Pioneering biomass transformation to unique multifunctional/ biocompatible ultrananocrystalline diamond (UNCDTM)

openaccessgovernment.org/article/pioneering-biomass-transformation-to-unique-multifunctional-biocompatible-ultrananocrystalline-diamond-uncdtm/163386

10 July 2023

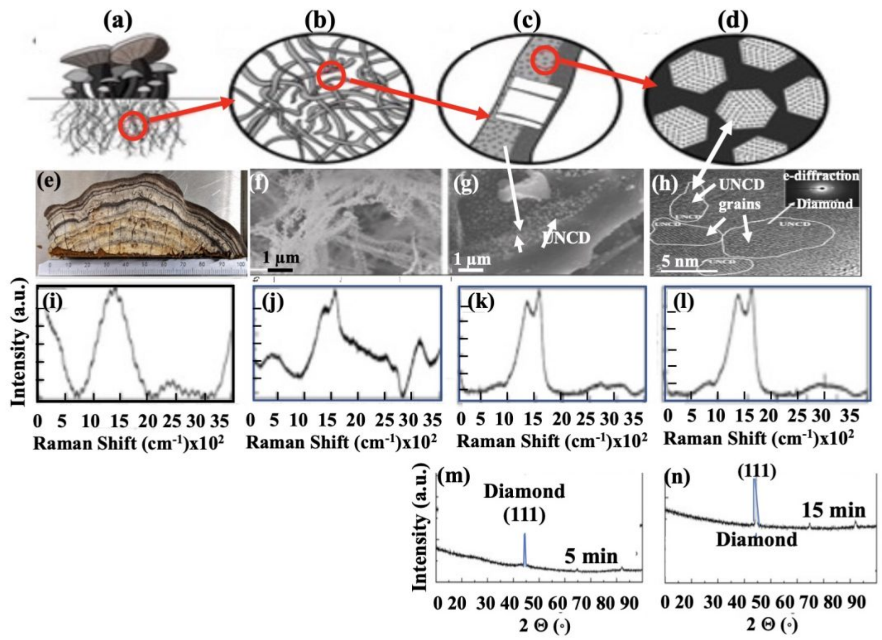

Figure 1. a) fungal mycelium schematic, showing filamentous roots (interconnected threads / tubes transporting water/mineral- nutrients, shown in schematic in (b); (c) schematic of chitinous cellular walls converted into graphitic matrix with integrated UNCD grains (3-5 nm diameter), shown in SEM image in (g), confirmed by HRTEM in (h), characteristic of UNCD, (m0 and (n) XRD spectra confirming the diamond structure of UNCD grans.

O. Auciello's group at The University of Texas-Dallas is developing a new revolutionary low-cost microwave plasma pyrolysis process, implemented in a kitchen microwave oven, for biomass transformation

The novel process transforms biomass materials (e.g. fungal-mycelium, flexible hemp) from natural soil on Earth into a unique best biocompatible Ultrananocrystalline Diamond (UNCDTM) material. The (UNCDTM) material is made of Carbon atoms/elements of life in human DNA, cells, and molecules, enabling the development of new generations of high-tech and external/implantable medical devices/prostheses to improve the quality of life of people worldwide.

Biomolecular polymer chains

Biomass is biological matter derived from agricultural processes for power generation, producing 233 Mega-Tons (MT in 2016 in the USA. [1,2] Research demonstrated that biomolecular polymer chains (e.g., cellulose) exposed to pyrolysis, i.e., high temperature-induced decomposition of hydrocarbons, yield carbon-material (char), liquids/resins and gasses.

These transformations are influenced by biomass type/process parameters (heating rates, temperature, moisture or oxygen content in the process gas). Pyrolysis was explored theoretically and experimentally for transforming biomass into amorphous-carbon material. [3,4]

Chitin/cellulose (natural biomolecules) can yield fiber bundles/fibril-matrix carbon-based char structures. Chitin is in crustacean shells and fungal mycelium walls, while cellulose is in nearly all vegetation. Methods to produce biochar from chitin/cellulose transformation were induced by nature long before humans developed processes. However, modern techniques can achieve fast/higher throughput for chitin/cellulose transformation to carbon materials for key products. The processes require drying/digestion/etching before the final thermal pyrolysis yielding powder biochar or pellets with C-atoms with graphite bonds on the surface. [4]

In analyzing fungal mycelium transformation into carbon materials, via microwave plasma processes (MPP), it is relevant to describe previously used methods to produce carbon films, such as microwave plasma chemical vapor deposition (MPCVD) used to produce CNT, graphene, and Ultrananocrystalline Diamond (UNCD™) coatings, in the market today. [5,6,7]

However, MPCVD requires expensive equipment that costs hundreds of thousands of dollars. The MPP process described earlier can transform biomass into solid structured UNCDTM material at a low cost, just a few thousand dollars. If developed to produce UNCD™ coatings, it could provide orders of magnitude lower cost process than MPCVD. (8) Thus, the novel MPP process described here represents a revolutionary approach for biomass transformation into the unique UNCD™ material, currently as a structured solid and potentially as a coating.

Biomass transformation to solid carbon-materials

Microwave Assisted Pyrolysis (MAP), involving microwave (MW) energy coupled to biomass directly or via microwave absorbers (activated carbon), was demonstrated for biomass-char transformation. <sup(9) The MW energy induces pyrolytic biomass decomposition via photons penetrating the biomass, forming volatiles escaping the surface.

Alternatively, Argon/Hydrogen plasma processing of biomass induces pyrolysis, transforming wood and rice husk into H_2, CO, C_2H_2 and CH_4 gases for fuel production. [10] However, the plasma processing of fungi was not investigated for transformation into nanocarbon or UNCD material described here.

Innovative Microwave Plasma Process (MPP) for fungal- mycelium transformation into multifunctional UNCD™

The MAP process involves energy transfer fundamentally different from the MPP process, such that MW energy is directed to polar water molecules in the biomass or mixed activated carbon.

The MPP process delivers MW energy to a low-pressure (<10 Torr) Argon (Ar) gaseous environment via Ar gas flow through a glass tube inserted into a low-cost kitchen microwave oven. The MW power produces a plasma containing Ar+, N+ and O+ ions (from atmospheric residue), neutral atoms, and free electrons, inducing physical/chemical biomass transformation.

The MPP process transforms fungal- mycelium into UNCD via key steps (schematics in Figs. 1 (a-d)). The mycelium body exhibits a filamentous root network (Fig. 1 (a) /schematic in Fig. 1 (b)/ SEM image in Fig. 1 (f)), each thread/tube having a cellular structure for transporting water and minerals/nutrients, held together by a cellular wall made of chitin molecules (biopolymer).

The MPP process preserves the filamentous mycelium-network (Fig. 1 (c) schematic / SEM image in Figs. 1 (g)), although with high shrinkage/weight loss. The chitin walls change into the initial graphitic matrix (Fig. 1 (c) schematic) / SEM image in Fig. 1 (g)) with dispersed diamond grains (3-5 nm diameter), characteristic of UNCDTM, as demonstrated in years growing UNCD™ films via MPCVD. (7)

The ≥ 5 minutes MPP process produced fungal mycelium transformation to extended UNCD material (schematic-Fig. 1 (d)) / HRTEM image (Fig. 1 (h)). Complementary analytical techniques were used to confirm fungal mycelium-UNCD transformation. Raman analysis spectrum (Fig. 1(i)) revealed fungal mycelium. Fig. 1(j), corresponding to three minutes of MPP processing of fungal mycelium, shows the initial appearance of peaks (1300-1550 cm-1), fully defined in Fig. 1 (k) (5 minutes MPP processing) and Fig. 1 (l) (15 minutes MPP processing), showing characteristic Raman spectra of UNCD as films grown by MPCVD. [7]

The XRD analysis (Figs. 1 (m) and 1 (n)), correlating with Raman spectra of Figs. 1 (k) and 1 (l), respectively. The X-ray diffraction spectra (Figures 1 (m) and 1 (n) show the diamond (111) fingerprint peak, confirming the diamond structure of the UNCD grains, as done extensively for UNCD films grown by MPCVD [7].

The power of the MPP process

The MPP process can provide a new biomass transformation pathway to produce UNCD material in a solid structural form now and potentially in film (coating) form in the future.

Authors
Orlando Auciello, Benjamin Stein and M. Josefina Arellano Jimenez

References

1. M. Duque-Acevedo et al., International Journal of Environmental Research and Public Health, 17, 9549 (2020).
2. A. Malmgren, G. Riley, Reference Module in Earth Systems and Environmental Sciences (2018) doi:10.1016/B978-0- 12-409548-9.11014-0.
3. F.X. Collard, J.A. Blin, “Renewable and Sustainable Energy Reviews 38, 594 (2014).
4. J.W. Lawson, D. Srivastava, Physical Review B 77, 144209-1 (2008).
5. N. Bundaleska et al., “Physical Chemistry Chemical Physics 20, 13810 (2018).
6. E. Tatarova et al., Sci. Rep. 7 (2017).
7. O. Auciello, A.V. Sumant, Diamond and Related Materials 19, 699 (2010).
8. B.E. Stein, O. Auciello, M.J. Arellano-Jimenez et al., ACS Sustainable Chem. Eng. 10 (10), 3211 (2022).
9. E. C. Gaudino, S. Tabaso et al., Green Chemistry 21, 1202 (2019).
10. Z. Zhao, H. Huang et al.., Eng Life Sci 1(5), 197 (2001).

Please Note: This is a Commercial Profile