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# Graphene quantum dots with nitrogen and oxygen derived from simultaneous reaction of solvent as exfoliant and dopant

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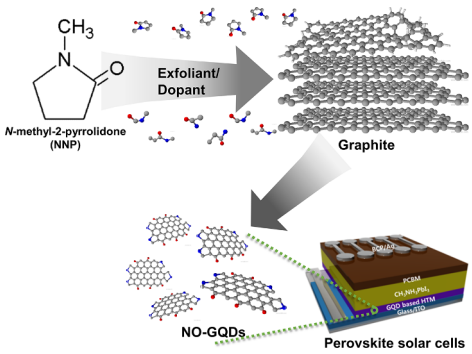
## HIGHLIGHTS

- N- and O- doped graphene quantum dots (NO-GQDs) were synthesized.
- Solvothermal reaction can exfoliate, cut, and transform the graphite into NO-GQDs.
- NO-GQDs have a less defective and edge-functionalized structure.
- NO-GQDs facilitate rapid hole-extraction in perovskite solar cells.
- Addition of NO-GQDs shows a 36.2% increase in the power conversion efficiency.

## GRAPHICAL ABSTRACT

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## ABSTRACT

Graphene quantum dots (GQDs) are promising materials for optoelectronic devices because their band-gap, derived from quantum confinement and edge effects, can be easily tuned via their size or surface/edge states. In this paper, a novel approach to synthesize nitrogen- and oxygen-doped GQDs (NO-GQDs) is presented. Nitrogen and oxygen are mainly bound at the GQD edges, resulting in high crystallinity and good electrical properties. A simple solvothermal reaction using *N*-methyl-2-pyrrolidone (NMP), whose surface energy is similar to that of graphite as a raw material, can simultaneously exfoliate, cut, and finally transform the graphite into the GQDs with heteroatoms derived from the decomposed NMP solution. The synthesized NO-GQDs have a less defective and more selectively edge-functionalized structure compared to other reported GQDs. The electrical properties of NO-GQDs are investigated using them as the additive of hole-transporting materials (HTMs) in an optoelectronic device such as perovskite solar cells (PeSCs). Compared with PEDOT:PSS, a mixture of NO-GQDs and PEDOT:PSS shows a 36.2% increase in the power conversion efficiency *(PCE)* (maximum *PCE*: 11.47%) and good device stability. Therefore, it is believed that the improvement of photovoltaics is solely attributed from NO-GQDs which act as a positive role of faster hole transfer. We could confirm that the NO-GQDs facilitate hole-extraction from a photoactive layer and guarantee the more stable operation of PeSCs.

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