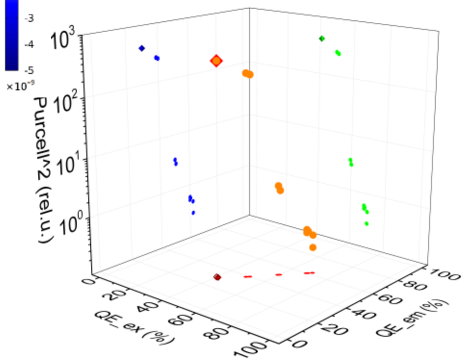


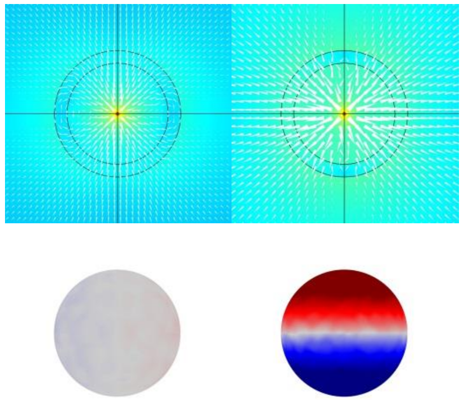






Purcell maximization with QE criterion





Purcell / QE criterion excitation / emission

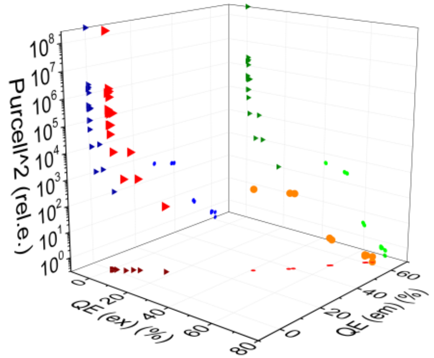
~1-1/1-100 excitation-emission enhancement

single peaks at 532 nm<λ<738 nm / 738 nm

Dual: both QE improves at excitation

with QE_{crit} better in emission enhancement, smaller detuning

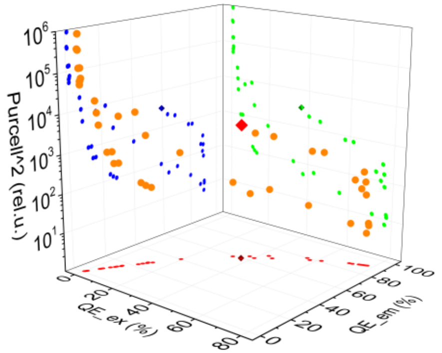
Integrated parameter cube

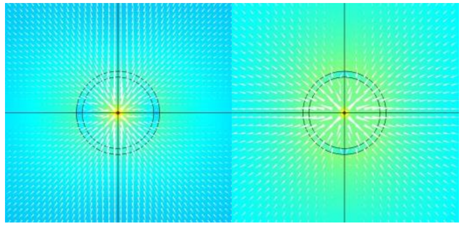


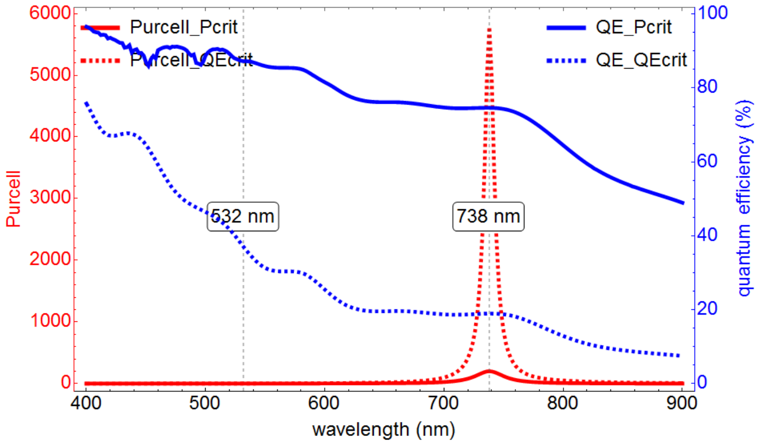
	excitation					emission												
	criterion	P	Q(%)	QxP	Δλ(nm)	criterion	P	Q(%)	Qcorr (%)	QxP	Δλ(nm)	QxP^2	2r(nm)	t(nm)	r/t	d(nm)	φ(°)
Purcell	10	10.00	16.93	1.69	102	10	10.01	10.27	5.41	1.03	-104	1.74	56.80	11.96	2.38	28.40	0.00
	Dual/Solo	0.33	1.00	0.33	2.22		0.19	0.21	0.13	0.04	-5.20						
QE	40	2.38	40.87	0.97	204	30	175.09	30.01	28.54	52.55	-2	51.11	83.26	10.28	4.05	41.63	0.00
	Dual/Solo	0.03	4.09	0.13	7.85		3.00	0.82	0.90	2.45	0.09						

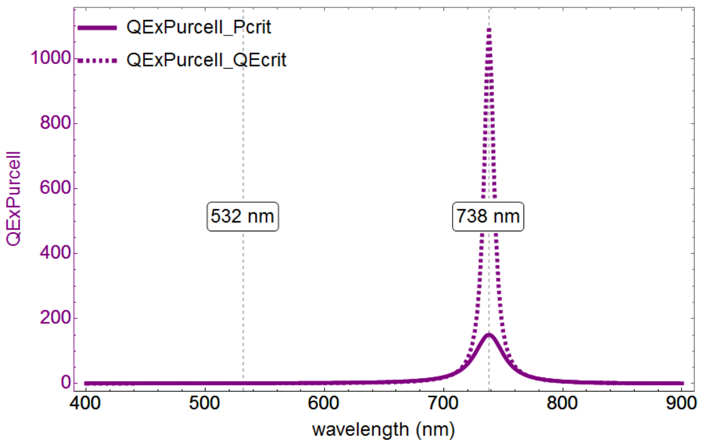
SiV center simultaneous enhancement via Ag

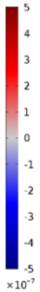
QE maximization with Purcell criterion



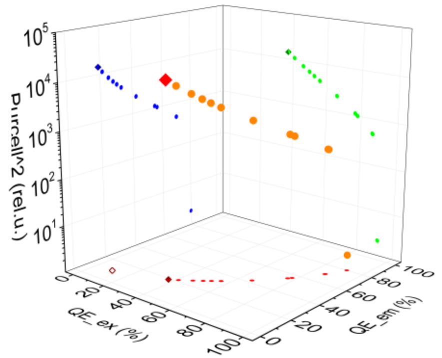


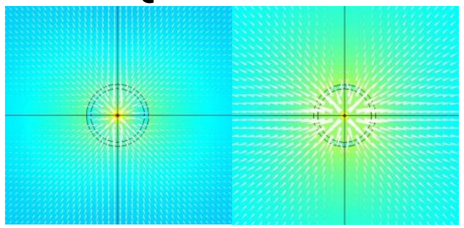






Purcell maximization with QE criterion



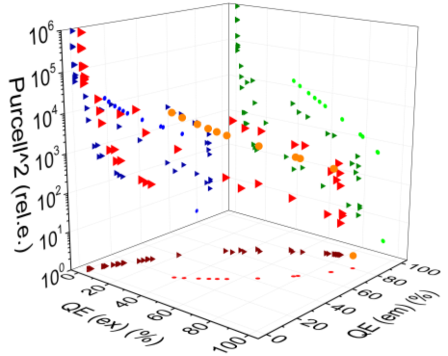


Purcell / QE criterion excitation / emission no detuning
~1-100/1-1000 excitation-emission enhancement
single peaks at 738 nm

silver is better in emission with P_{crit} and QE_{crit}

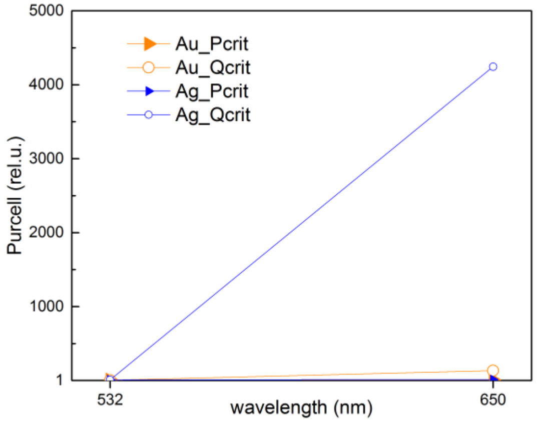
Dual: better in emission enhancement with P_{crit} and QE_{crit}

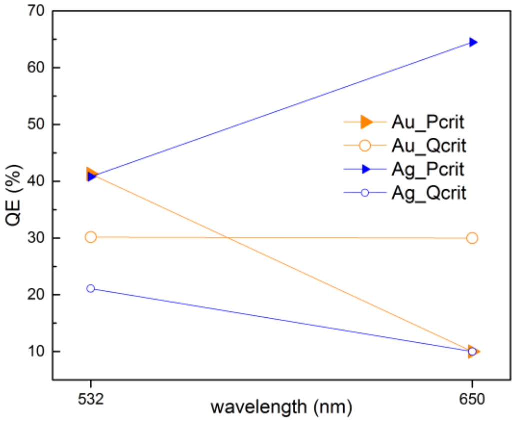
Integrated parameter cube

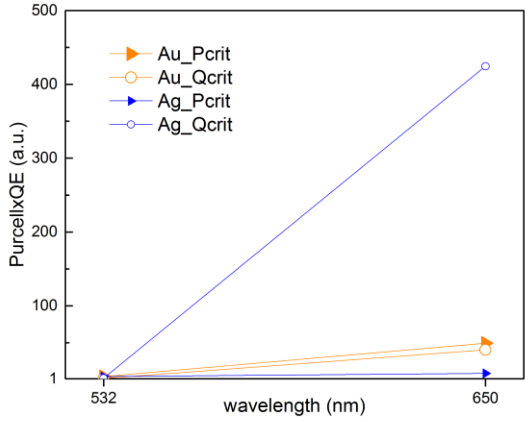


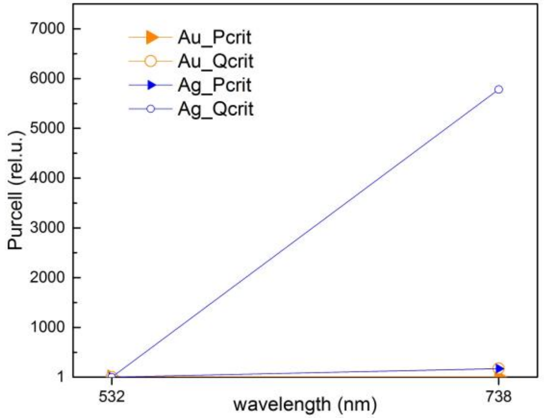
	excitation					emission											
	criterion	P	Q(%)	QxP	Δλ(nm)	criterion	P	Q(%)	Qcorr (%)	QxP	Δλ(nm)	QxP^2	2r(nm)	t(nm)	r/t	d(nm)	φ(°)
Purcell	1	1.64	89.31	1.46	206	1	172.41	75.22	69.51	129.68	0	189.94	99.31	8.98	5.53	49.66	0.00
	Ag/Au	0.16	5.27	0.86	2.02		17.22	7.32	12.85	126.10	0.00	109.03					
	Dual/Solo	0.07	1.03	0.07	9.36		4.14	0.83	0.94	3.45	0.00						
QE	10	2.44	36.85	0.90	206	10	5.78E+3	18.98	18.95	1.10E+3	0	985.59	43.99	3.56	6.18	21.99	0.00
	Ag/Au	1.02	0.90	0.92	1.01		33.02	0.63	0.66	20.89	0.00	19.28					
	Dual/Solo	0.02	0.58	0.01	34.33		24.59	0.30	0.32	7.49	0.00						

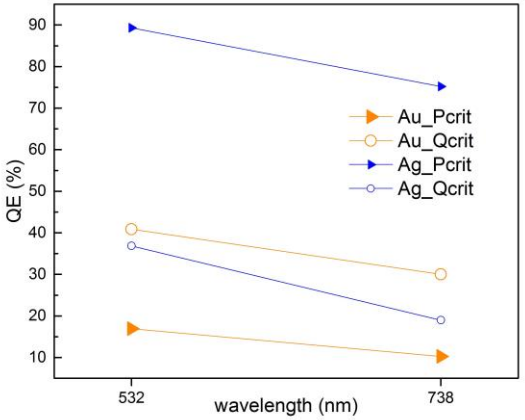
Centralized dipole: dual wavelength tendency

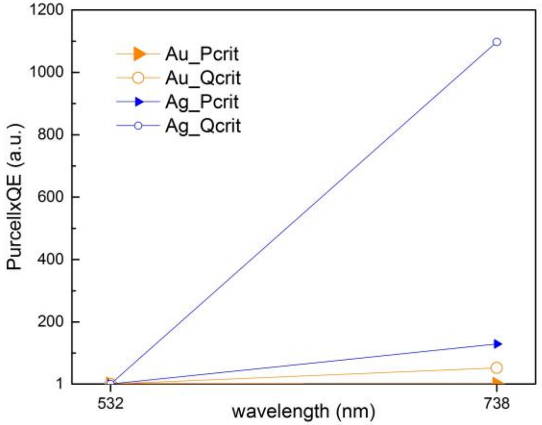








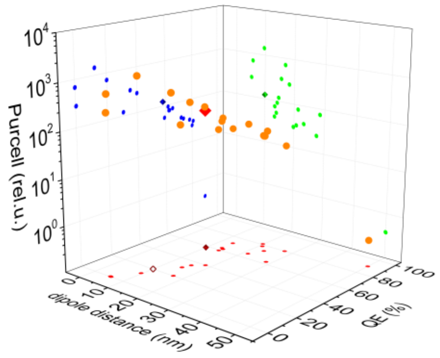


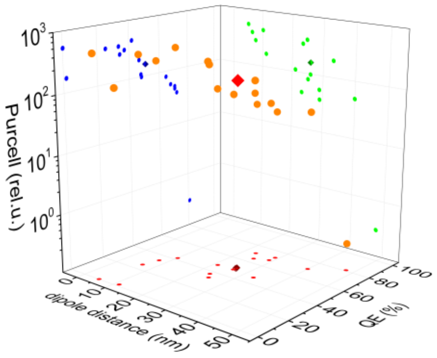


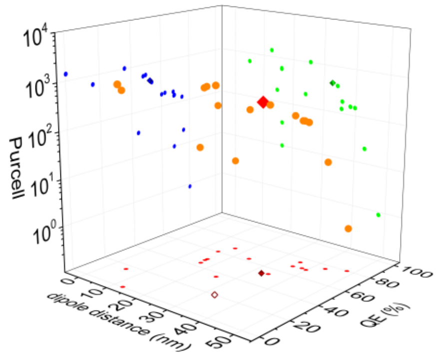
Larger number of artificial constraints =>
Discrepancies with respect to the expectations based on wavelength and material dependent limits
Radiative rate in accordance / contradiction with material limits in case of QE_{crit} / P_{crit}

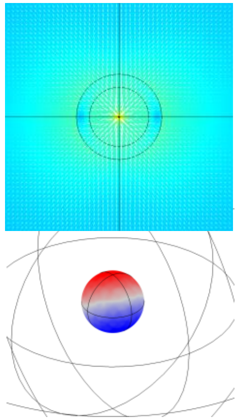
NV and SiV color center excitation/emission enhancement, Ag

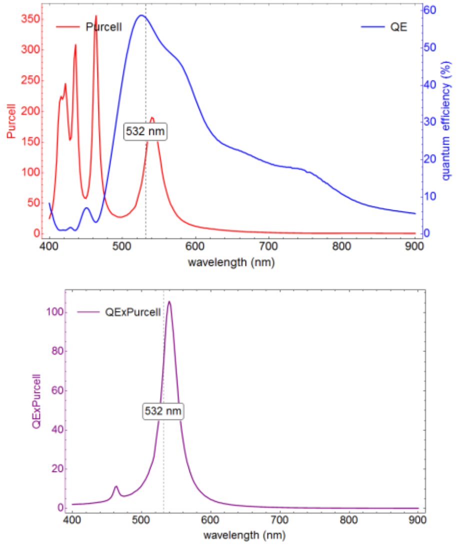
Single wavelengths, Purcell factor maximization with QE criterion; de-centralized dipole

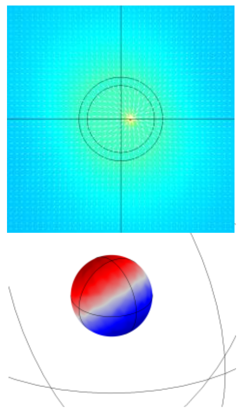


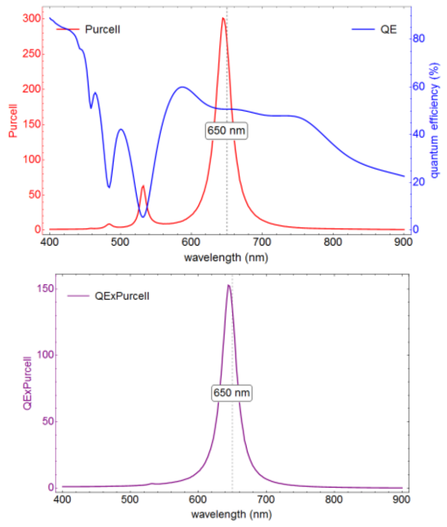


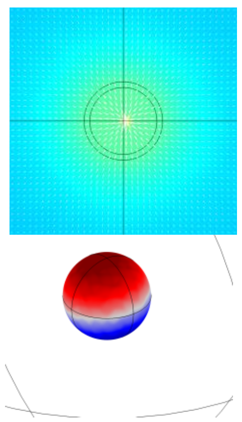


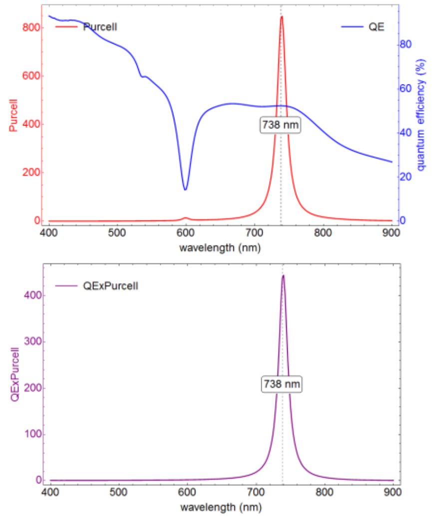












Smaller radiative rate

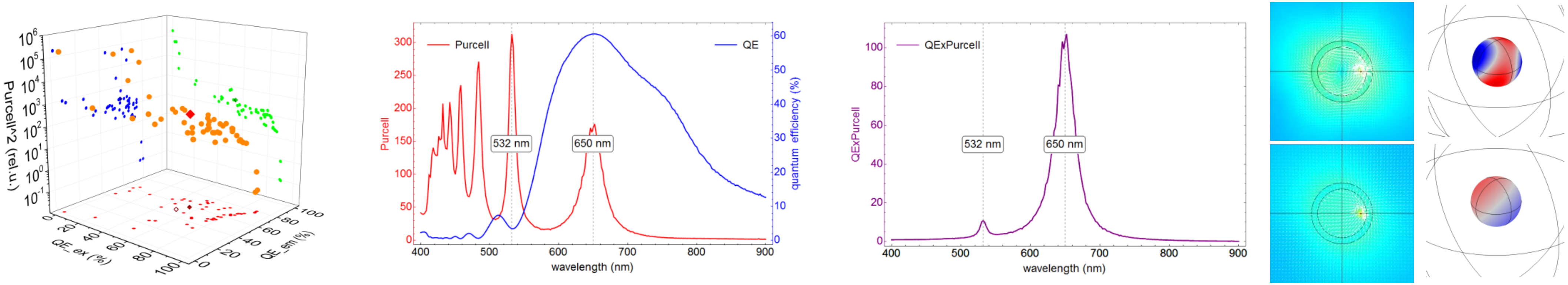
Smaller radiative rate

Larger radiative rate

	criterion (%)	P	Q(%)	Qcorr (%)	QxP	Δλ(nm)	2r(nm)	t(nm)	r/t	d(nm)	θ (°)	φ(°)
532	*20*	*124.51*	*58.24*		*72.52*	*8*	*61.84*	*13.17*	*2.35*	*9.97*	*34.42*	*173.72*
	shifted/central	*0.91*	*0.92*		*0.84*	*1.33*	*0.97*	*0.94*	*1.03*	*0.31*		
650	*50*	*158.88*	*50.77*		*80.66*	*-6*	*72.27*	*8.99*	*4.02*	*25.98*	*39.82*	*109.99*
	shifted/central	*1.12*	*0.78*		*0.87*	*-0.60*	*0.84*	*0.83*	*1.01*	*0.60*		
738	*20*	*426.05*	*52.48*	*51.39*	*223.58*	*4*	*72.32*	*6.16*	*5.87*	*32.64*	*10.16*	*143.51*
	shifted/central	*1.81*	*0.84*	*0.86*	*1.53*	*-2.00*	*0.44*	*0.82*	*1.07*	*0.79*		

NV and SiV color center excitation & emission enhancement, Ag

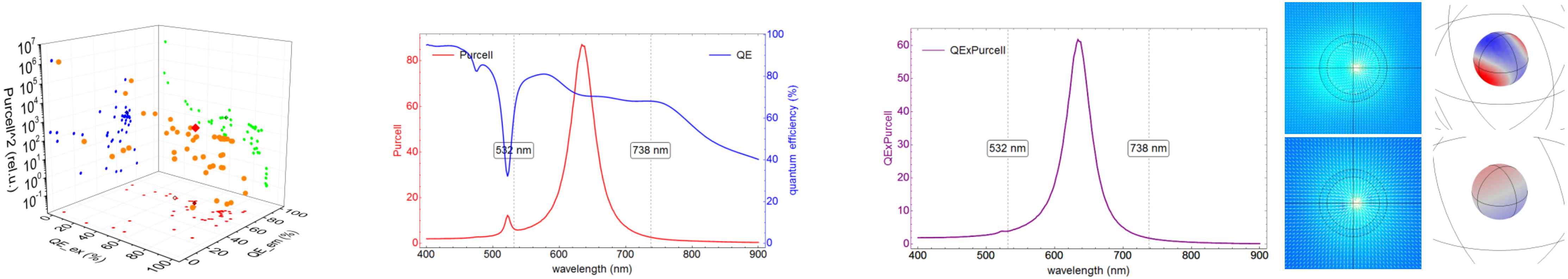
Dual wavelengths, Purcell maximization with QE criterion; de-centralized dipole



NV

Capable of resulting in enhancement at both wavelengths, better/weaker excitation/emission via de-centralized dipole

					emission											
criterion (%)	P	Q(%)	QxP	Δλ(nm)	criterion	P	Q(%)	QxP	Δλ(nm)	QxP^2	2r(nm)	t(nm)	r/t	d(nm)	θ (°)	φ(°)
0	283.71	3.51	9.94	0	40	203.56	60.61	123.38	2	1226.92	83.10	10.57	3.93	9.52	47.48	123.04
shifted/central	31.20	0.17	5.19	0.00		0.05	6.06	0.29	-	1.51						



SiV

Capable of resulting in enhancement at both wavelengths, better/weaker excitation/emission via de-centralized dipole

excitation					emission												
criterion (%)	P	Q(%)	QxP	Δλ(nm)	criterion	P	Q(%)	Qcorr (%)	QxP	Δλ(nm)	QxP^2	2r(nm)	t(nm)	r/t	d(nm)	θ (°)	φ(°)
40	3.18	0.64	2.04	-8	60	1.47	68.18	9.59	1.00	-104	2.05	94.09	13.51	3.48	40.47	33.31	15.75
shifted/central	1.31	0.02	2.28	-0.04		2.55E-4	3.59	0.51	9.15E-04	-	2.08E-3						

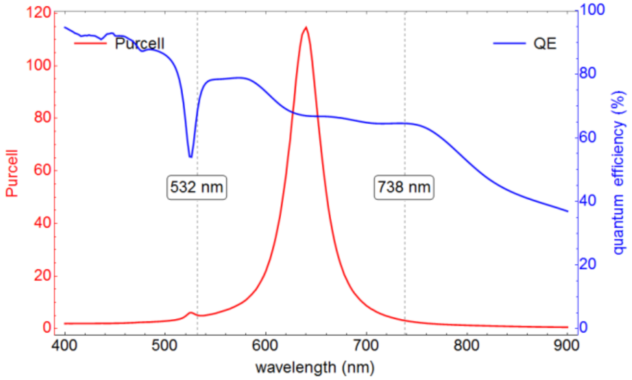
NV and SiV color center excitation & emission enhancement, Ag

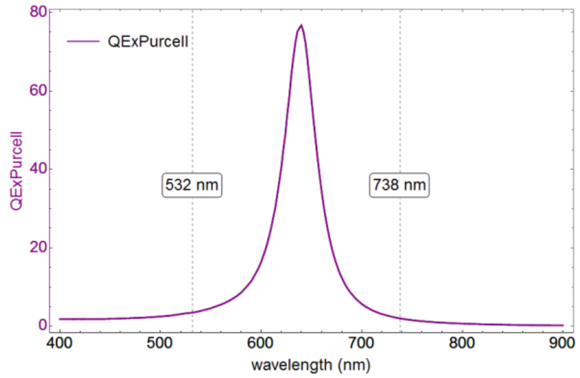
Dual wavelength, Purcell^2 maximization, de-centralized dipole, corrected QE criterion

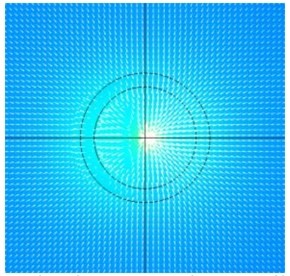
WRT non-corrected
Excitation: better QE, smaller Purcell*QE, larger detuning
Emission: better Purcell, Purcell*QE, smaller detuning

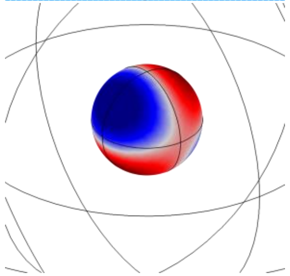
WRT to central
Excitation: better QE, larger Purcell*QE, smaller detuning
Emission: better QE

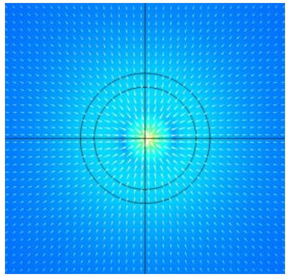
SiV

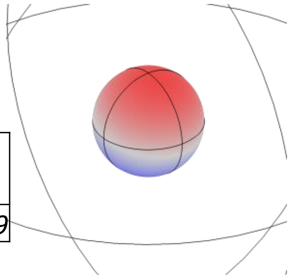












excitation					emission												
criterion (%)	P	Q(%)	QxP	Δλ(nm)	QEcorr criterion (%)	P	Q(%)	Qcorr (%)	QxP	Δλ(nm)	QxP^2	2r(nm)	t(nm)	r/t	d(nm)	θ (°)	φ(°)
70	2.38	71.42	1.70	108	10	1.72	64.82	10.42	1.12	-98	1.90	89.27	12.11	3.69	41.44	12.73	190.09
corr/non-corr	0.75	111.22	0.83	-13.50		1.17	0.95	1.09	1.11	0.94	0.92						
corr/central	0.97	1.94	1.89	0.52		2.98E-04	3.41	0.55	1.02E-03	-	0.00						

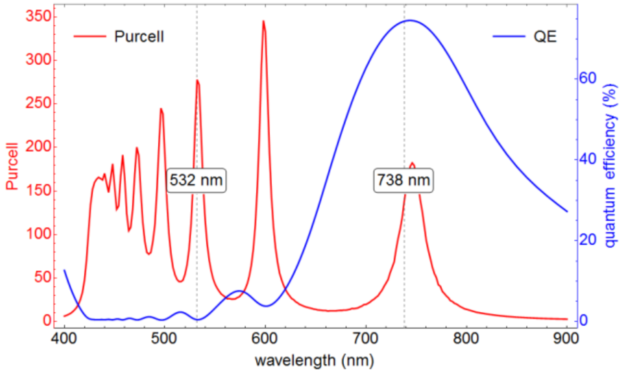
NV and SiV color center excitation & emission enhancement, Ag

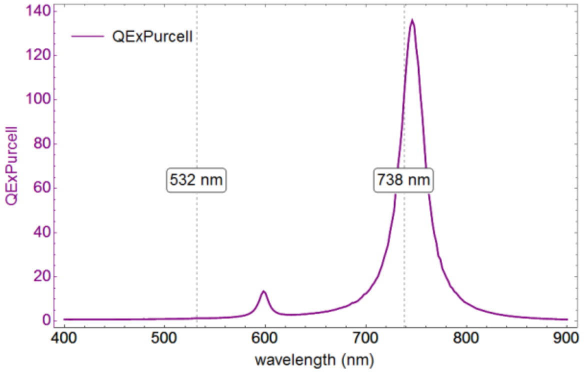
Dual wavelength, QExPurcell^2 maximization, de-centralized dipole, corrected QE criterion

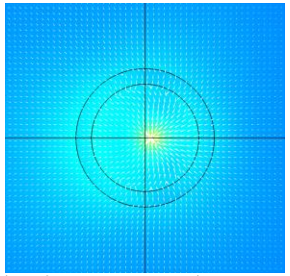
WRT non-corrected
Excitation: better QE, smaller Purcell*QE, larger detuning
Emission: better Purcell, QE, Purcell*QE, smaller detuning

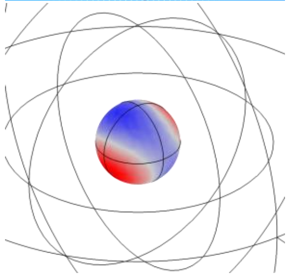
WRT to central
Excitation: better Purcell, larger Purcell*QE, smaller detuning
Emission: better QE

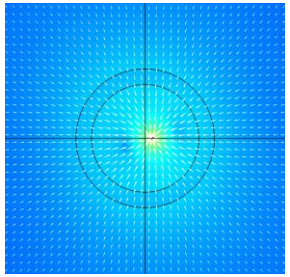
SiV

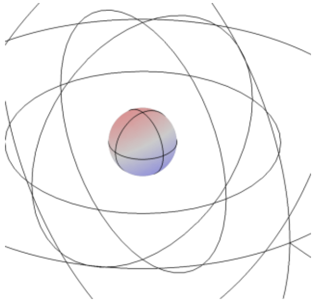












excitation					emission												
criterion (%)	P	Q(%)	QxP	Δλ(nm)	QEcorr criterion (%)	P	Q(%)	Qcorr (%)	QxP	Δλ(nm)	QxP^2	2r(nm)	t(nm)	r/t	d(nm)	θ (°)	φ(°)
0	167.31	0.70	1.17	66	10	230.64	74.30	71.51	171.37	8	200.35	99.66	8.99	5.54	10.67	70.38	148.71
corr/non-corr	52.56	1.09	0.57	-8.25		156.59	1.09	7.46	170.64	-0.08	97.61						
corr/central	68.65	0.02	1.30	0.32		0.04	3.91	3.77	0.16	-	0.20						

Conclusions on core-shell type nano-resonators

- Single wavelength optimization
  - Purcell*QE radiative rate enhancement increases with the wavelength
  - Radiative rate enhancement is smaller than 10^3
  - Optimization results in better QE and Purcell*QE enhancement in Ag-based core-shells

- Dual wavelength optimization
  - Purcell*QE enhancement is larger at the emission wavelength except configuration_Au_SiV_Purcell
  - In optimized configurations_532-650/738 the radiative rate enhancement smaller/larger than 10^3
  - Material dependence of radiative rate at the excitation and emission
    - slightly and more considerably larger in configuration_Ag_Purcell&QE for NV
    - slightly smaller and significantly larger in configuration_Ag_Purcell&QE for SiV

  - Dual with respect to single wavelength optimization
    - larger QE at the excitation in Au based core-shells in case of 532-650 and 532-738
    - larger Purcell*QE at the emission, smaller detuning both in Au and Ag-based configuration_Au/Ag_QE

- De-centralized with respect to centralized
    - Larger Purcell * QE at 738 nm single wavelength, and at the excitation in both cases of NV and SiV

- De-centralized with corrected QE criterion optimized for P^2 and Purcell*QE^2
  - smaller/larger excitation rate than in case of de-centralized /centralized, optimized with QE
  - larger/smaller emission rate than in case of de-centralized /centralized, optimized with QE.

Acknowledgements

SZÉCHENYI 2020

Európai Unió
Európai Szociális Alap

MAGYARORSZÁG KORMÁNYA

BEFEKTETÉS A JÖVŐBE

The research was supported by National Research, Development and Innovation Office-NKFIH through project “Optimized nanoplasmonics” K116362.

Maria Csete acknowledges that the project was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

BOLYAI ÖSZTÖNDÍJ 2015

Lóránt Zsolt Szabó

András Szenes

Balázs Bánhelyi

Prof. Tibor Csendes

Gábor Szabó

A. Szenes, B. Bánhelyi, L. Zs. Szabó, G. Szabó, T. Csendes, M. Csete: "*Enhancing diamond color center fluorescence via optimized plasmonic nanorod configuration*", Plasmonics, DOI: 10.1007/s11468-016-0384-1