Photoluminescence excitation spectra in T-shaped quantum wires

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Outline

- About T-wire
- Experimental method and results
- Computational method
- Comparison and Discussion

about "T-shaped quantum wire"

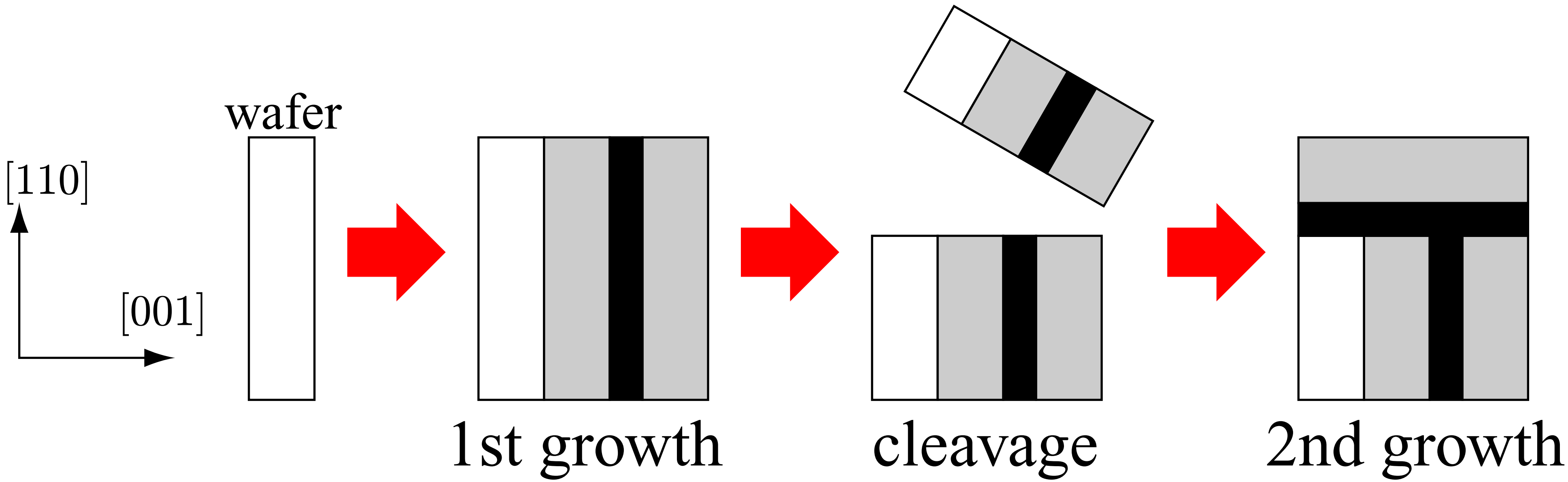
quantum wire

- quasi one-dimensional system
- interest on physics and application

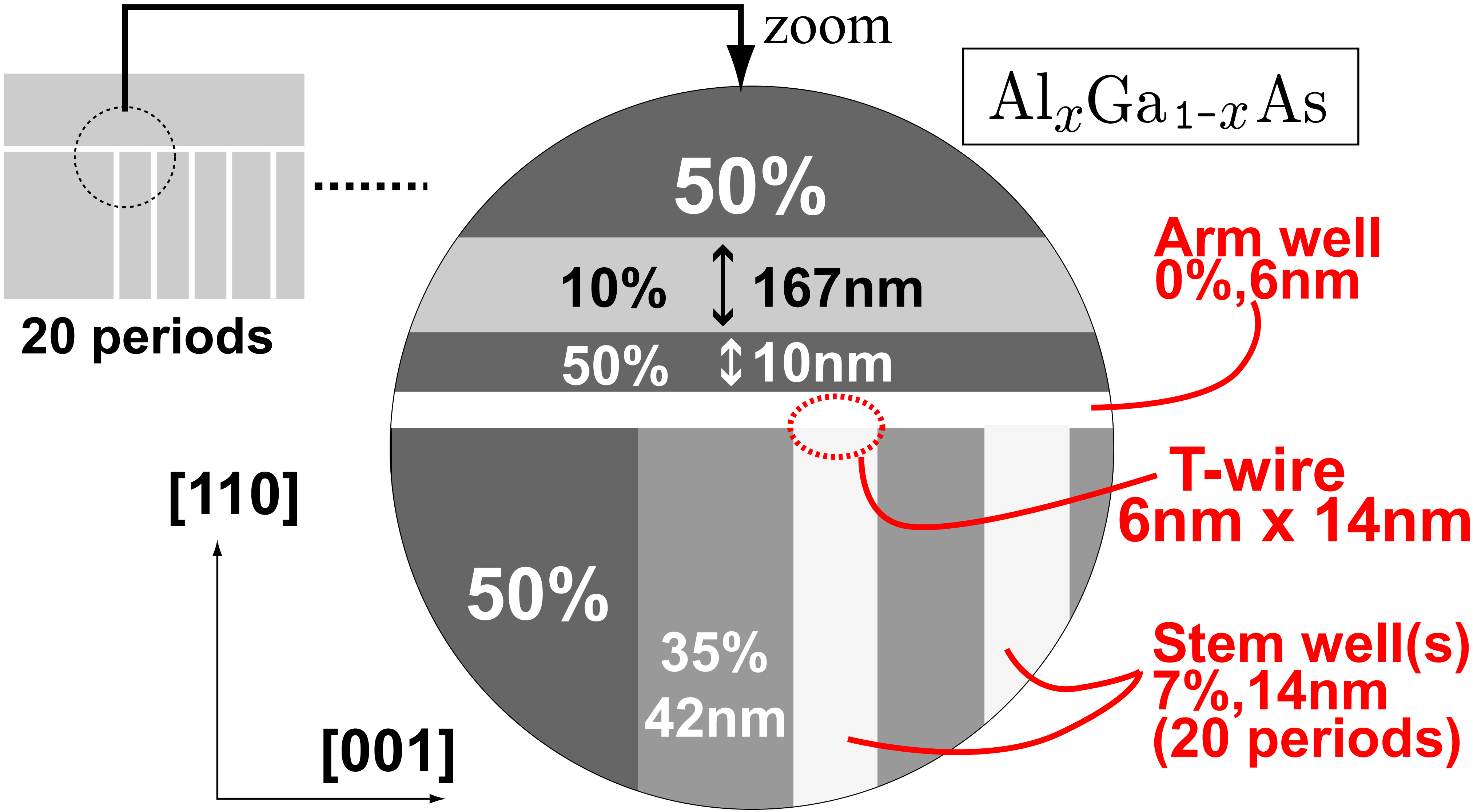
T-shape

- 2-stepped growth of quantum well (cleaved edge overgrowth)

→ the intersection of them behaves as a quantum wire

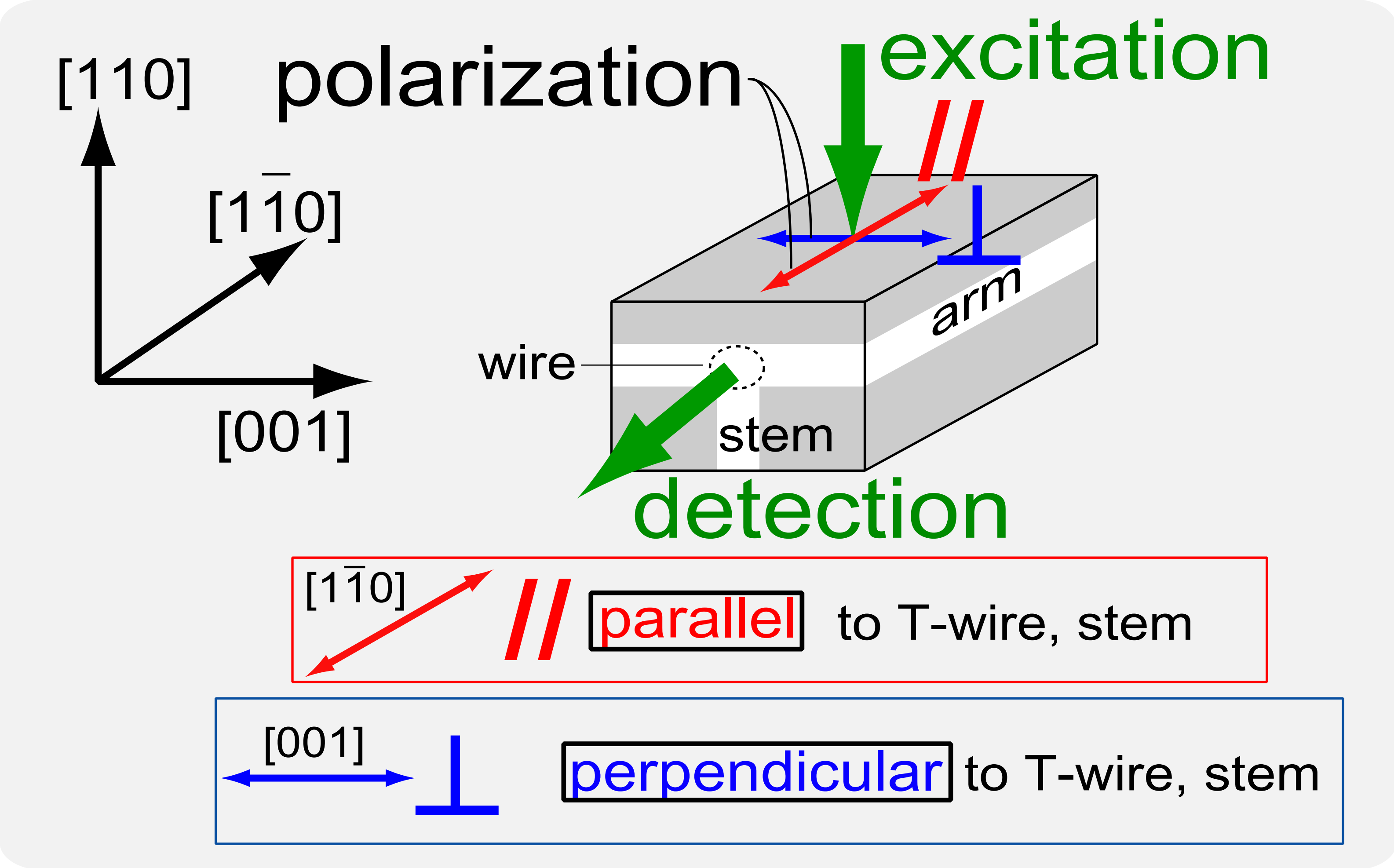


details of the quantum wires



20 T-wires (6nm x 14nm) are formed at the intersections of "Arm well"(6nm) and "Stem well"s (14nm)

Experimental method (PLE)

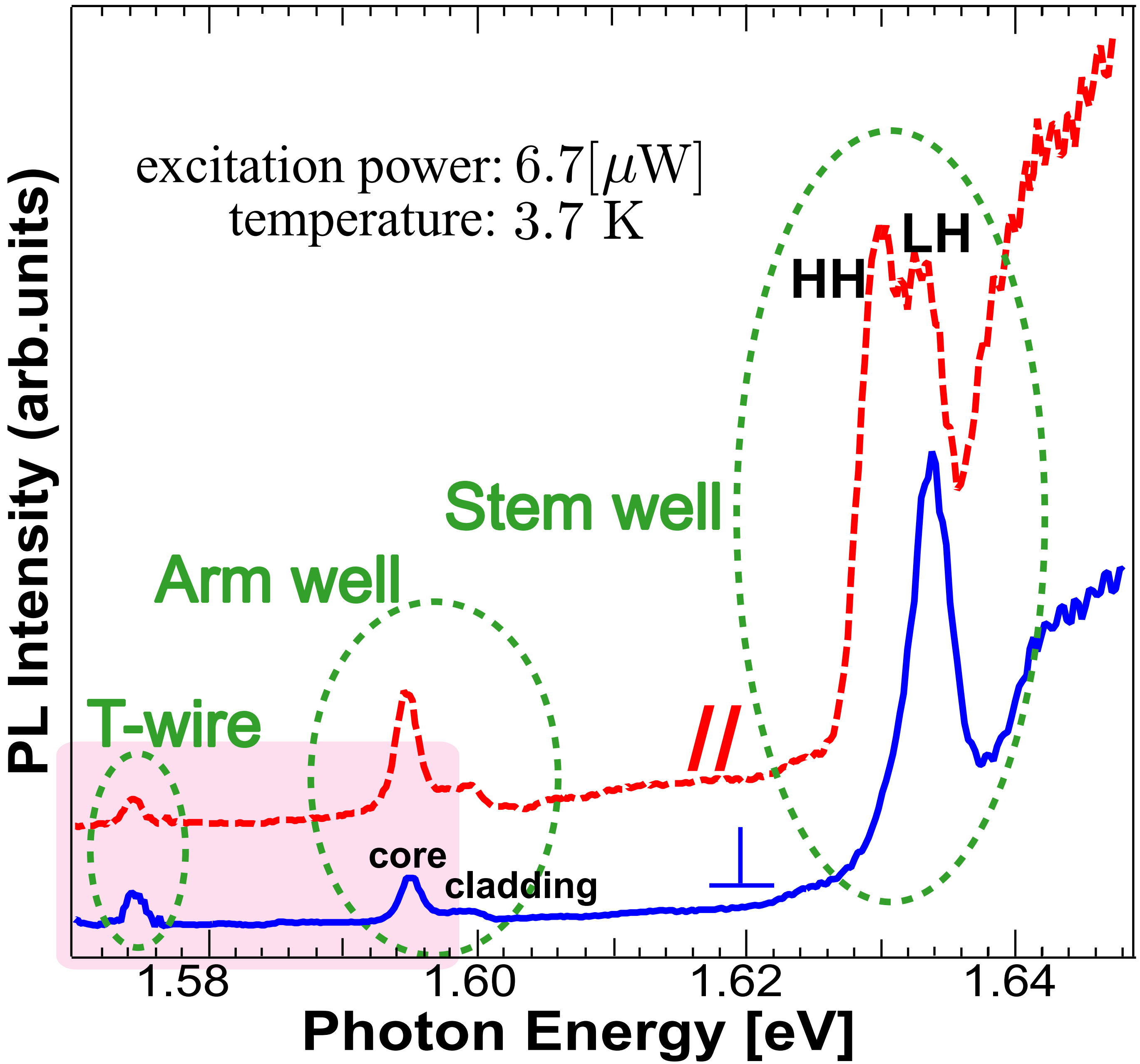


excited at: $\sim 7[\mu \mathrm{W}]$

~ 4 K (in cryostat)

by: tunable cw-TiS laser (resolution: 0.3 [meV])

Experimental results (overview)

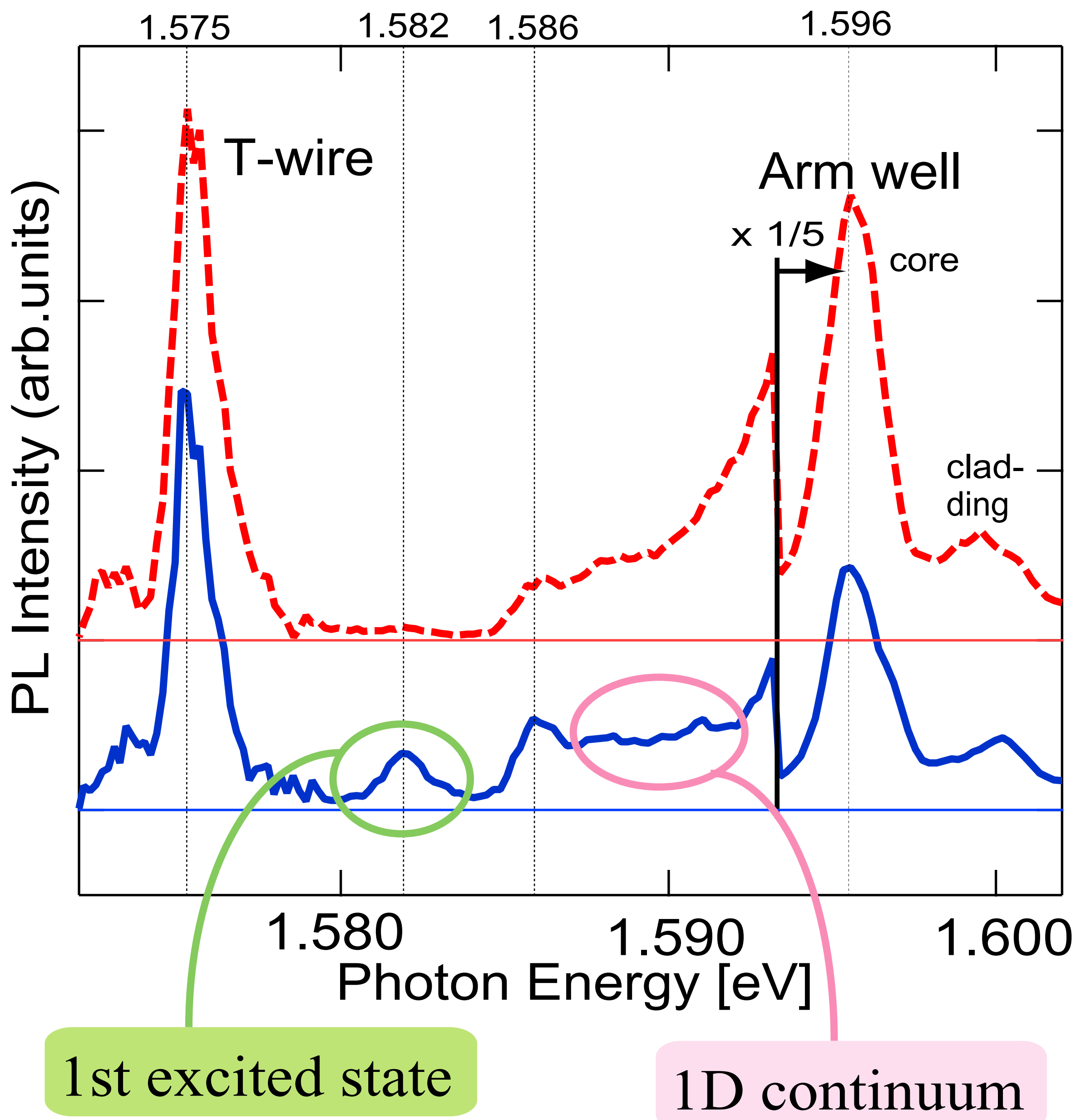


PLE spectrum of T-wire sample

* Typical optical anisotropy in both "Stem well" and "Arm well"

* Physics of quantum wire exists in pink region

Experimental results (detail)



- 1D continuum state

  ~~$\propto E^{-\frac{1}{2}}$ (1D DoS)~~

  suppressed by strong Coulomb interaction

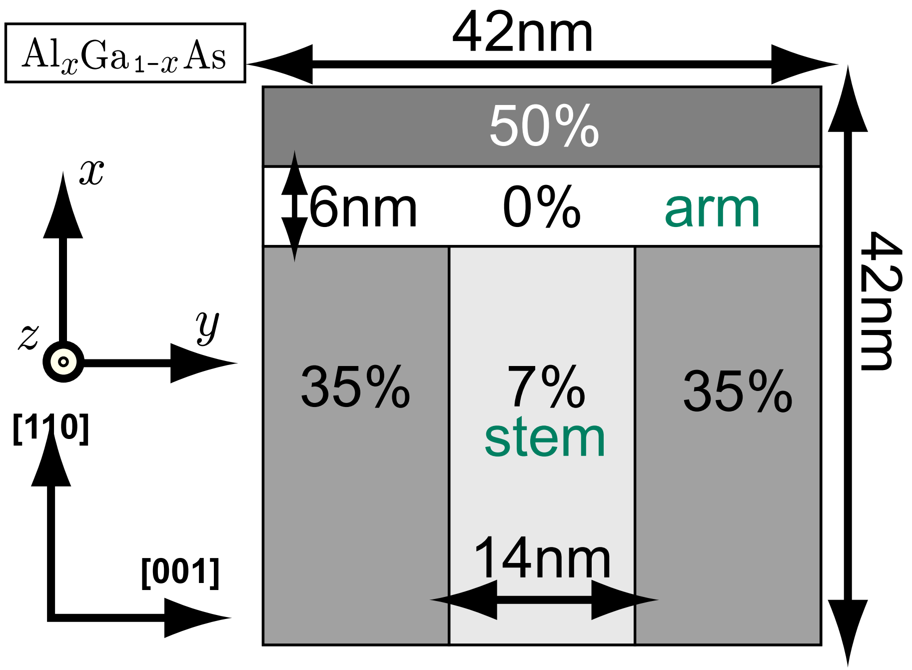
  Ogawa and Takagahara PRB **43** 14325 (1991)

- "1st excited state"

  excitonic state of electron in 1st subband and hole in 2nd subband

  Szymanska *et al.* PRB **63** 205317 (2001)

The computational method by Szymanska *et al.*



$$\mathcal{H} = \mathcal{H}_e + \mathcal{H}_h + q$$

$\mathcal{H}_e$, $\mathcal{H}_h$: one-particle Hamiltonian of an electron and a heavy hole (effective mass approximation)

q: Coulomb interaction

diagonalized by the basis set of:

$$\sum_{i,j,k} c_{i,j,k} \sin\left(\frac{z\pi}{L_z}k - \frac{\pi}{2}k\right) \chi_i^e(x_e, y_e) \chi_j^h(x_h, y_h)$$

- $\sin\left(\frac{z\pi}{L_z}k - \frac{\pi}{2}k\right)$: plane wave in z axis
- $\chi_i^e(x_e, y_e)$: one-particle electron
- $\chi_j^h(x_h, y_h)$: one-particle heavy hole

$\longrightarrow$ $\Psi_n(x_e, y_e, x_h, y_h, z)$

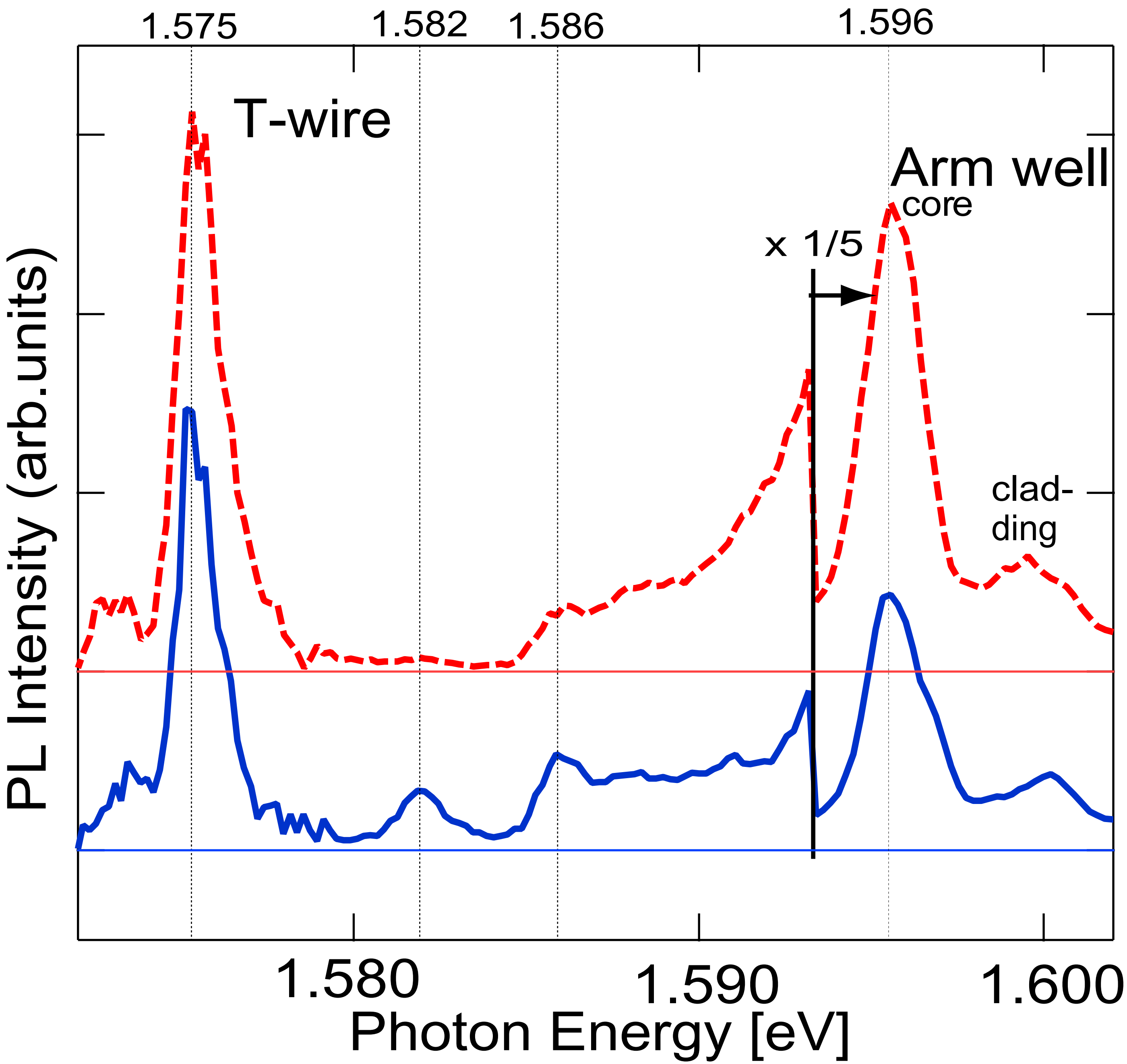
n: number of the states

$z = z_e - z_h$

$\longrightarrow$ relative axis

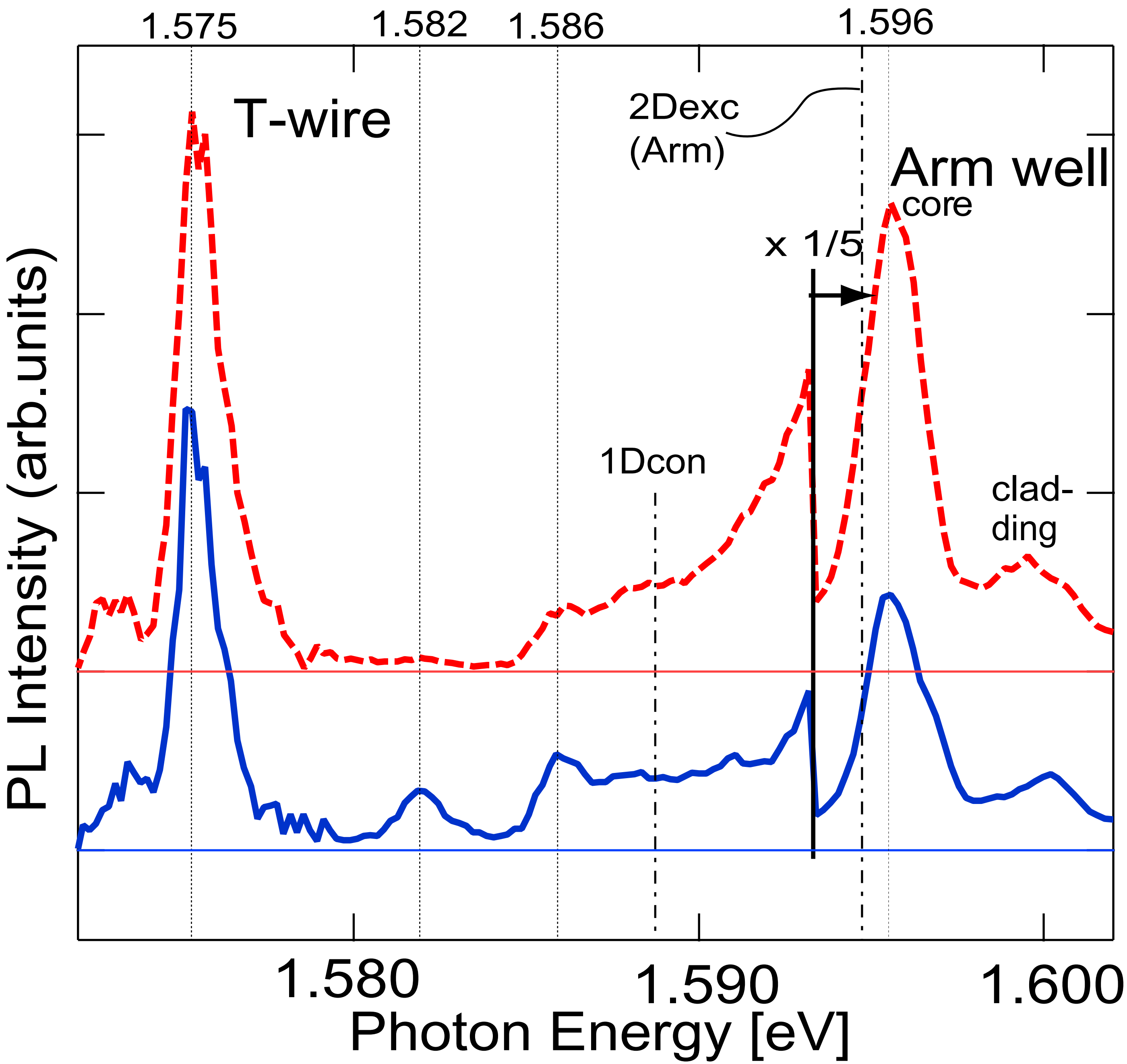
(and the energy of 1D-continuum and 2D exciton, also)

comparison



1.575
1.582
1.586
1.596
T-wire
Arm well
core
x 1/5
clad-
ding
PL Intensity (arb.units)
1.580
1.590
1.600
Photon Energy [eV]

comparison



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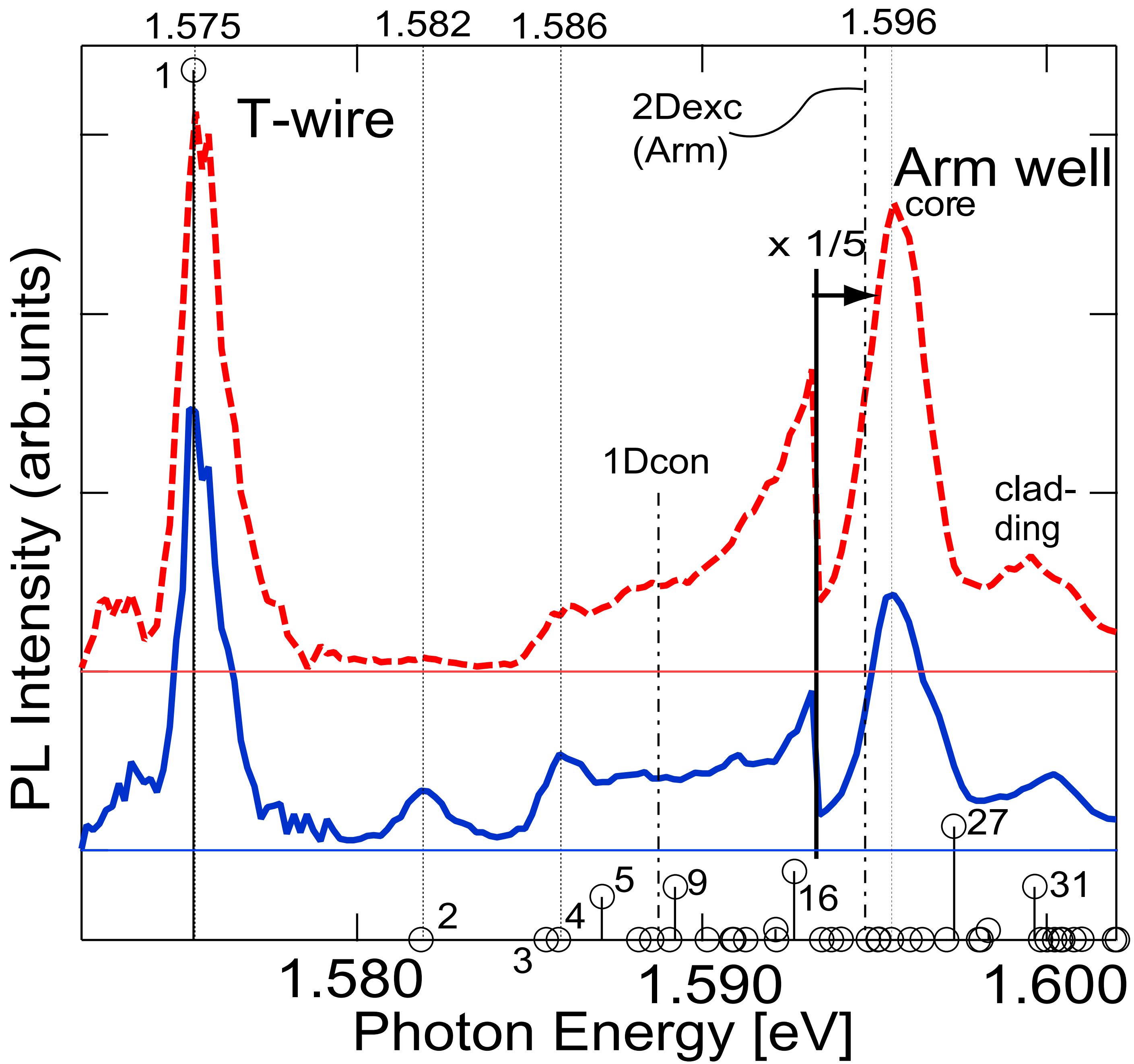
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9
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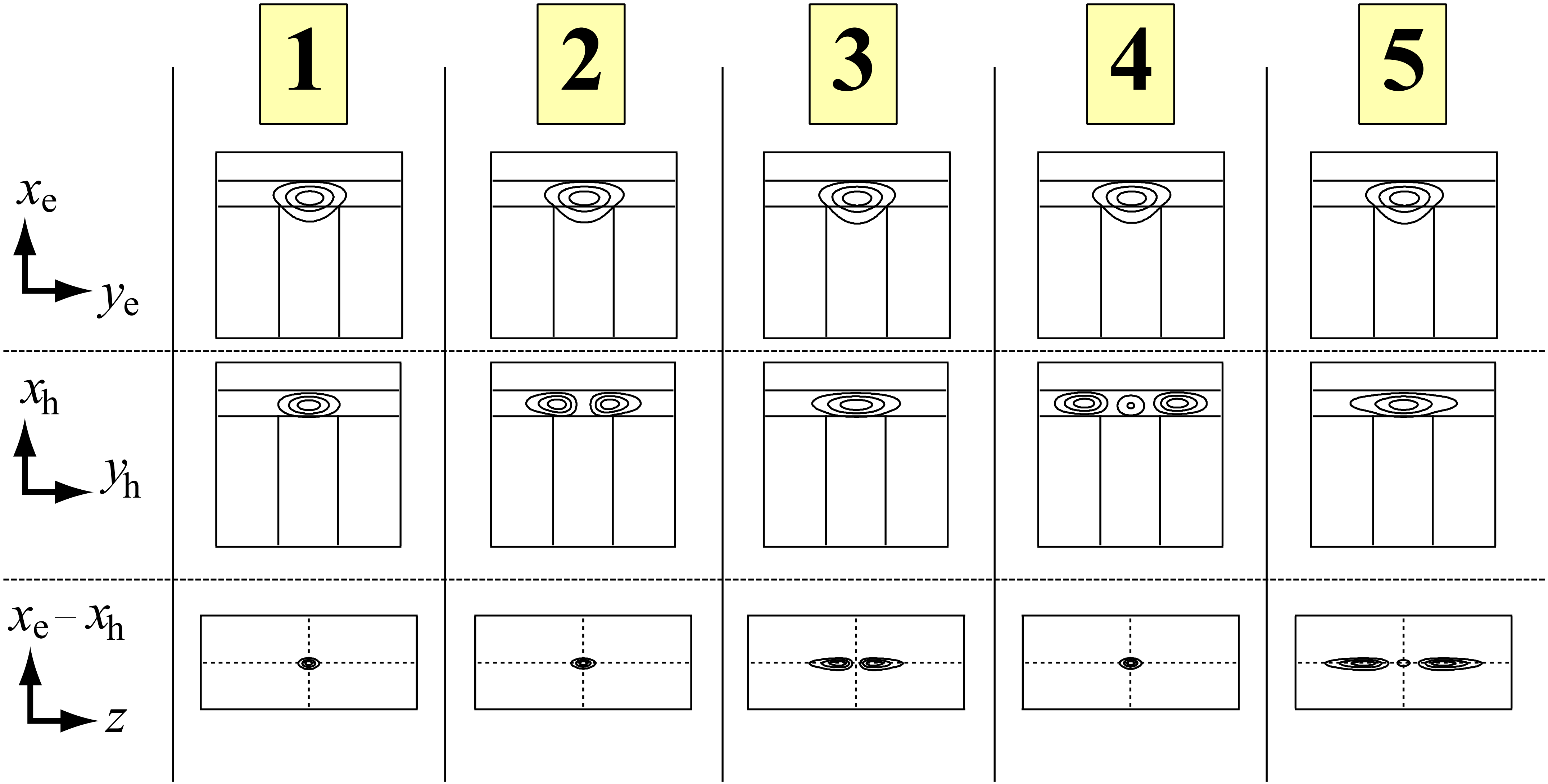
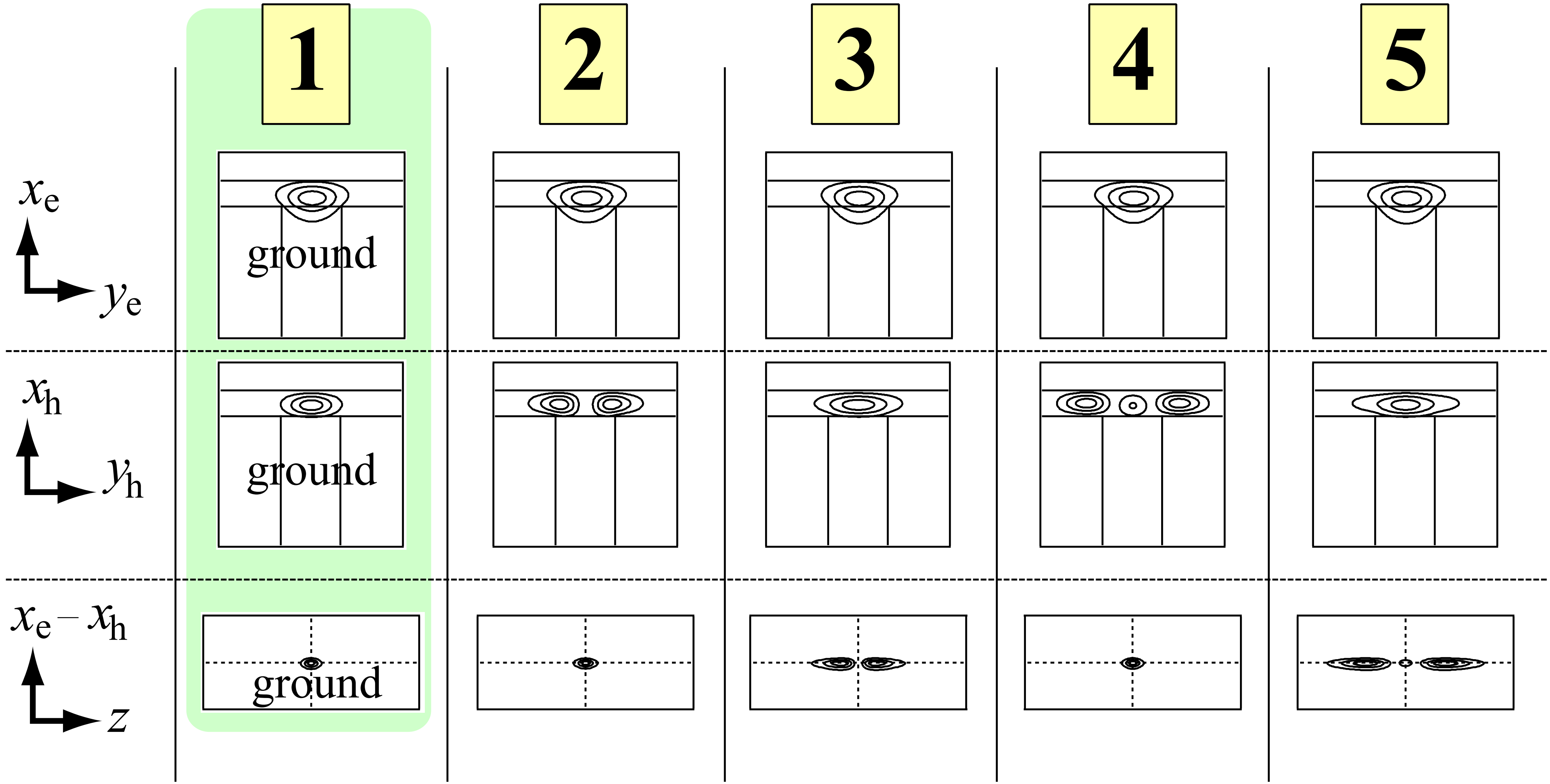
Photon Energy [eV]
PL Intensity (arb.units)

wavefunction (1 - 5)

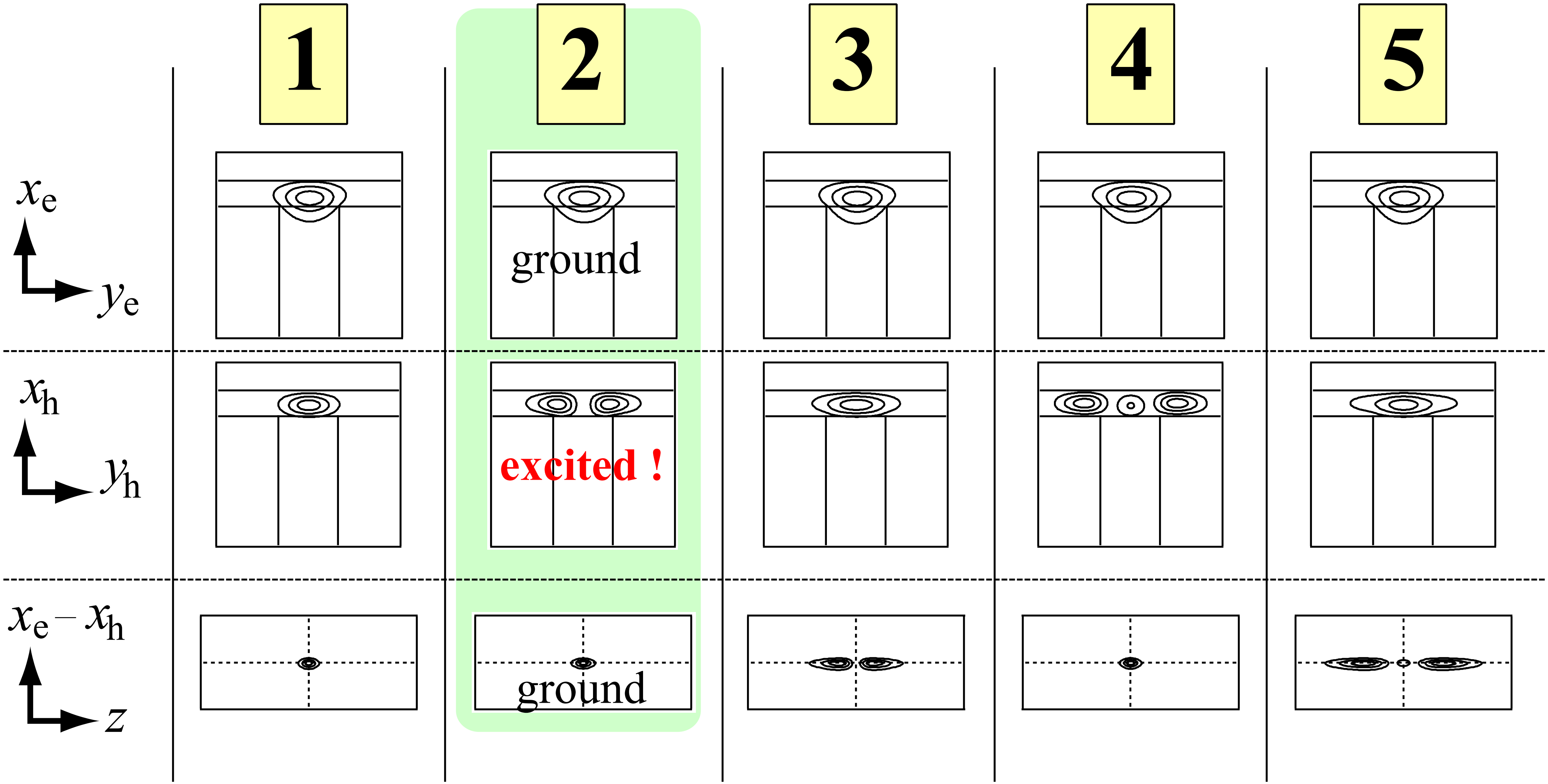


wavefunction (1 - 5)



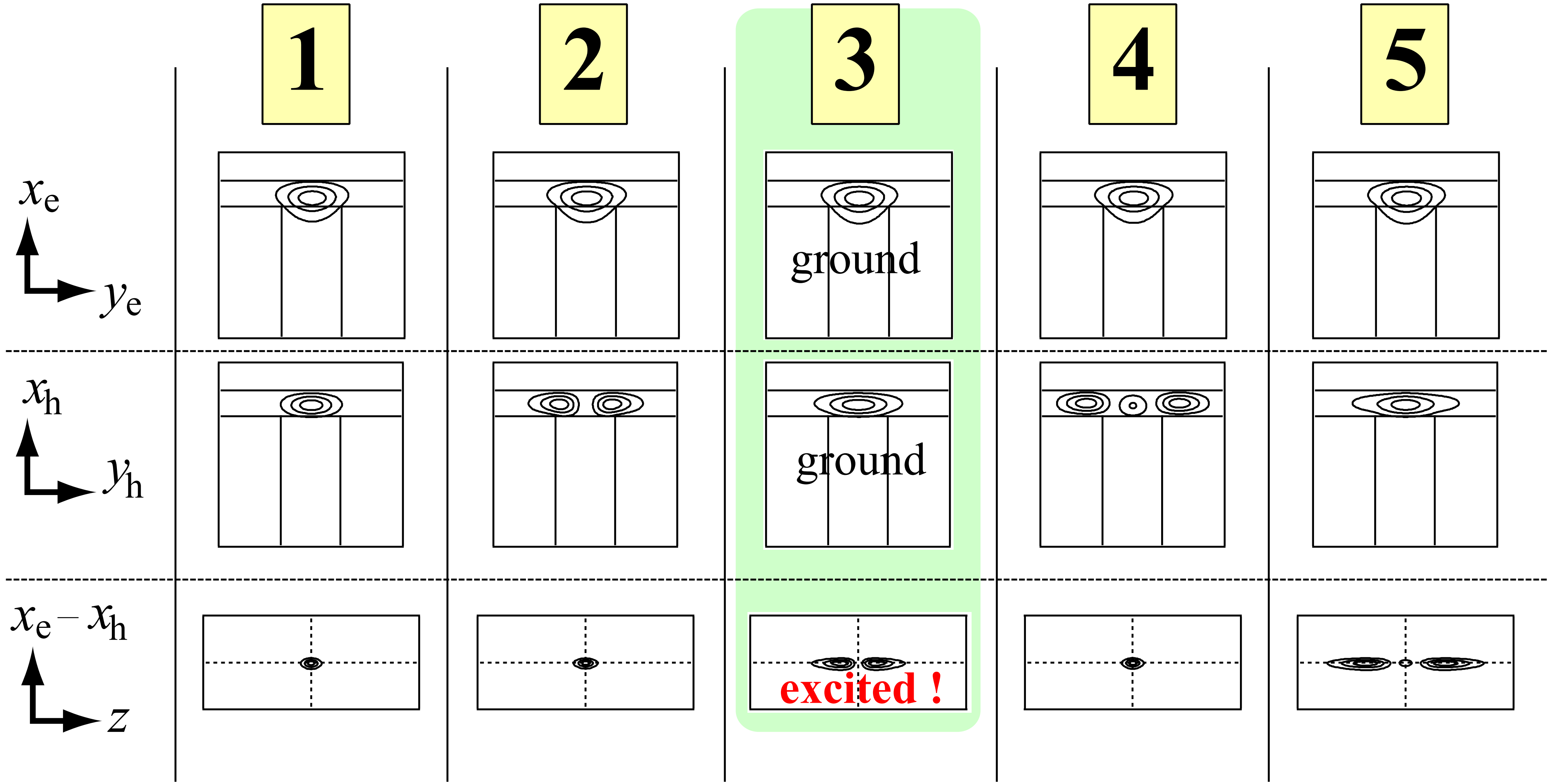
ground state (no node)

wavefunction (1 - 5)



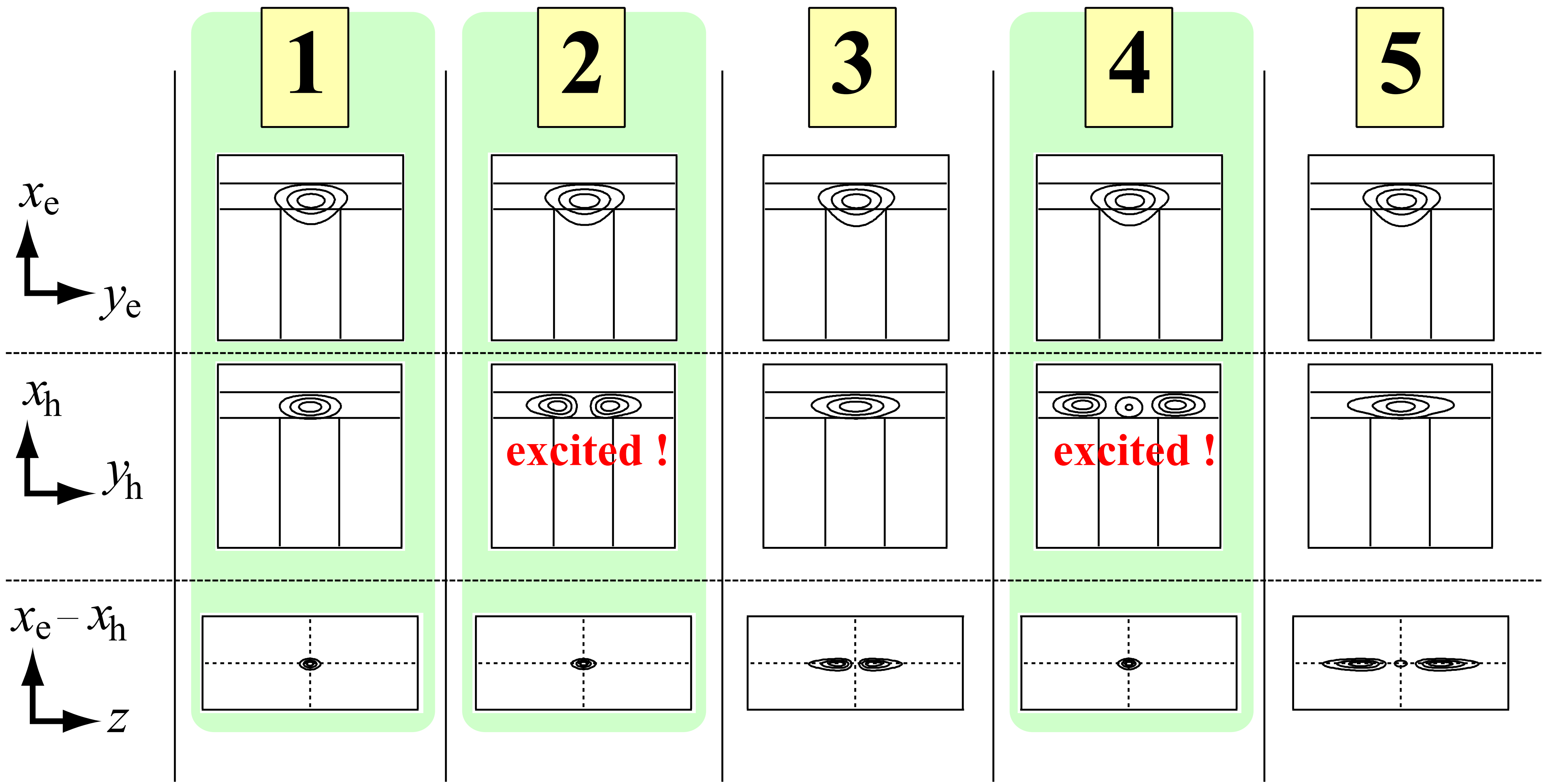
2nd state (hole excited)

wavefunction (1 - 5)



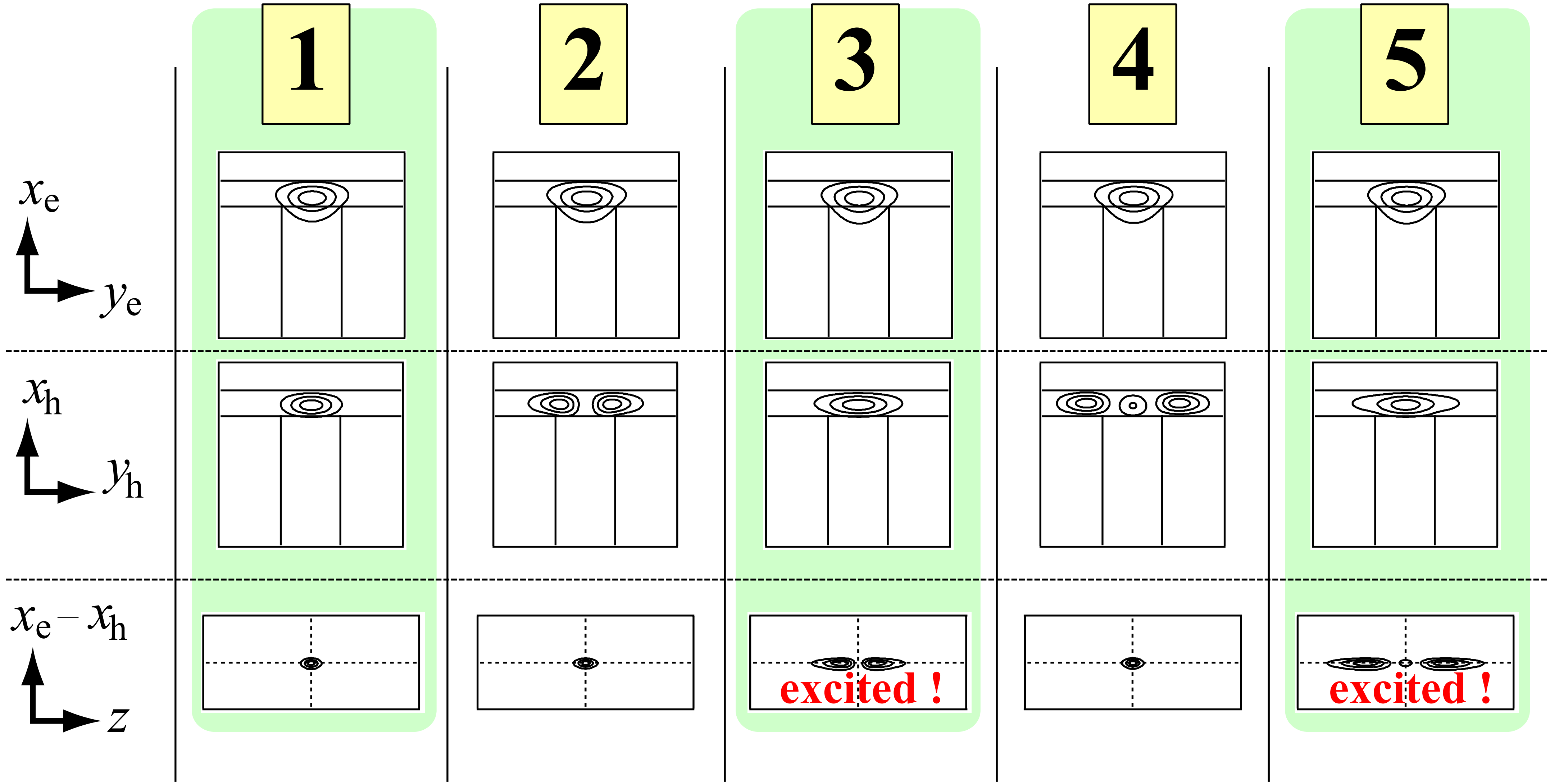
3rd state (exciton excited)

wavefunction (1 - 5)



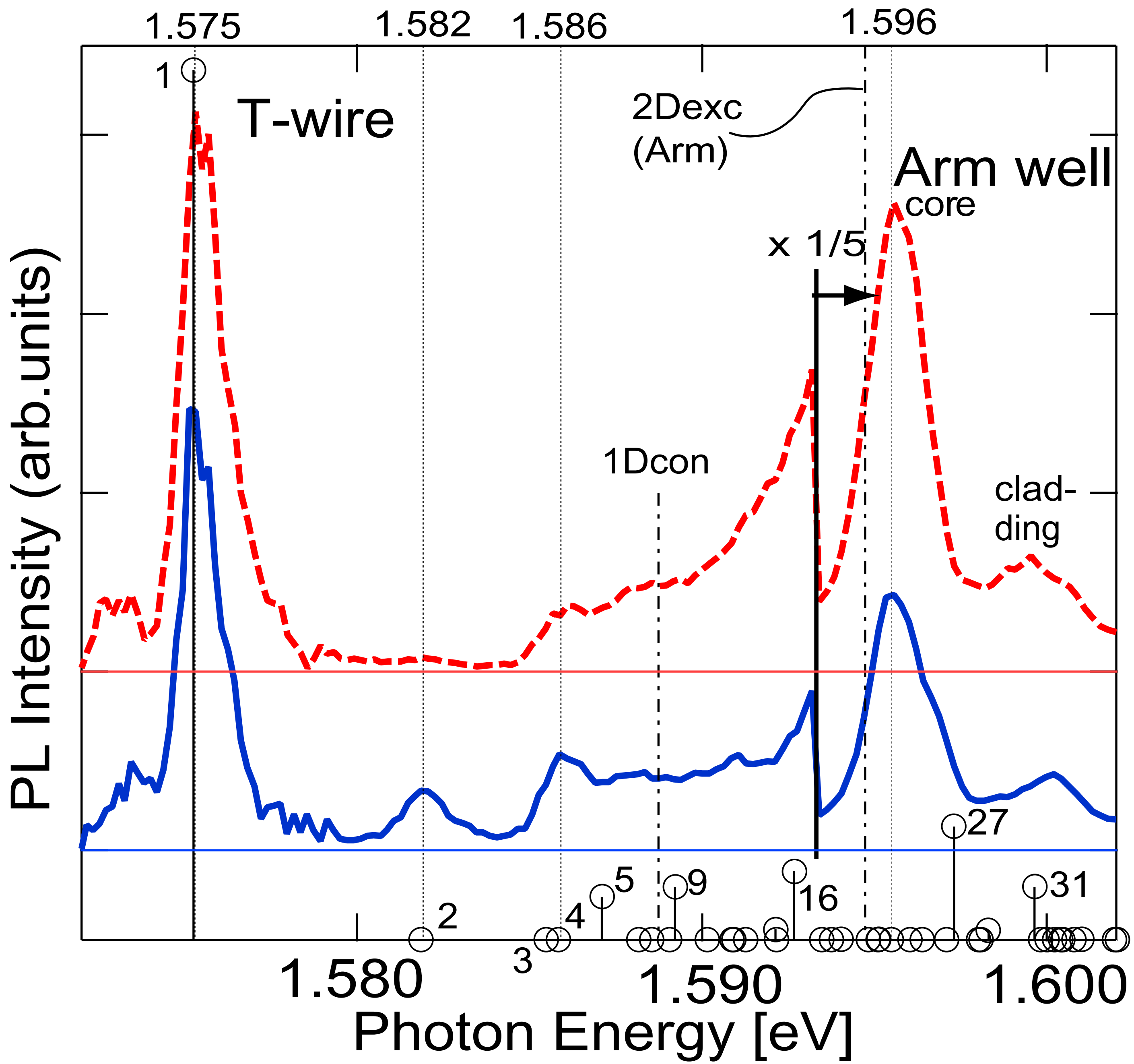
"excited hole" series

wavefunction (1 - 5)



exciton Rydberg series

comparison



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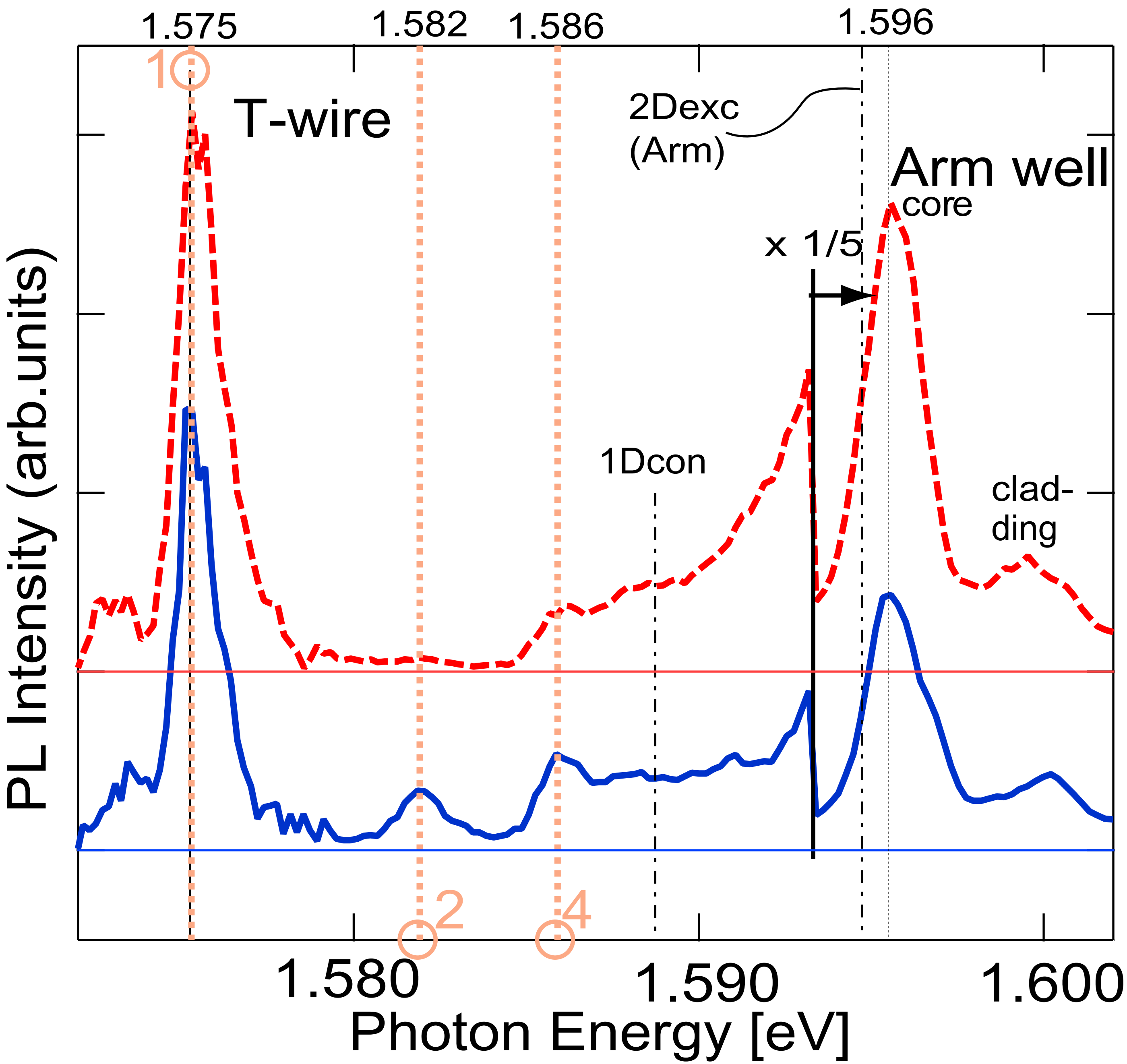
Photon Energy [eV]
PL Intensity (arb.units)

comparison



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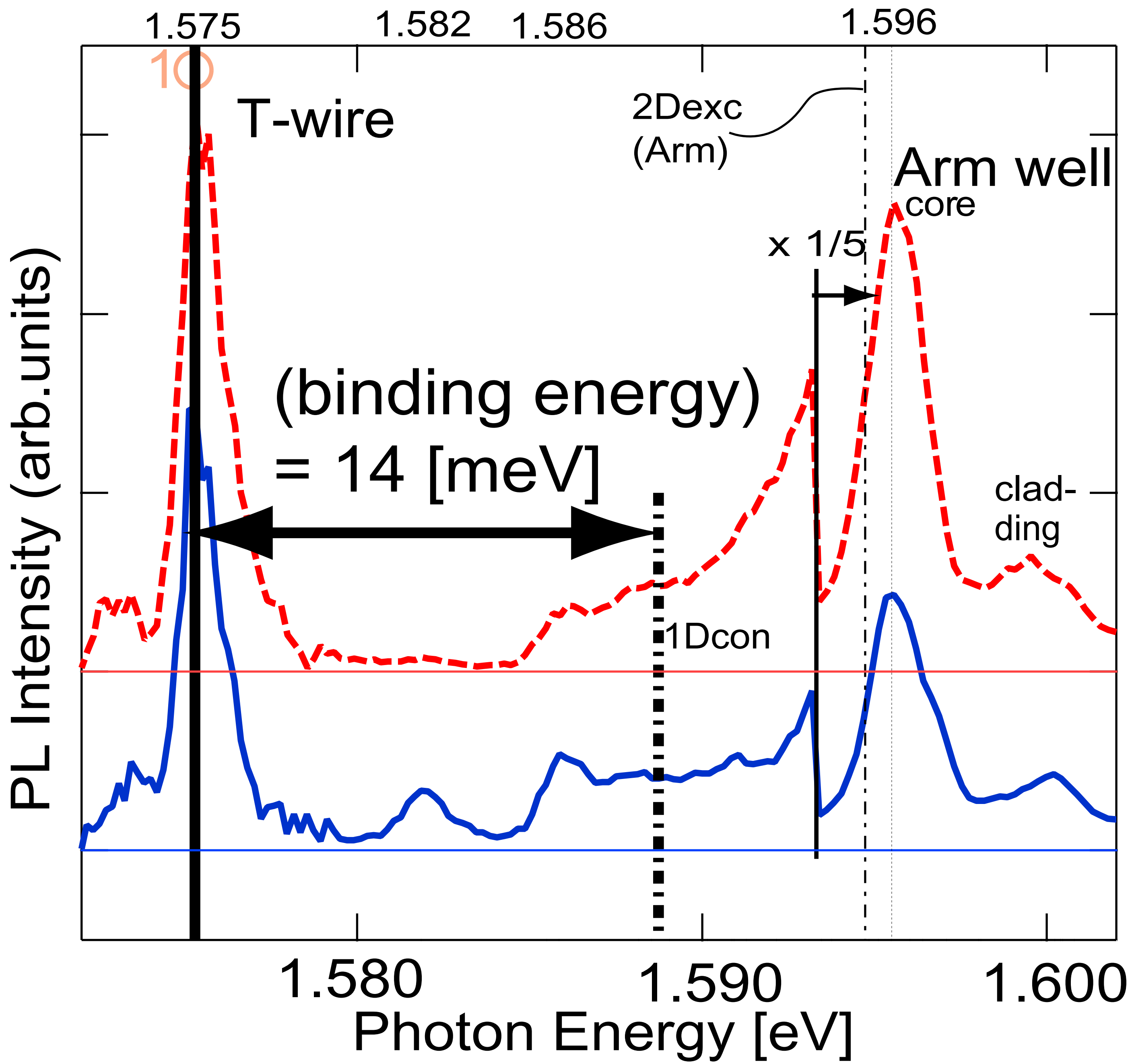

1.575
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1D
T-wire
2Dexc
(Arm)
Arm well
core
x 1/5
(binding energy)
= 14 [meV]
clad-
ding
1Dcon
PL Intensity (arb.units)
1.580
1.590
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Photon Energy [eV]

summary

conclusion

- T-wire exciton ground state and 1D continuum states were separately observed.

- The oscillator strength of T-wire exciton ground state is very large, while the absorption of 1D continuum states is small. **(Nature of 1D system)**

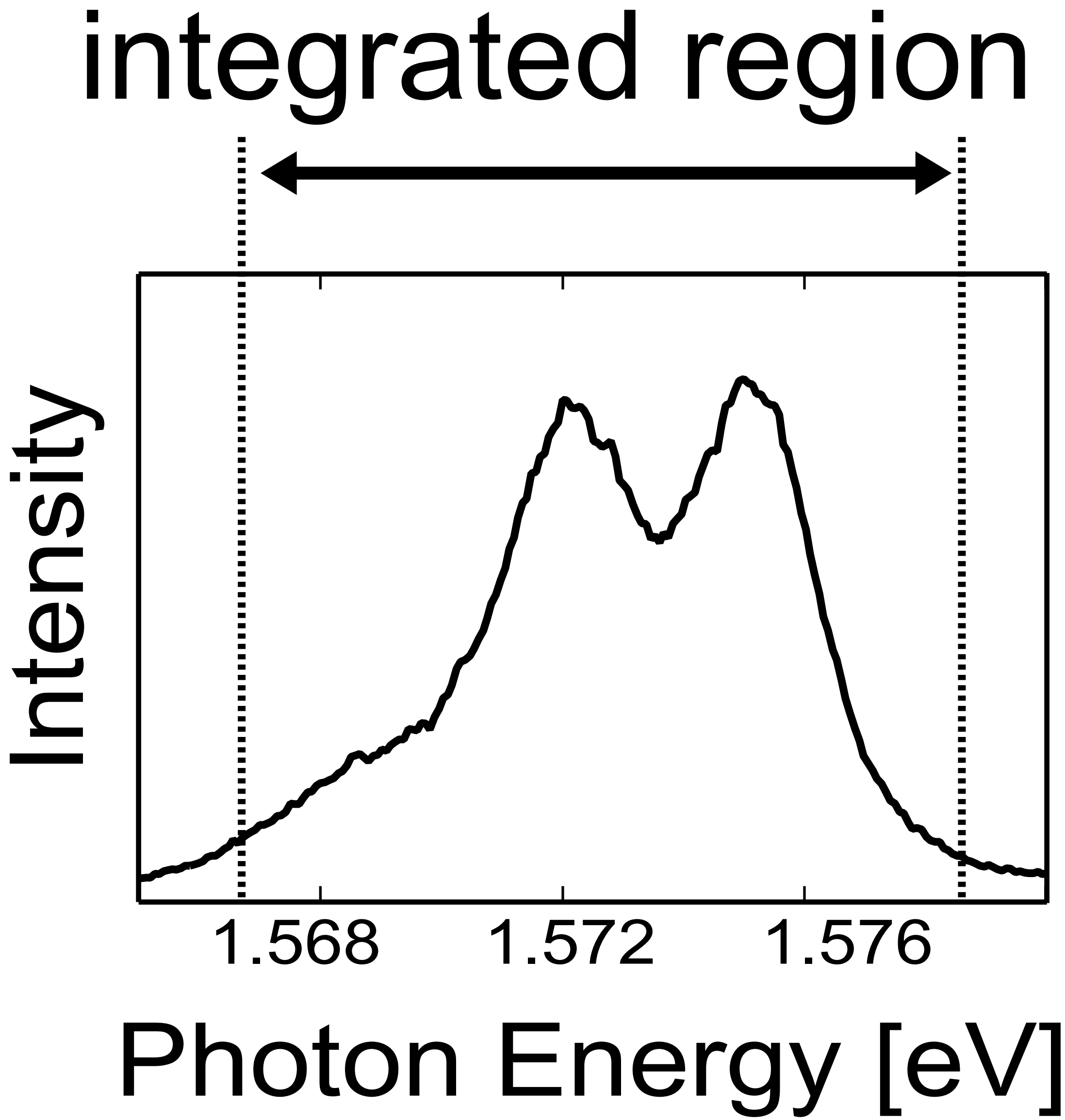
- The binding energy of the T-wire exciton is 14 [meV]

- We attribute some small peaks to the exciton states consisting of excited hole subbands.

future problem

- A calculation in the form of Luttinger Hamiltonian

probed region



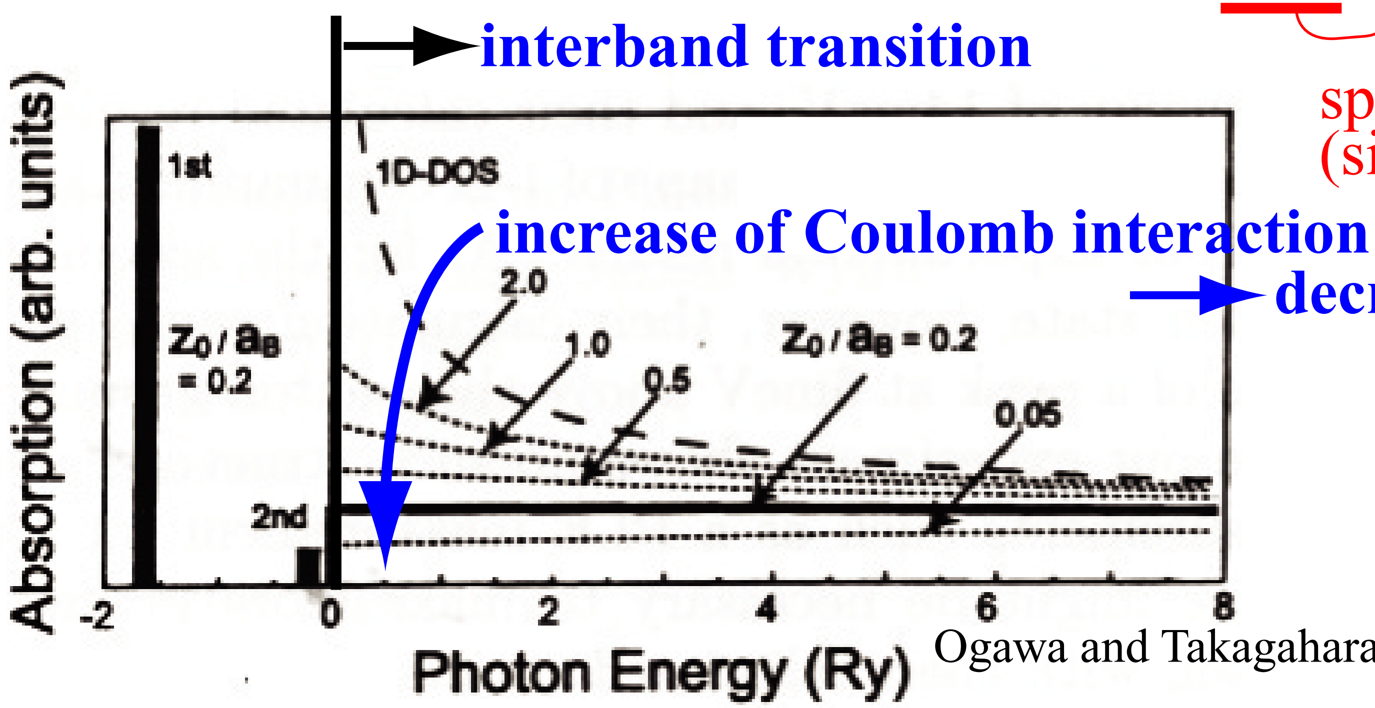
PL spectrum
excited at 758[nm]
(1.635[eV])

The computational method by Ogawa *et al.*

Exactly calculated optical absorption spectra in 1D electron-hole system.

To avoid divergence of E_b, the potential $-\dfrac{e^2}{\epsilon(|z|+z_0)}$ is introduced.

spreading of the system
(size of the wire)

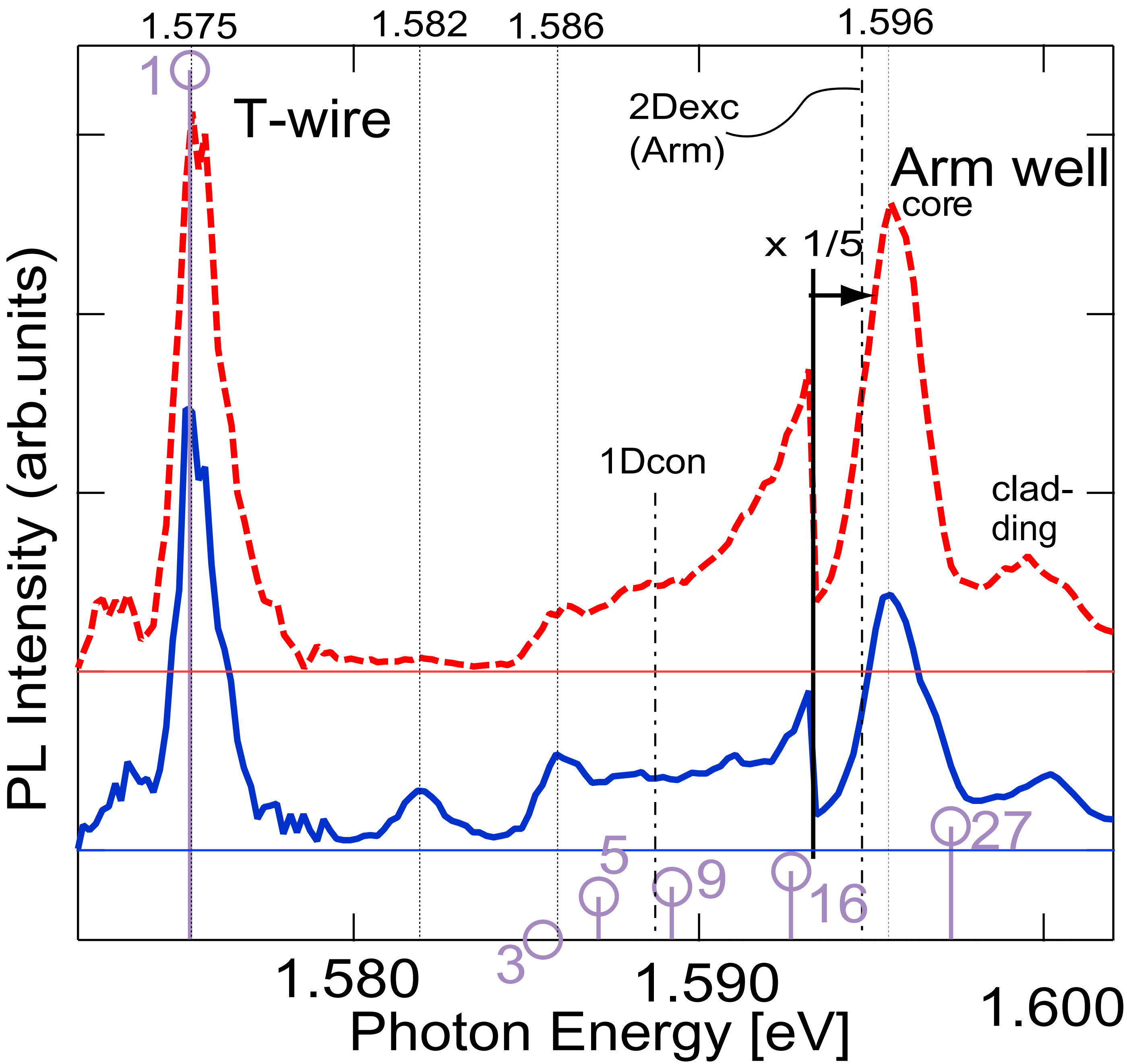


Ogawa and Takagahara PRB **43** 14325 (1991)

Sommerfelt factor $S_{1D} < 1$ --- specific in 1D system cf. S_{2D}, $S_{3D} > 1$

$$S \equiv \frac{\text{absorption with Coulomb potential}}{\text{absorption without Coulomb potential}}$$

comparison



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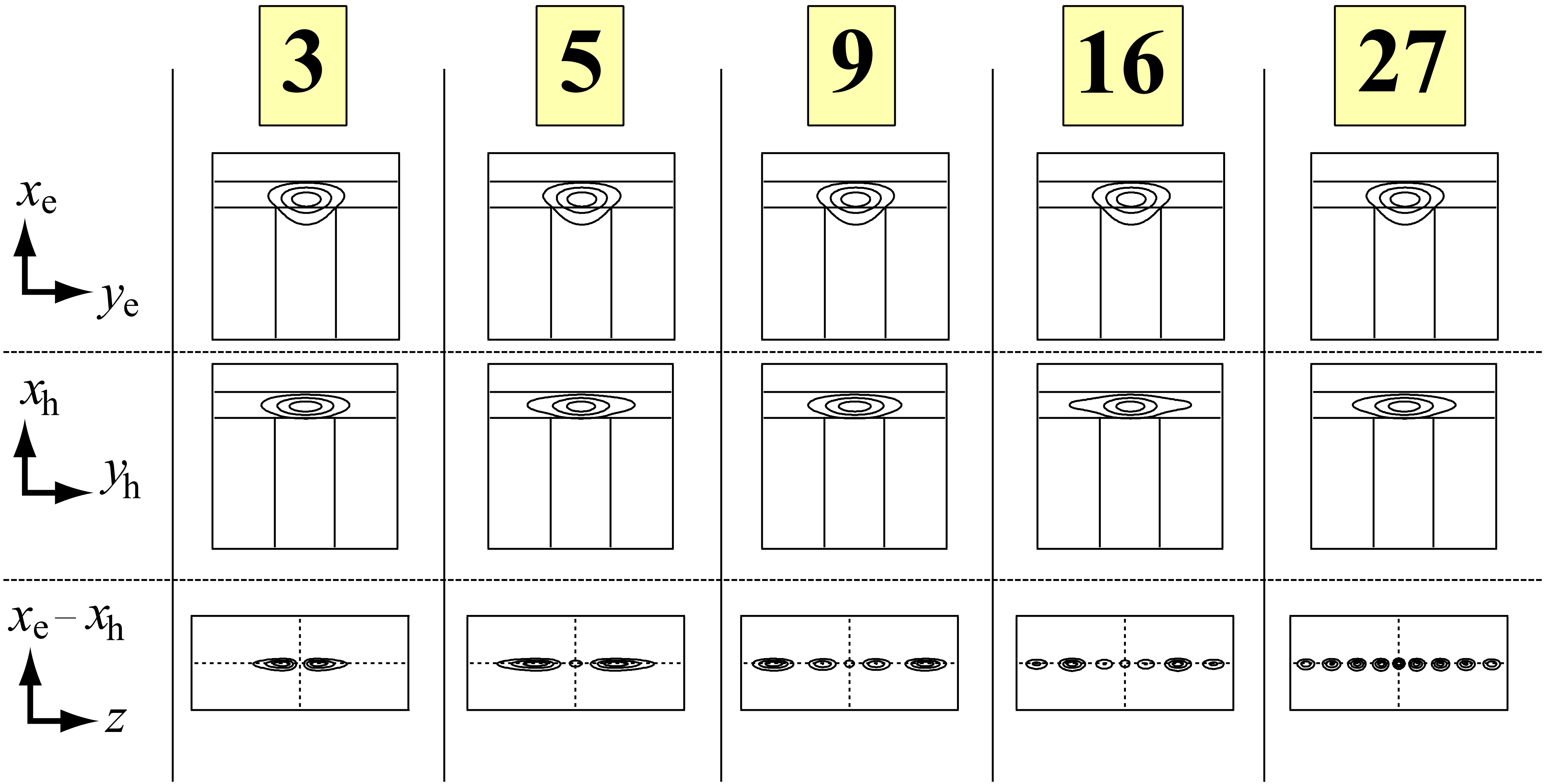
wavefunction (3, 5, 9, 16, 27)



exciton Rydberg series