

## 2D and 3D Carbon Nitrides and Carbon Nitride/Graphene Hybrids: Preparation, Characterization and Energy Applications

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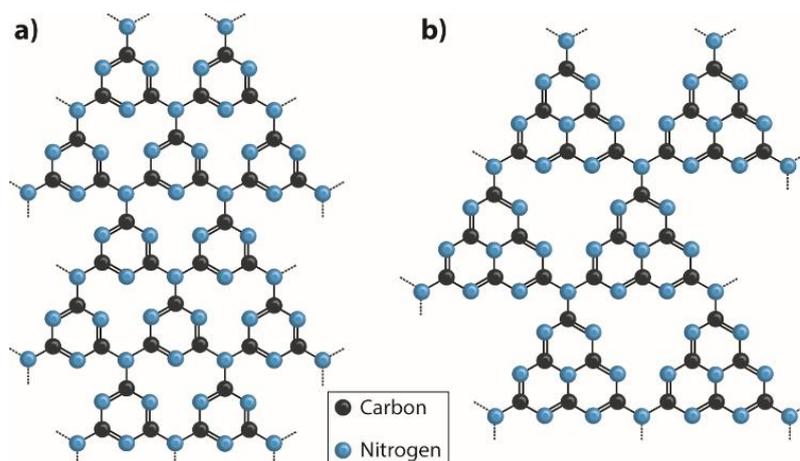
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### Abstract

Graphitic carbon nitrides (gCNs) are solid state polymers which have  $sp^2$ -bonded structures which are related to graphite and graphene, but formed from C- and N-containing heterocycles such as triazine or heptazine units linked via –N-, –NH- groups (Figure 1) [1]. They have been under intense investigation during the last decade due to unique semiconducting, optoelectronic and catalytic properties. This has led to their development as an important class of materials for applications including visible-UV light harvesting for photocatalysis and photovoltaics, fuel cell and electrolyzer catalyst supports, charge storage in batteries and supercapacitors and also as ion-exchange or redox catalyst materials in their own right [2-4].

The emergence of two-dimensional (2D) gCNs has increased the potential of this class of materials and despite the fact that the materials shown thus-far are largely amorphous, with pseudo 2D dimensions, they have already shown great potential, for example as photocatalysts for water splitting [5].



**Figure 1:** Structural motifs found in graphitic carbon nitrides. (a) Fully condensed  $C_3N_4$  layer based on triazine units. (b) Fully condensed  $C_3N_4$  layer based on heptazine (tri-s-triazine) units.

Here we will present a summary of our recent results, covering the synthesis and characterization of unique 2D and three-dimensional gCN structures, as well as their use as part of hybrid materials in energy applications, specifically as catalytic supports for proton exchange membrane fuel cells [3]. These robust materials are shown to outperform conventional Pt/C catalysts due to their excellent mechanical, chemical and thermal stability, allowing their implementation in industrial demonstrator-scale systems.

### References

- [1] E. Kroke, M. Schwarz, *Coord. Chem. Rev.*, **248**, (2004), 493.
- [2] V. Wing-hei Lau *et al.*, *Nature Communications*, **7**, 12165
- [3] N. Mansor *et al.* *J. Phys. Chem. C*, **118**, **3**, (2014), 6831.
- [4] Y. Wang *et al.* *Angew. Chem. Int.*, Ed. 51, **1** (2012), 68.
- [5] J. Liu *et al.* *Science*, **6225** (2015) 970.