High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

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INTERNATIONAL SUMMER SCHOOL ON FLUORESCENT NANO-PARTICLES IN BIO-MEDICINE
XlX Escuela Internacional de Verano Nicolás Cabrera, 15-20 de Julio de 2012

High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

- Background
- Experimental results
  - CdTe vs size
  - CdTe vs temperature
  - CdTe vs CdSe
  - CdTe as thermal sensor in microfluidic
- Conclusions

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- Background

Thermal sensing at the micro/nano scale

- Integrated photonics
- micro/nano electronics
- Biomedicine

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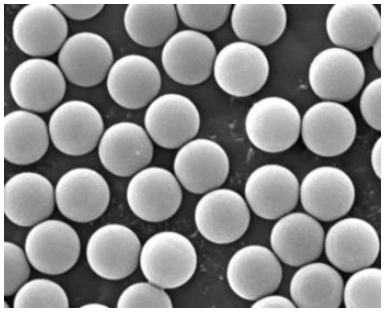
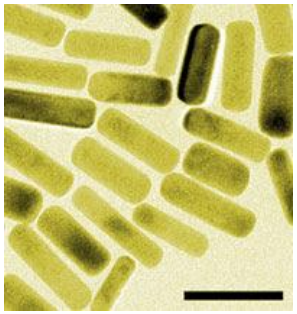
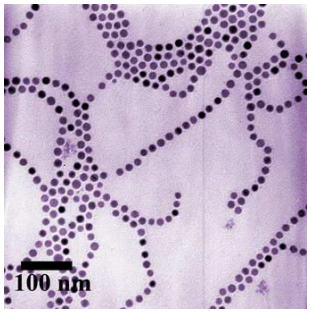
- Background







Nanometric sized materials

(QDs, nanotubes, nanospheres…)

System to study

(microfluidics, living cells)

High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

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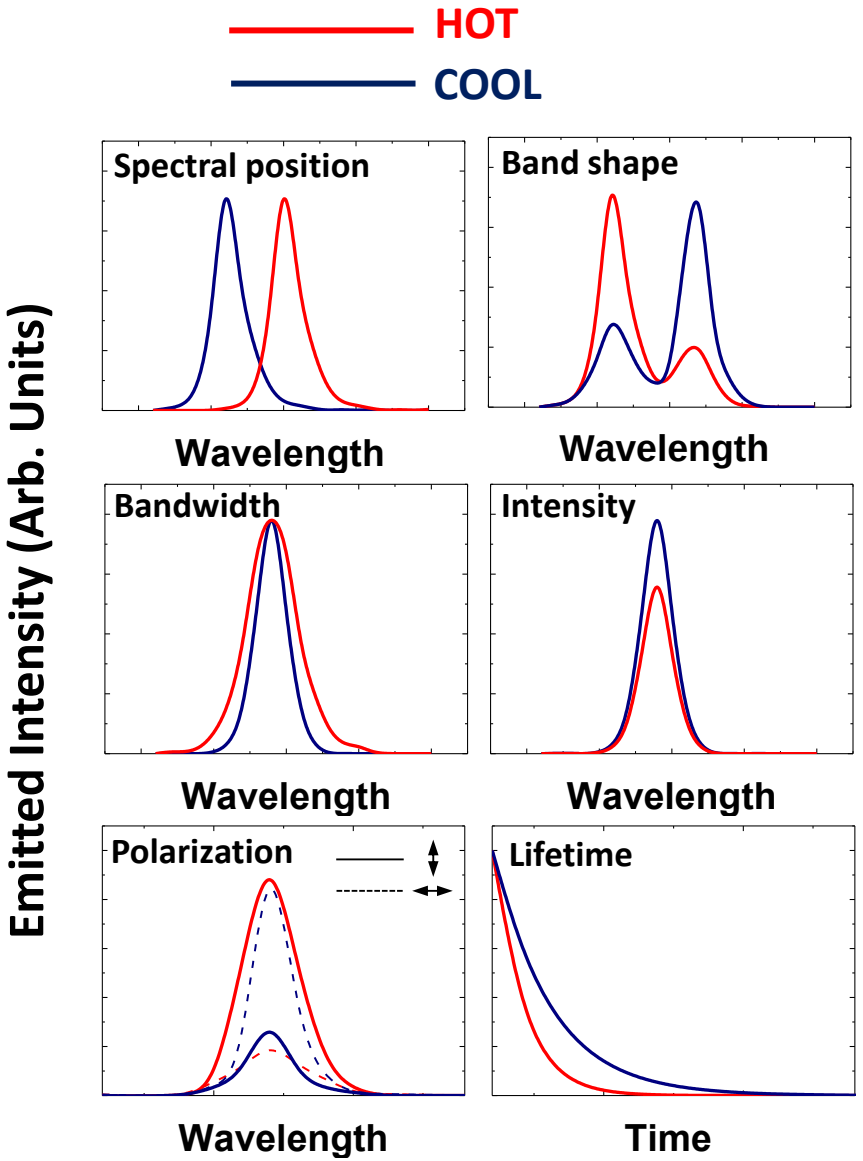
Optical nanothermometry is based on the analysis of temperature-induced changes in the optical properties of materials.

Schematic representation of the possible effects caused by a temperature increment on the luminescence. Red lines correspond to higher temperatures.



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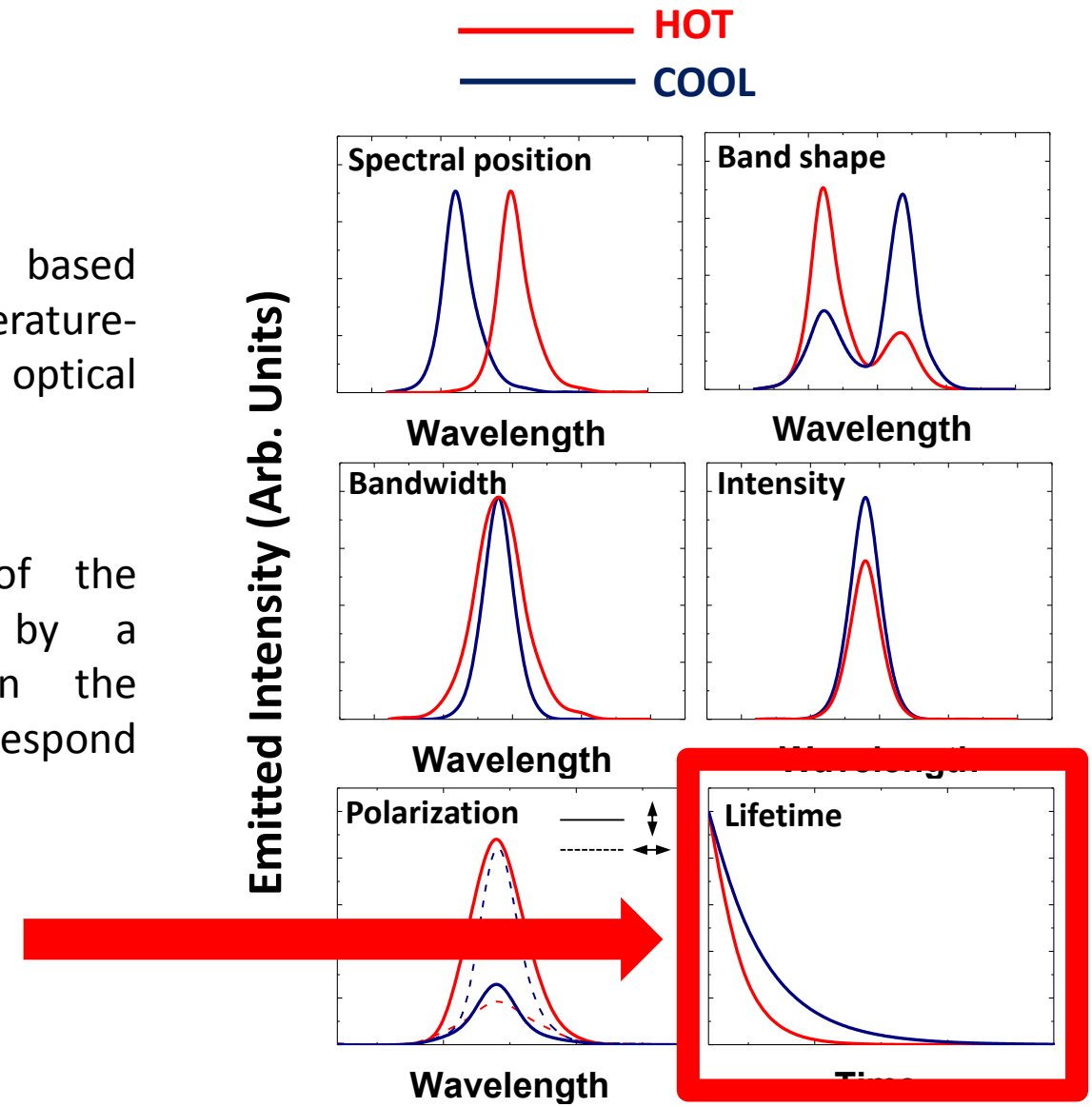
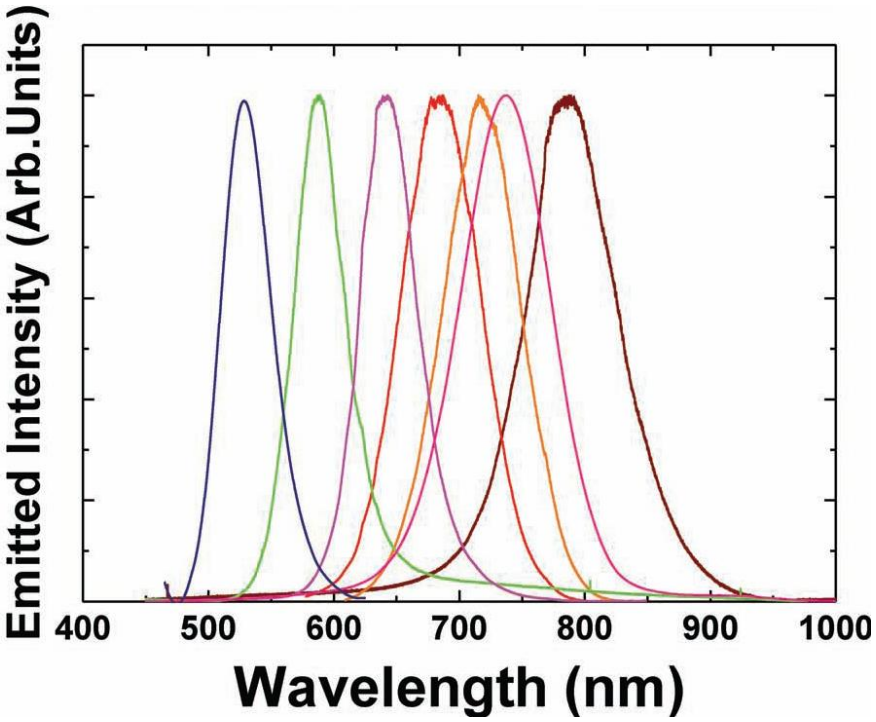
Lifetime Luminescence Nanothermometry



High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

- Experimental results: CdTe



• Plasmachem Inc.

• Nominal emission wavelengths at 510, 540, 570, 630, 660, 690, 710 and 780 nm.

• Sizes of 1, 2.3, 3.1, 3.6, 3.8, 4.3, 4.7 and 7.9 nm.

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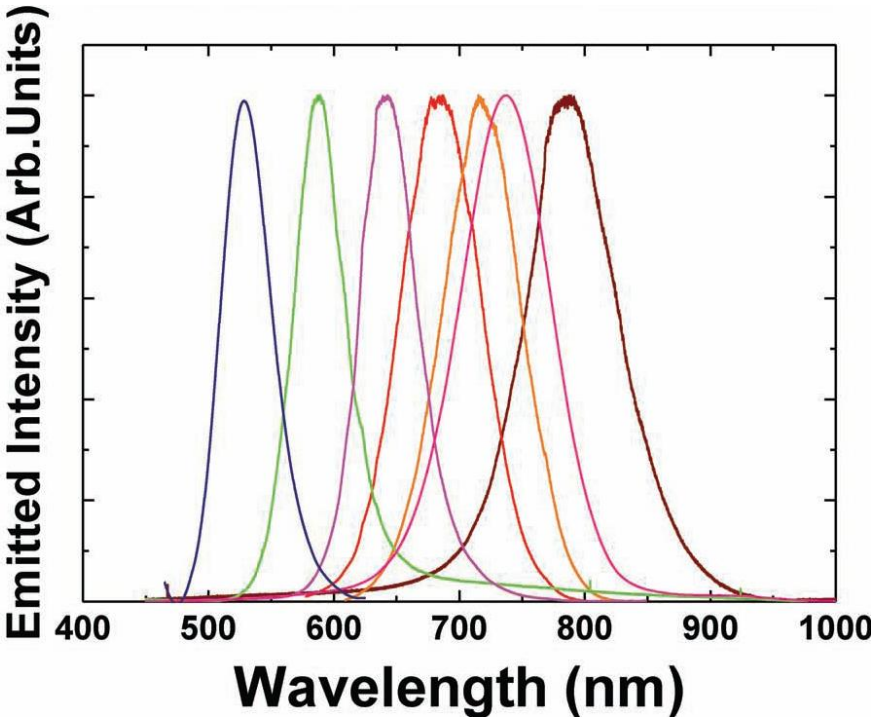

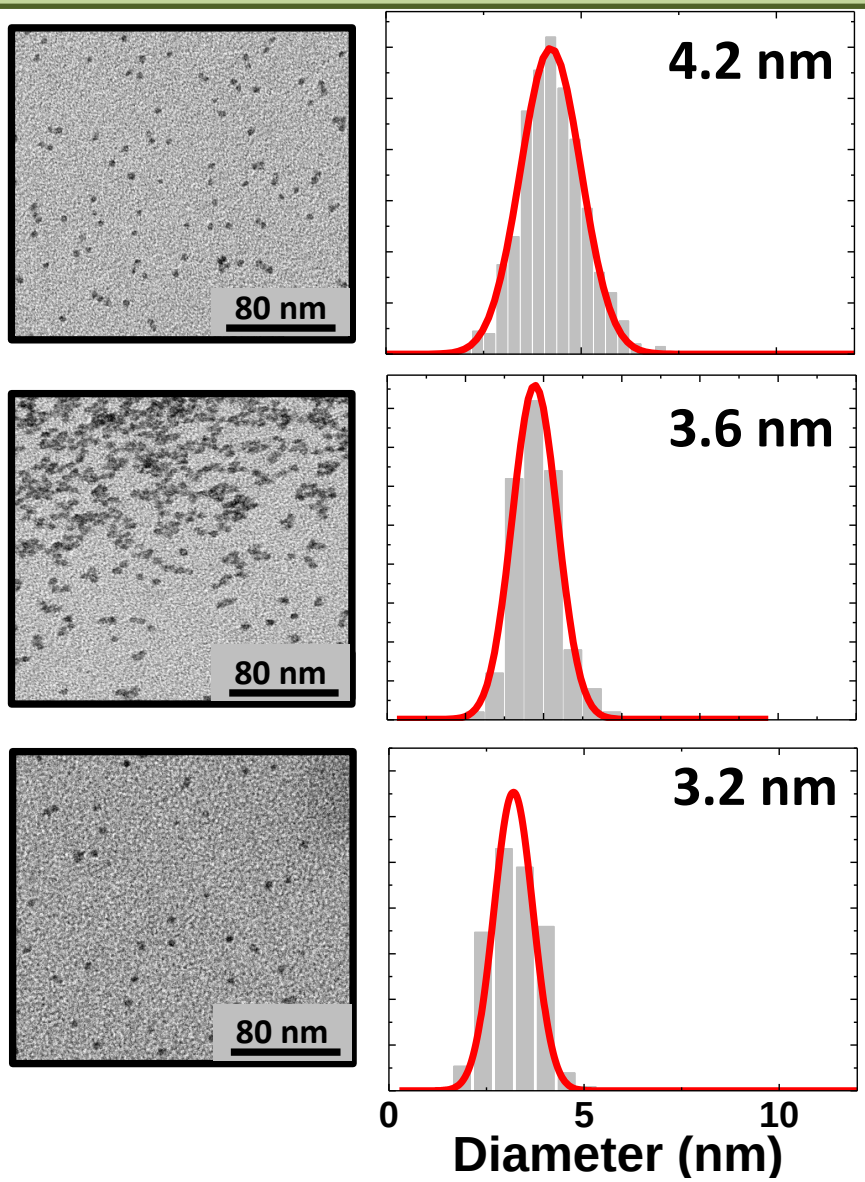

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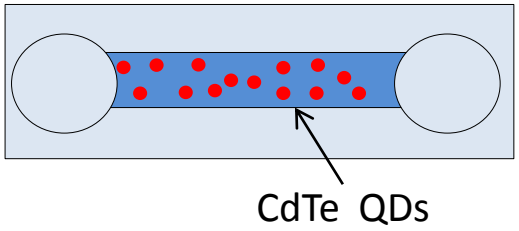
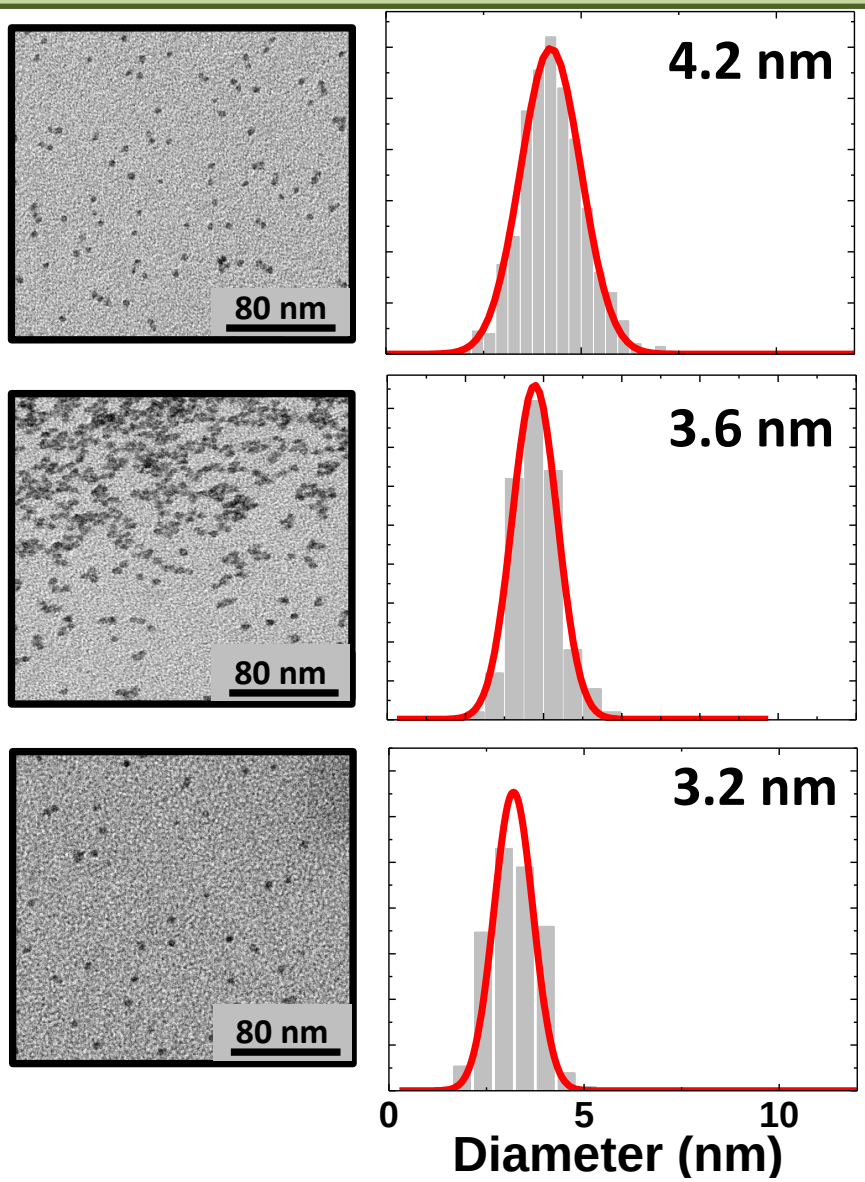
- Experimental results: CdTe

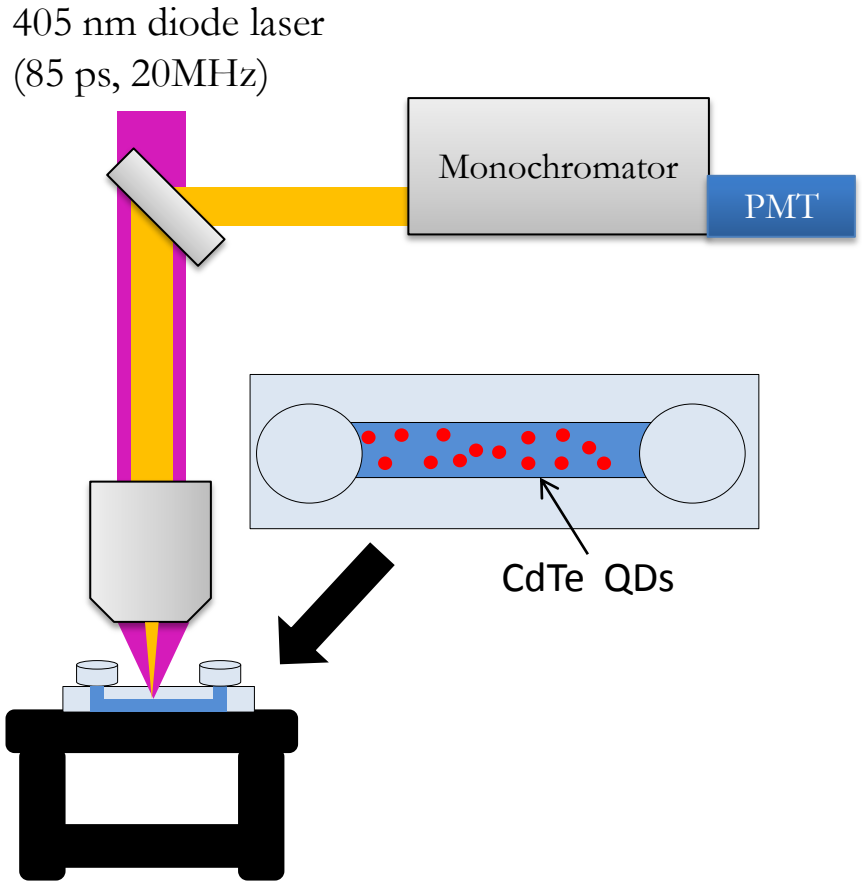
QDs were dispersed in distilled water with a concentration of 0.3% by mass and no evidence of precipitation was observed.





High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

- Experimental results: CdTe vs size



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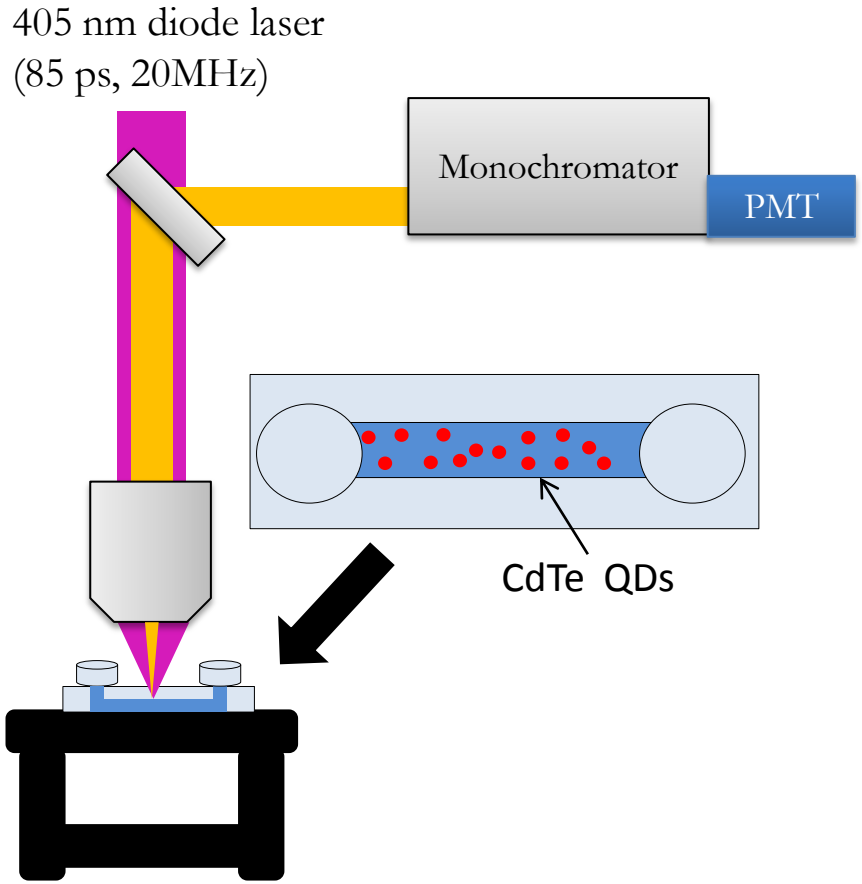
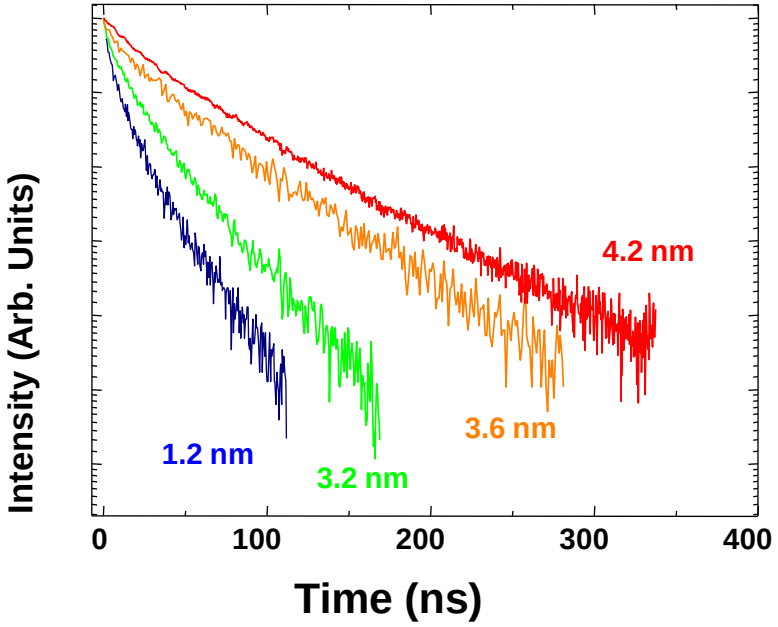
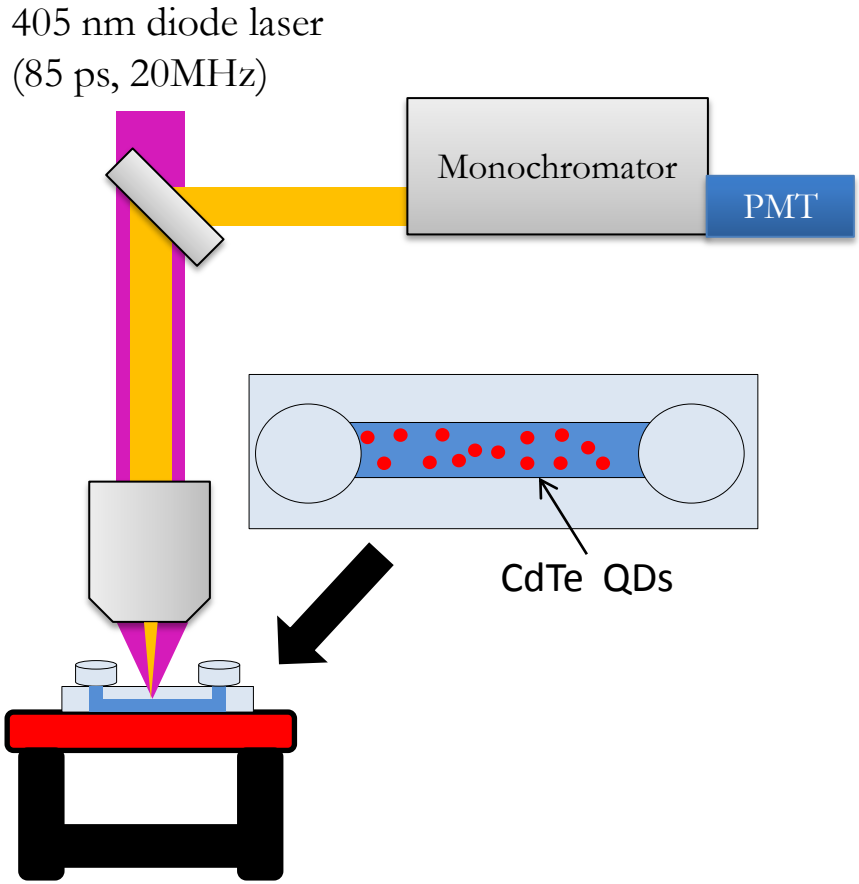




Some characteristic room temperature fluorescence decay curves of CdTe-QD of different sizes as obtained after optical excitation at 405 nm

High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

- Experimental results: CdTe vs temperature



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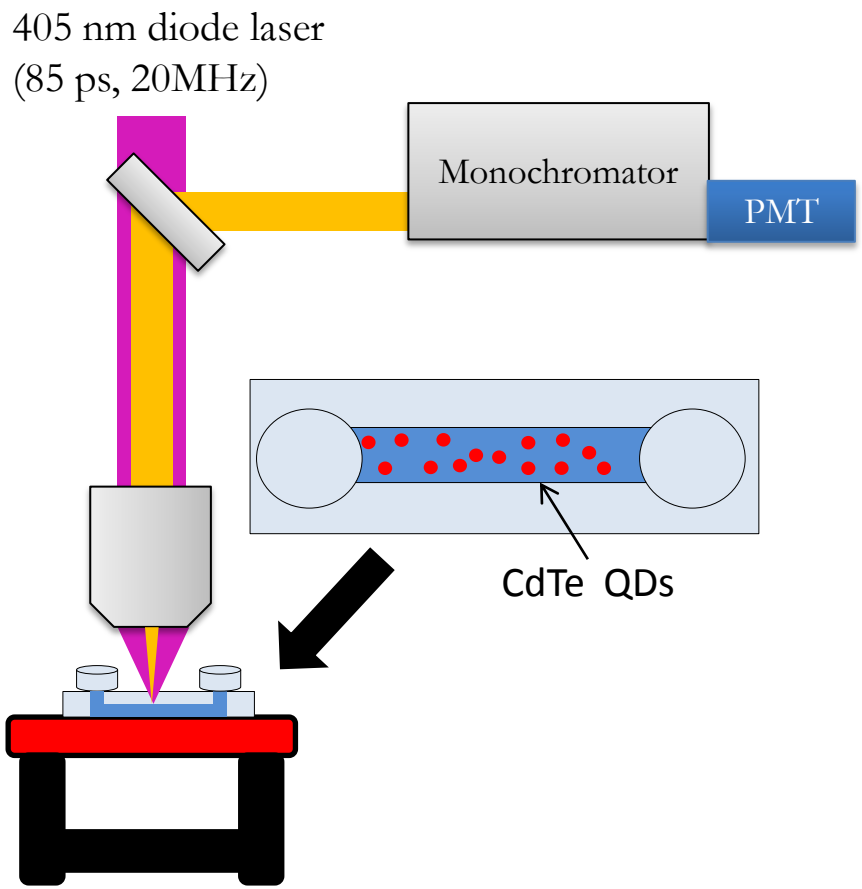

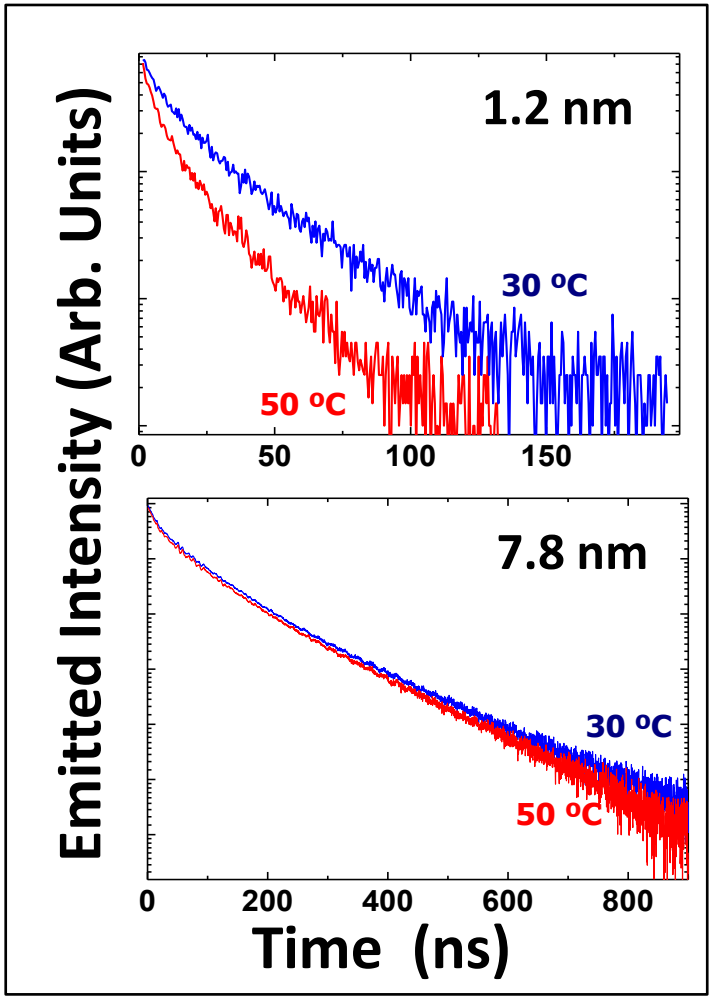

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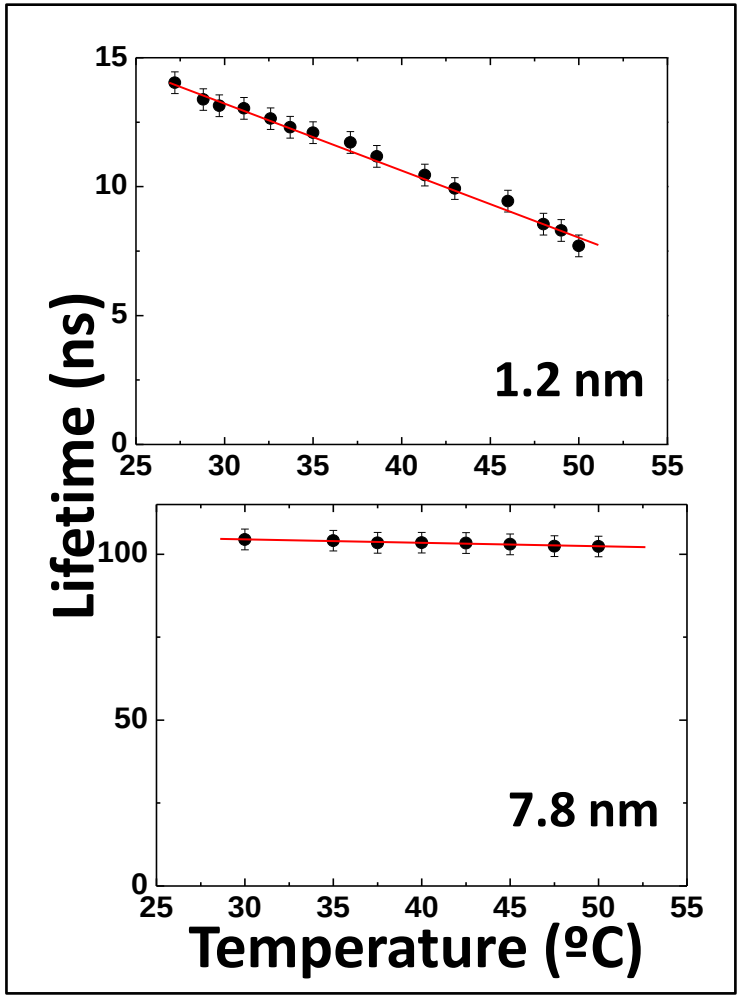
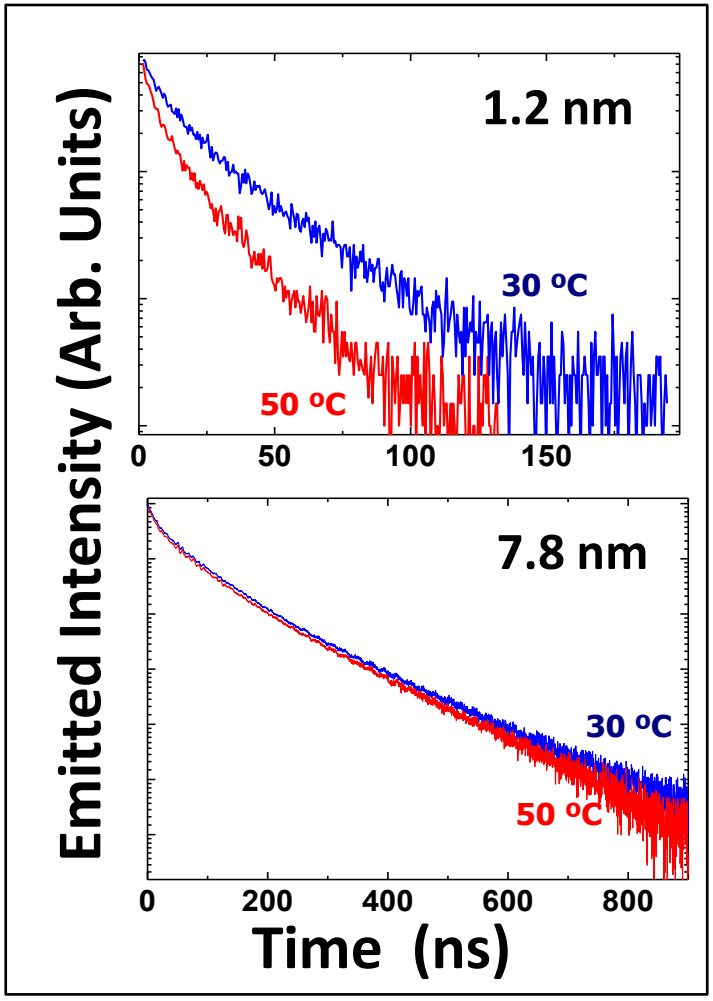


$$\tau_f = \frac{\int I(t)dt}{I_0}$$



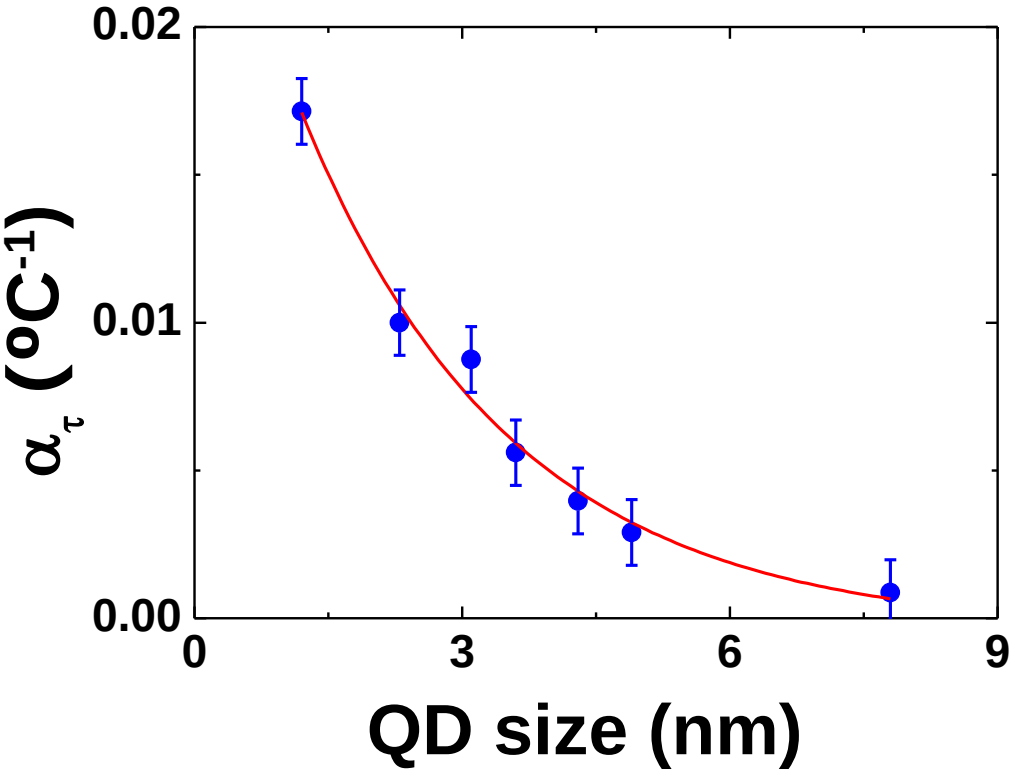
High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

- Experimental results: CdTe vs temperature

Normalized lifetime thermal coefficient (α_τ) of CdTe-QDs as a function of the QD size.

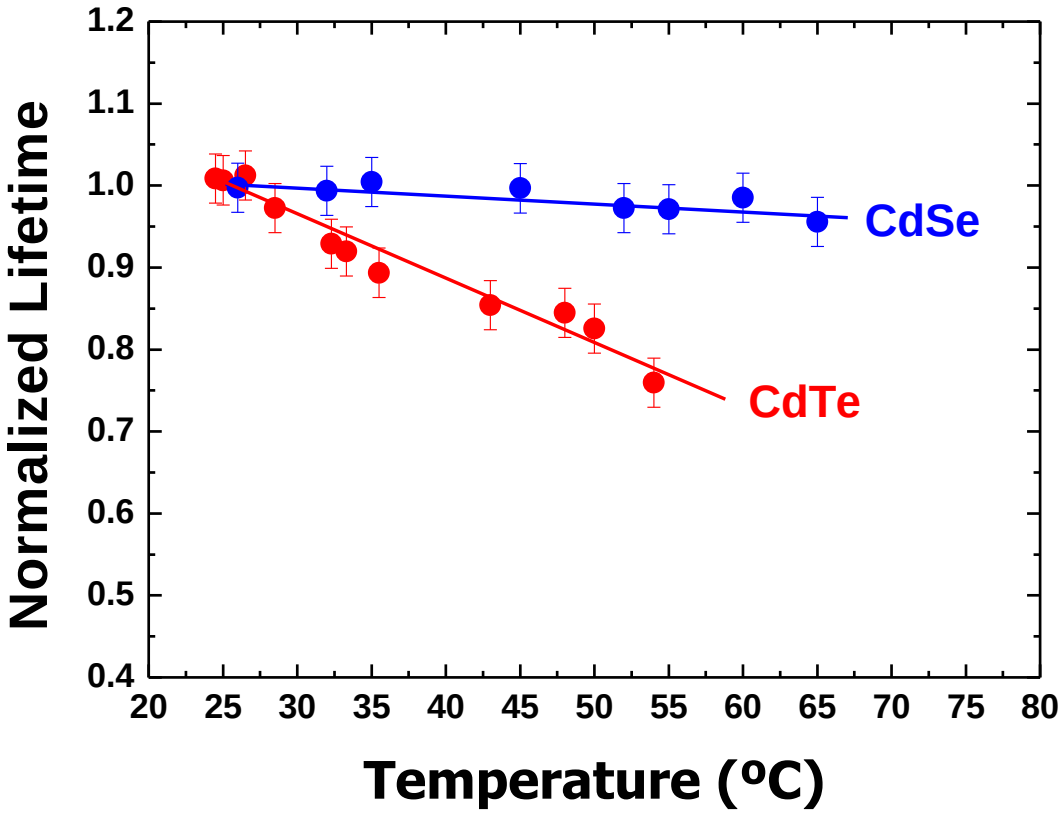
$$\alpha_\tau = \left| \frac{d\tau_{nor}(T)}{dT} \right|$$

$$\tau_{nor}(T) = \frac{\tau_f(T)}{\tau_f(25ºC)}$$



High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

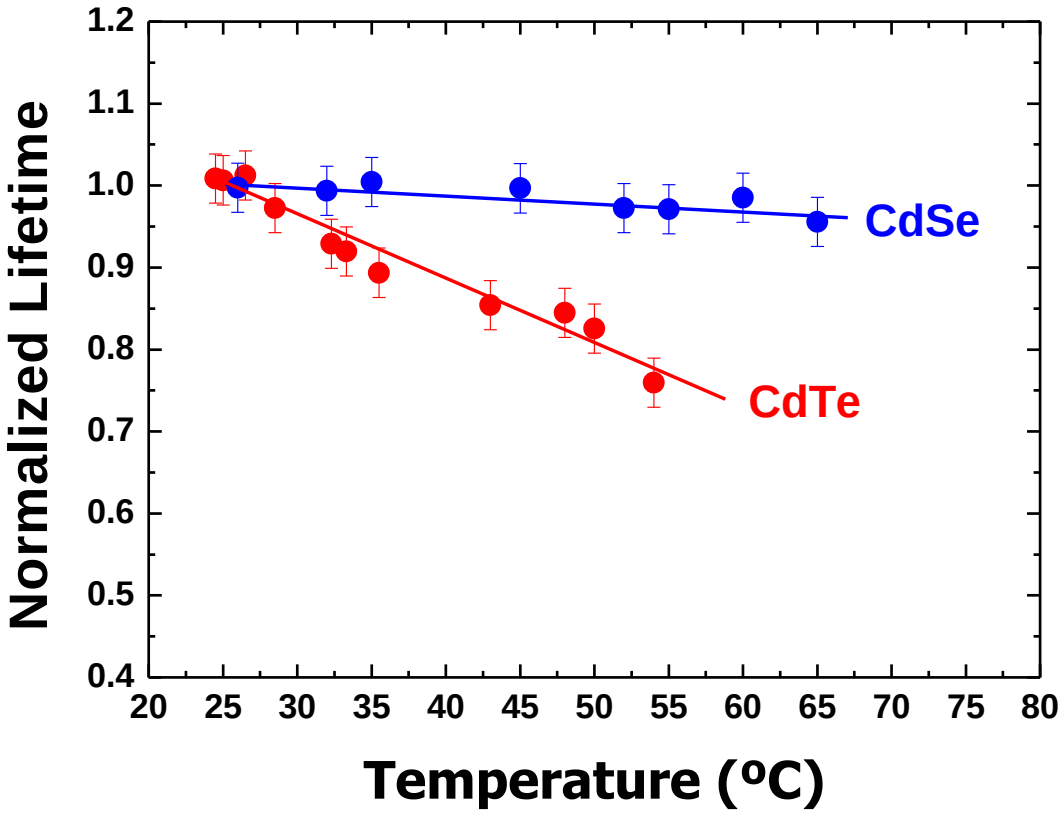
- Experimental results: CdTe vs CdSe



Variation of the normalized lifetime as obtained for CdTe and CdSe-QDs of similar size.

High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

- Experimental results: CdTe vs CdSe



The thermal sensitivity of the CdTe-QDs for FLTI clearly surpasses that of the CdSe-QDs.

$$\alpha_\tau(\text{CdTe}) \approx 5\ \alpha_\tau(\text{CdSe})$$

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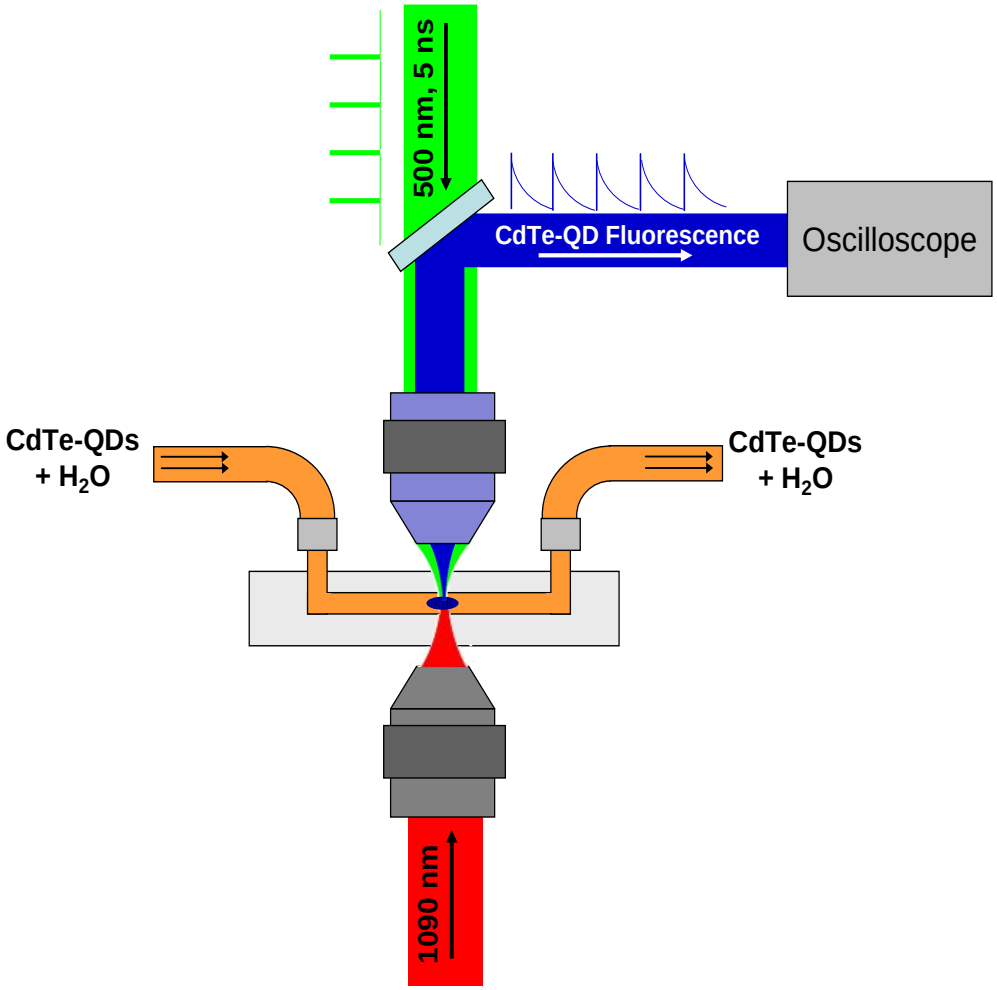
High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

- Experimental results: CdTe as thermal sensor in microfluidic



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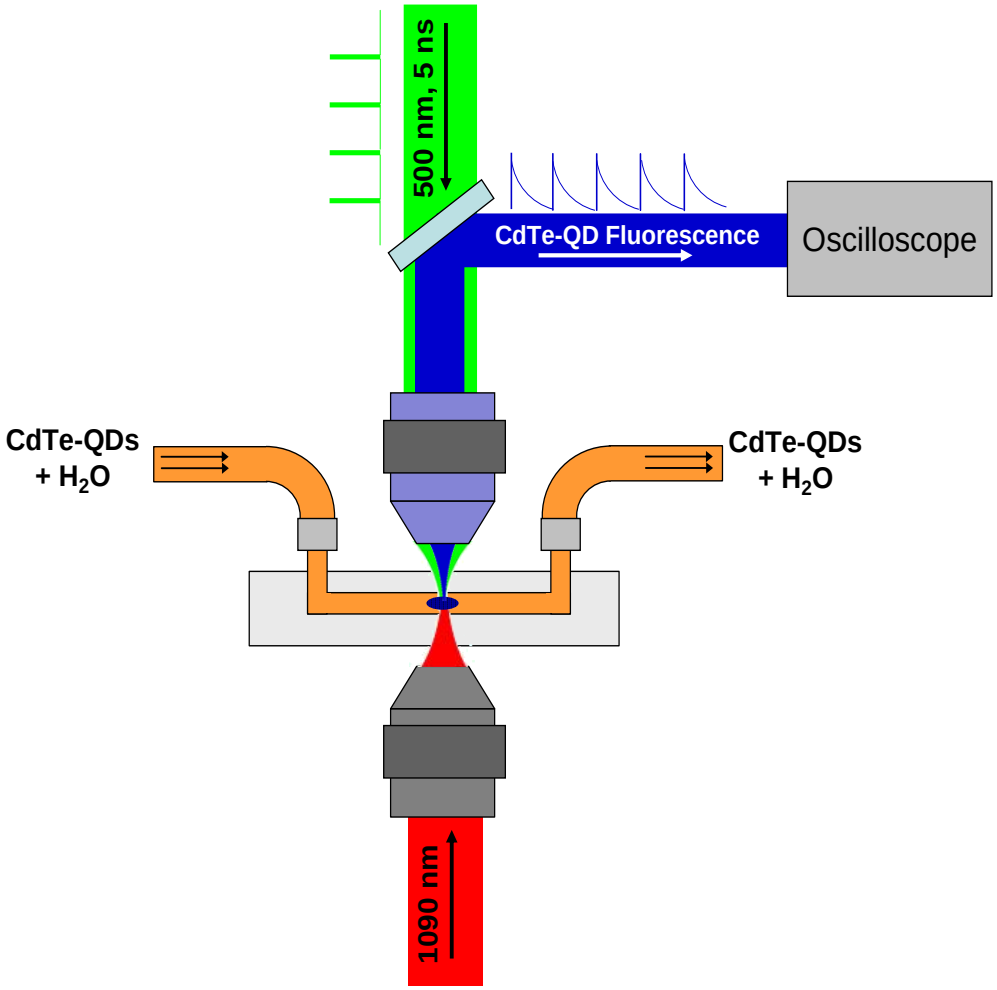

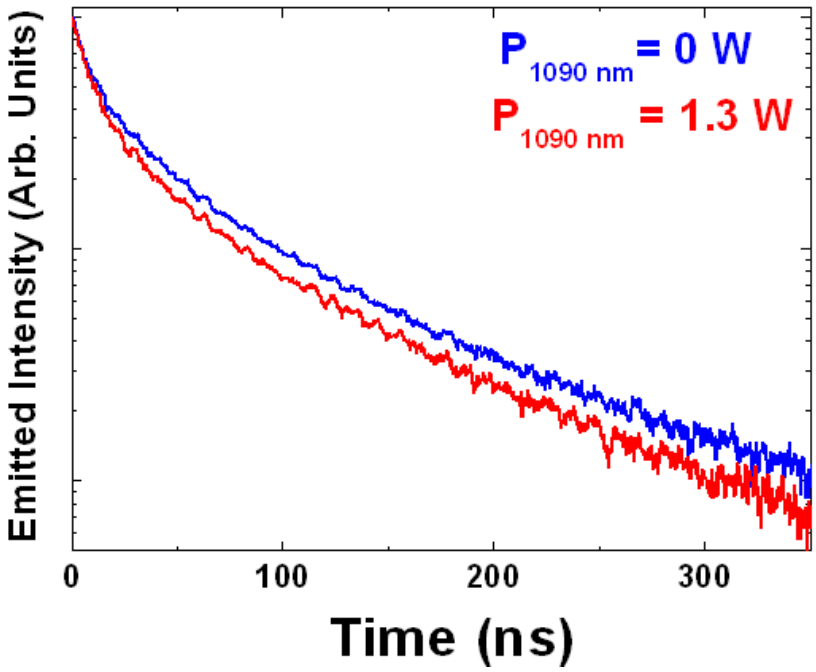

Fluorescence decays curves at two different laser powers.

High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

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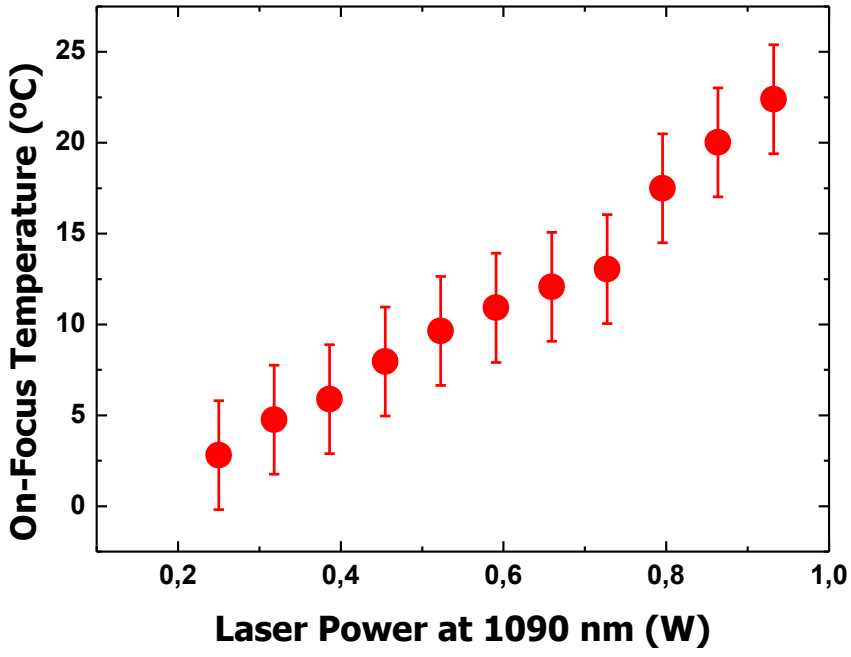
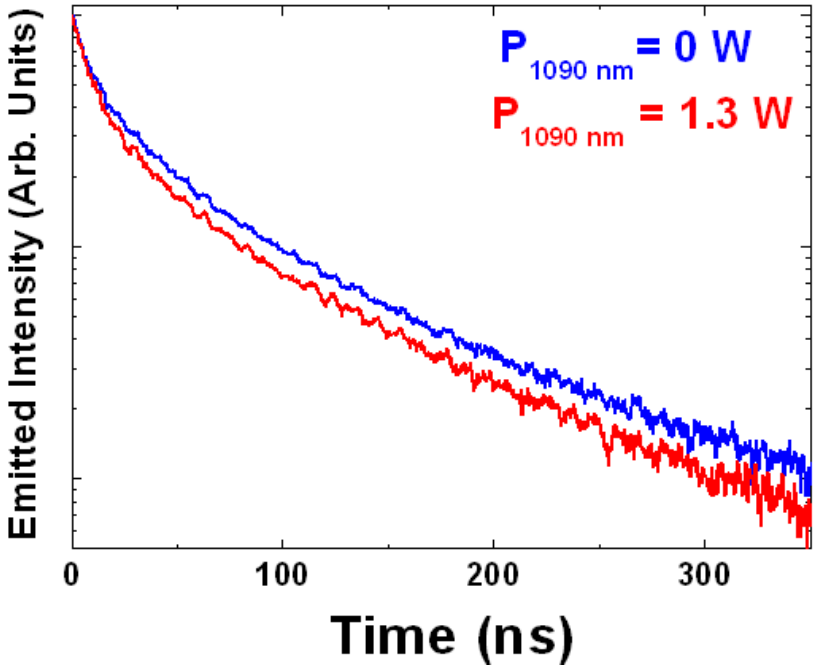


Increment of the temperature on the laser focus as a function of the incident laser power.



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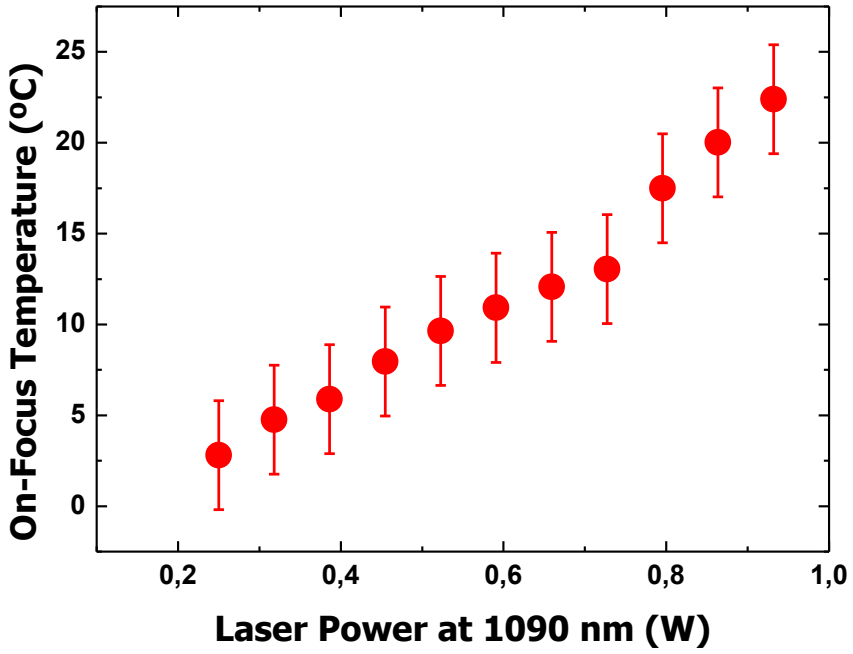

$$\Delta T_{focus} = \frac{p_{in}\alpha_w}{2\pi K} Ln\frac{D}{w_l}$$

p_{in}= laser incident power
α_W = absorption coefficient of water
K = thermal conductivity of water
D = height of the μ –chamber
w_l = laser beam radius

Increment of the temperature on the laser focus as a function of the incident laser power.

H. B. Mao , *Biophys. J.* ***2005 , 2 , 1308***

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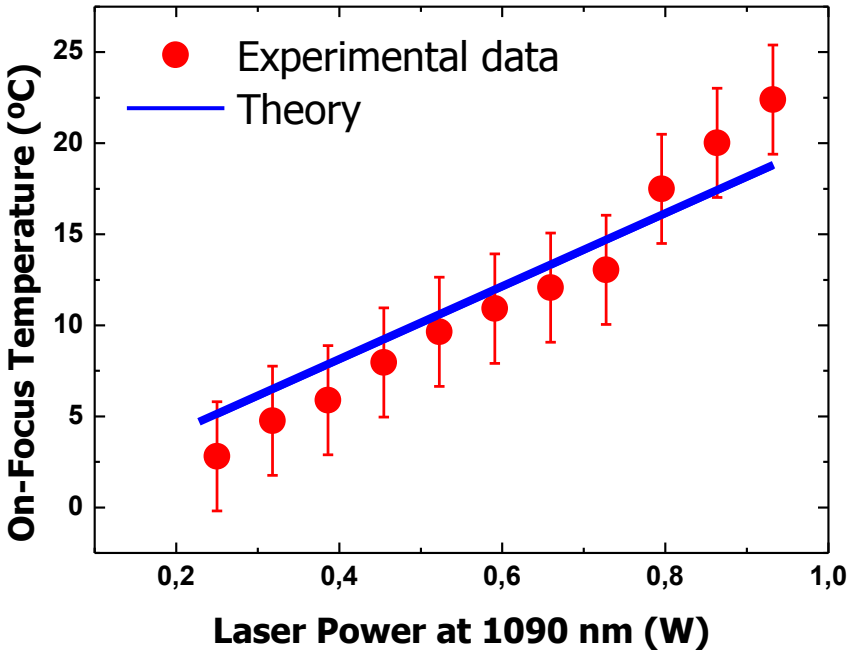

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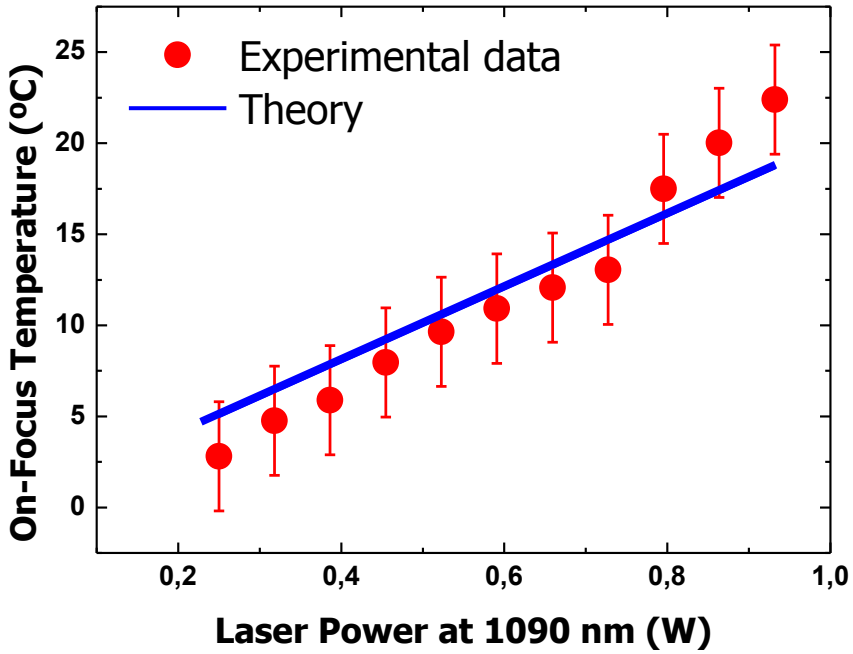


Increment of the temperature on the laser focus as a function of the incident laser power.

Predictions based on expression are included in Figure together with experimental data, showing a rather good agreement and thus demonstrating ***the suitability of CdTe-QDs for high-resolution fluorescence lifetime thermal sensing in bio-compatible fluids.***

High sensitivity Fluorescence Lifetime Thermal sensing based on CdTe Quantum Dots

- Conclusions

✓ CdTe vs sizes

✓Fluorescence lifetimes decrease with the QDs sizes

✓CdTe vs Temperature

✓High sensitivity for the samllest QDs, increasing with the sizes.

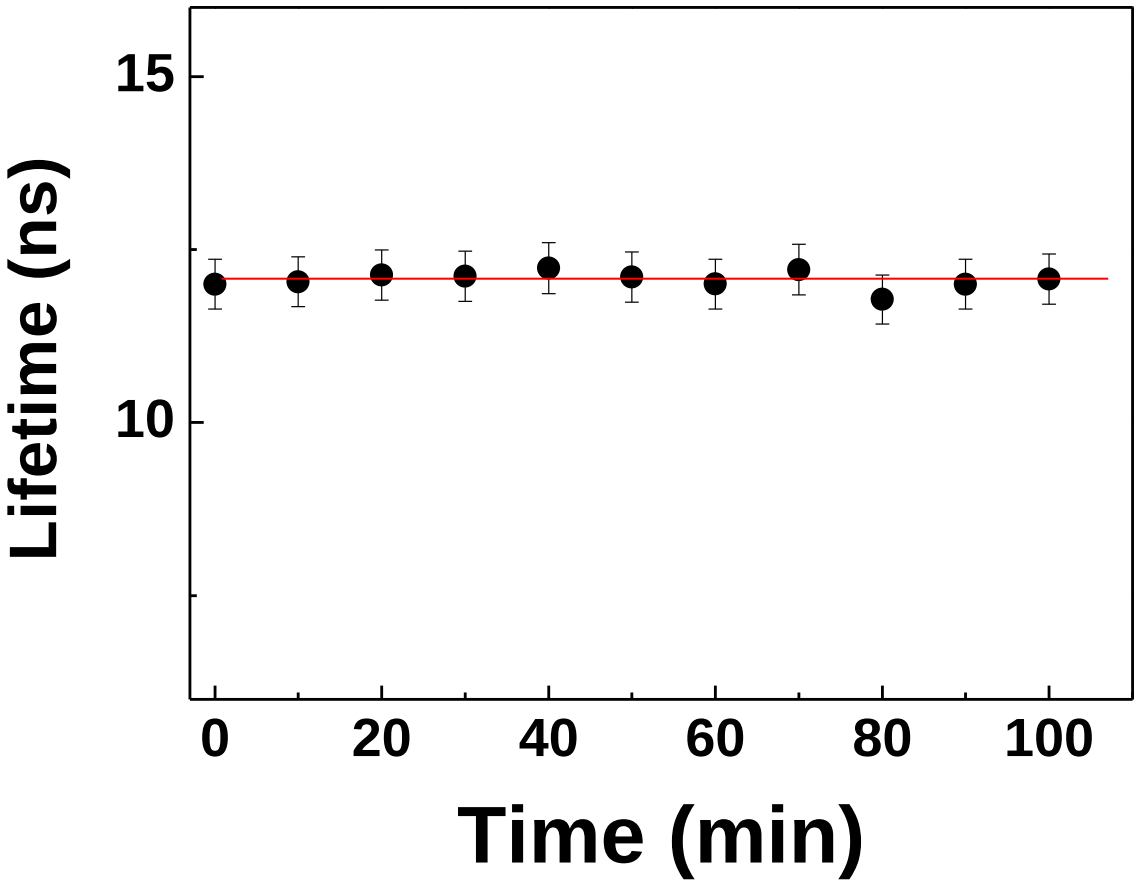
✓CdTe vs CdSe

✓thermal sensitivity of the CdTe 5 times higher than CdSe

✓CdSe as thermal sensor

✓Good Agreement between the experimental data and the theory


Thank you for your attention



Lifetime of the 1 nm CdTe-QDs as a function of illumination time. Excitation intensity was kept at maximum (130 W/cm 2). Circles are experimental data and solid lines are guides for the eyes.

small NANO MICRO

Thermal Sensing

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	Working range (ºC)	Sensitivity ($ºC^{-1}$)	Linearity	τ_{RT}	Reference
Rhodamine B doped microsphere	20-70	0.016	YES	1.5 ns	[5]
di-4-ANEPPDHQ dye	20-40	0.005	Unknown	3.5 ns	[6]
Single molecule Rhodamine B	15-45	0.012	YES	2.5 ns	[3]
Europhium doped complex	0-42	0.007	YES	0.7 ms	[4]
Kiton Red dye	20-90	0.011	NO	8.	[42]
Fluor.-Labeled DNA Oligomers	15-35	0.013	YES	3 ns	[43]
DBDAE-co-NIPAM	22-38	2.5 @ T =32ºC 0 @ T ≠ 32ºC	NO	2.8 ns	[44]
4 nm CdSe Quantum Dots	27-50	0.0008	YES	20 ns	This work
1 nm CdTe Quantum Dots	**27-50**	**0.017**	**YES**	**14 ns**	**This work**

$$\tau = \frac{1}{k_{rad} + k_{nrad}}$$

On one side the decrease of the QDs size implies an increase of the surface-to-volume ratio and, thus, of k_{nrad} thorough surface (trap) states.

On the other hand, the Fermi´s "golden rule" predicts a monotonous increment of k_{rad} *as the emission frequency increases (i.e. as the QD size* decreases)