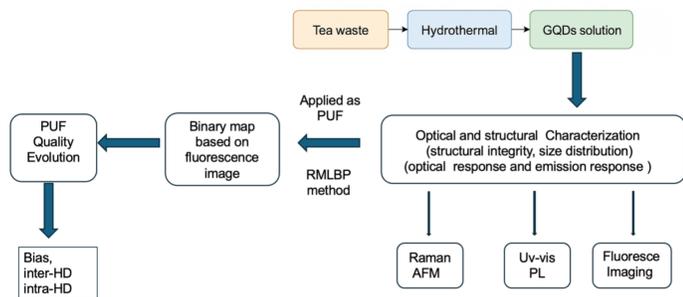


Carbon quantum dots from waste materials for anti-counterfeiting

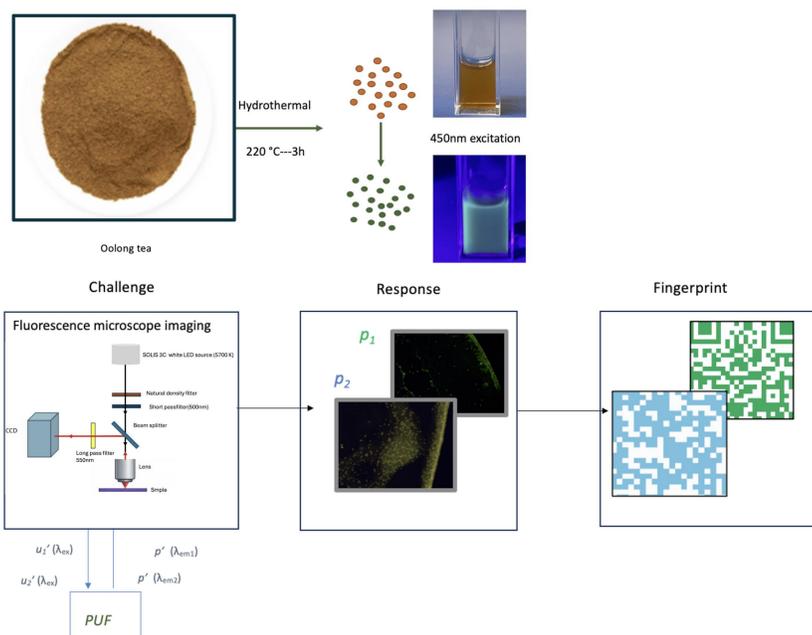
Introduction

Research goal: Turning biowaste to quantum security key



- The amount of world tea consumption has grown from 234 to 297 billion liters from 2013 to 2021. Oolong tea waste contains 3.5–7% inorganic components, as well as 93.0–96.5% organic components [1].
- The organic components from oolong tea waste can be recycled into green emissive carbon quantum dots.
- These CQDs can be incorporated into inks for anti-counterfeiting applications and beyond!

How Carbon quantum dots applied as physical unclonable functions

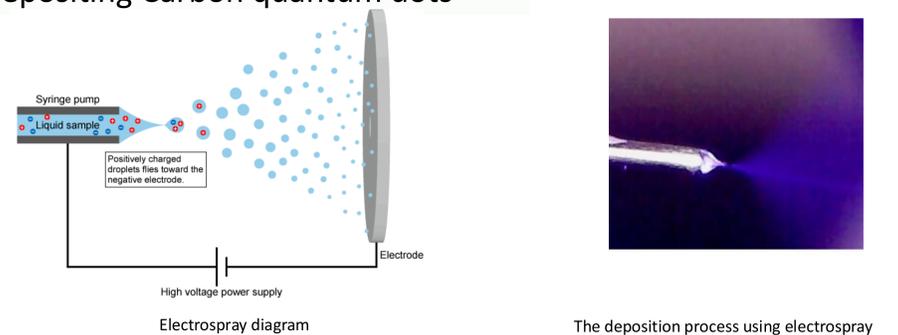


Fabrication

Hydrothermal synthesis Carbon quantum dots

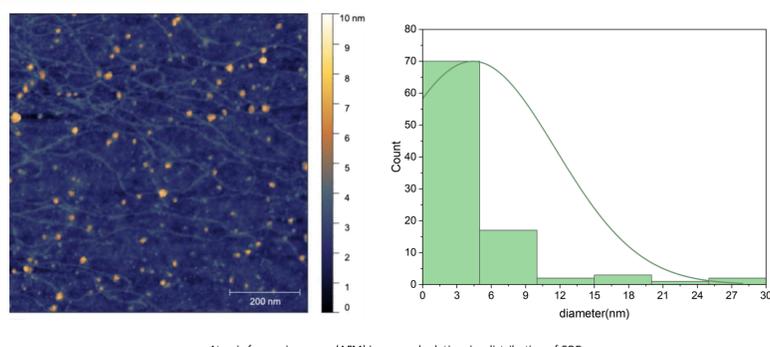


Depositing Carbon quantum dots



Characterization

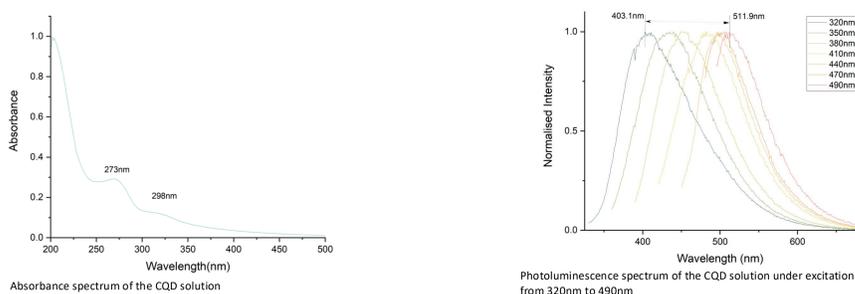
Atomic Force Microscopy



Atomic force microscopy (AFM) image and relative size distribution of CQD

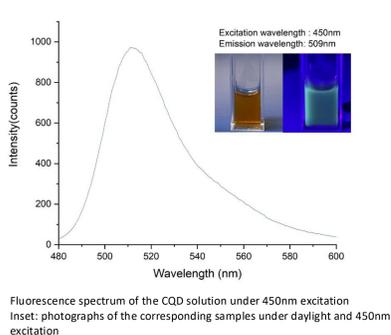
- The size distribution of the CQDs is relatively small and the majority falls within the range from 1.7 nm to 6.0 nm.
- Based on the statistical analysis of above 100 particles, the average diameter of the N-CDs is around 5 nm.

Photoluminescence



Absorbance spectrum of the CQD solution

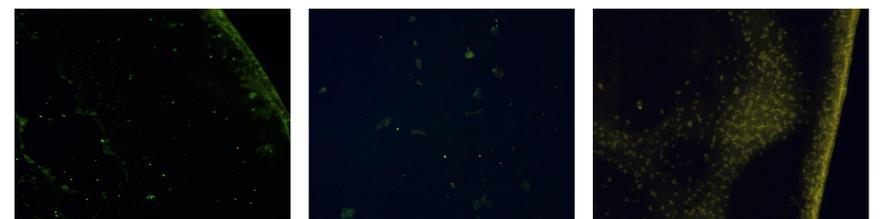
Photoluminescence spectrum of the CQD solution under excitation from 320nm to 490nm



Fluorescence spectrum of the CQD solution under 450nm excitation. Inset: photographs of the corresponding samples under daylight and 450nm excitation

- The UV/vis spectrum in exhibits a strong peak at 273 nm with a shoulder around 298 nm. The peak at 273 nm is ascribed to the $\pi-\pi^*$ transition of the C=C bands of localized sp^2 clusters in the core, whereas the shoulder is due to the $n-\pi^*$ transition of the C=O bands of carboxyl groups on the shell of the CQDs[2].
- With increasing excitation wavelength, the PL peak of the CQDs shows a red shift indicating that PL peak are dependent on excitation. This excitation-dependent fluorescence behaviour may be resulting from certain dimensional limits and surface states[3].
- The emission wavelength of the CQDs is 509nm under 450nm excitation. The inset image shows that the CQDs are brown under daylight and emit bright green fluorescence under 450 nm excitation.

Physical unclonable function



Fluorescence microscope images of different position of CQD solution deposited on SiO₂



Binary bitmap of the CQD extracted from small crop of the fluorescence image

- Fluorescent images show the randomness of the position of the CQDs and aggregation shapes, which can be the first proof to be potentially applied in the physical unclonable function.
- Early work suggests that unique binary identifiers can be produced from these images.
- Further fingerprint performance measurements need to be done to prove the conciseness quality of the fingerprint.
- The primary goal is to generate keys that remain unchanged or change slightly when the CQD fluorescence pattern preserving modifications are made to the image.

Conclusion

- In this study, green luminescent carbon quantum dots (CDs) were hydrothermally synthesized from wasted oolong tea leaves, providing an environmentally friendly method for the production of CQDs without further surface passivation or modification.
- The distribution of the obtained CQDs mainly falls within 1.7 nm to 6.0 nm, and the average diameter of the CQDs is around 5 nm based on AFM measurement. These CQDs exhibit strong green fluorescence under 450 nm excitation and show excitation-dependent fluorescence behaviour, which maybe because of the surface states and the existence of the sp^2 domain.
- The fluorescence images show strong promise for the sustainable synthesis of fluorescent CDs for anti-counterfeiting applications.

Future work

- Further fingerprint generation.
- Testing the fingerprint preference including randomness, uniqueness, conciseness, storage capacity, and stability.

References

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