Graphene hydrogels: from fundamentals to applications

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Porous materials in our life

- CO$_2$ / pollutant capture
- Electrochemical energy storage
- Tissue engineering
- Filtration, ion exchange
Traditional carbon gels

Classical Resorcinol-formaldehyde (RF) system (1989)

- Complex system
- Need of pyrolysis and post activation
- Low mechanical properties


Graphene oxide as gel building block

Graphene oxide (GO)

- High colloidal stability in solvents ($M_w=10^6$-$10^7$ g/mol)
- Rich chemistry for crosslinking
- High surface area material ($\sim 750$ m$^2$/g)
- Restoration of graphene structure
Hydrothermal gelation of GO (2011)

Graphene oxide (GO) → Reduced graphene oxide (RGO)

Hydrothermal reduction

Increasing Hydrophobic interaction

- Simple system
- Strong and conductive gels
Today’s talk

• How does hydrothermal **reduction chemistry** work?

• What is the **structure** of the gels?

• Can we use this information to **rationally design** new gels?
Identifying gelation products

- Low pH: Gas entrapment
- High pH: Absorbed by ammonia
  \( \text{CO}_2 \) formation?
- Acidic solution after gelation: Formation of acidic species?

Quantification of products

Impact on structure and properties

GHG-N-0  GHG-N-60  GHG-N-170  GHG-N-290

Compression

Elastic modulus (kPa)

Ammonia addition (µl)

Volume (cm³)

V(ammonia) (µl)

GHG-N-0  GHG-N-60  GHG-N-170  GHG-N-290

A closer look at the gel structure

- Compact shell vs. porous bulk
- Forms at interfaces

Difference between bulk and shell

Shell:
1. Highly order multilayer up to 70 layers
2. 4 orders more conductive

Mechanism and ways to remove shell

Shell-less hydrogel:
- Lower density
- Homogenous open structure

Homogenous nanoparticle composite gel

Three step method:

I. Homogeneous citrate-Hydroxyapatite (HA)/GO suspension

II. Hydrothermal hydrogel formation

III. Dialysis induced HA deposition on graphene

✔ Free standing HA-RGO hydrogel

Dialysis?
Distribution of HA on gel

40% HA loading

✓ Homogenous HA nano-needles on graphene!
Good biocompatibility

✓ >93% of live cells on both rGO and G/HA-40
Cell morphology

- More elongated cells on G/HA
- Filamentous extensions on G/HA
Summary

• Conductive, elastic gels can be produced by hydrothermal reduction of GO

• Mechanical and electrical properties can be tuned by changing pH or other reduction conditions (pre-reduction)

• Nanocomposite porous, biocompatible, conductive, elastic structures for tissue engineering…. And what more?
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