Small Carbon Quantum Dots, Large Photosynthesis Enhancement

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Introduction
The Case for Rare-Earth doped Carbon Quantum Dots (RE-CQDs)

- Argument for further investigation into RE-CQDs and photosynthesis enhancement
- Why photosynthesis enhancement?
- RE-CQDs could lead to nanofertilizers and new class of synthetic materials that can “grow.”

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ACS Applied Nano Materials 2020 3 (6), 4920-4924
Previous Work with Photosynthesis Enhancement and RE-CQDs

- The authors present other groups’ research as support:
  - CQDs bind with isolated chloroplast (2014)
  - Rare-earth elements augment photosynthesis (2001)
  - RE-CQDs have desirable properties

Background and Results
Quantum dots (QD) for nonradiative energy transfer

- CdSe QD as energy donors to LHC-IIb
  - Fluorescence resonance energy transfer (FRET).
  - Helps fill the ‘green gap’
- 3x increase in excitations in LHCs vs. control
- Maximum enhancement:
- More recently w/ Si-based QD

Issues:
1. Cytotoxicity.
2. Mechanism isn’t fully understood.

Solution to 1:
Carbon Quantum Dots (CQDs)

Rare-earth (RE) elements and quantum efficiency

- RE doped into solids → long lived, optical transitions
- Complete $5s^25p^6$ orbitals shield the outermost $4f^n$ orbital from external fields.
- RE solid state devices:
  - optoelectronics, signal processing
  - quantum memory, quantum networking
- Ongoing work at UIUC!!! Goldschmidt group\(^5\)

Direct impact of REs on photosynthesis in vivo

- **Tobacco seedlings**\(^7\)
  - Accelerated photosynthesis $\rightarrow$ stimulated seedling growth
  - Optimum concentration due to toxicity

- **Green Algae**\(^8\)
  - Low intensity: 300% increase in photosynthetic rate $\rightarrow$ 36% enhancement in growth
  - Found an overall increase in chlorophyll.

- **Corn**\(^9\) and many other agricultural goods, dating back to the 60s.\(^{10}\)

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RE-CQDs for improved photosynthesis

- Proposed work: Eu doped CQDs
  - Transitions in the green (speculative)
  - Chelation of Eu-CQDs demonstrated\(^\text{11}\)

- Eu CQDs for Hg detection in water\(^\text{12}\)
  - Dual fluorescence
  - Cool but not really relevant

Argument Analysis
Argument Structure

- The conclusion is a hypothesis motivating future experiments
- Motivation:
  - Prior studies showing how carbon nanotubes improve photosynthesis
  - Semiconductor CQDs improved energy transfer in light harvesting complexes, but are toxic
- Narrowing the range of CQDs:
  - Many prior studies of heteroatoms (lattice substitutes)
  - Few on CQDs doped with rare-earth chelates
  - Rare-earths by themselves increase photosynthesis
  - Europium CQDs promising
Critique of Argument Validity

● Logical flow of motivating RE-CQDs and narrowing down to Eu is valid

● Citations of detailed experimental papers

● I would add citations for two claims:
  ○ One mentions author but does not include citation
  ○ Another makes claim about prior studies of RE but does not cite studies
Critique of Argument Validity, cont.

- Needs discussion of CQD’s themselves
  - Can at least reference literature
Citation Analysis
Citation Analysis: Pre-Paper

- Interdisciplinary Field: 17 total references
Citation Analysis: Pre-Paper

- Interdisciplinary Field: 17 total references
- Activity clustered around last 10 years
Citation Analysis: Pre-Paper

- Interdisciplinary Field: 17 total references
- Activity clustered around last 5 years
- Variety of Journals
Citation Analysis: Post-Paper

- Few citations: 7-9
  - Relatively recent paper (published 2018)
  - Survey-style, No novel results
  - Niche intersection of fields
  - Authors early in career or unestablished
- Small but growing topic
Citation Analysis: Post-Paper

TITLE-ABS-KEY (quantum AND dot AND photosynthesis)
Conclusions
Main Takeaway from article

- QDs connect to plants’ LHC and aid in energy transfer
- Doping QDs with carbon to make CQDs is more plant-friendly
- CQDs doped with rare earth elements (RE-CQDs) make photosynthesis even more efficient due to elements’ properties
What's Next in this new field?

- Europium doped CQDs are stable and have high fluorescence quantum efficiency
- These QDs have emission peaks that overlap with what is available to chloroplasts and could hence use chloroplasts as energy donors
- The effect of RE-CQDs on plant photosynthetic physiology and biochemistry must also be studied
What is possible with these next steps?

- We could develop a better understanding of this technology’s effect on the environment.
- Seeing how RE-CQDs work with chloroplasts could lead to developing synthetic materials with natural growing and repairing capabilities.
- This type of research could guide us towards more eco-friendly sources of obtaining energy!
Questions