Pulsed Laser Annealing for Derivatization of Carbon Nanostructure: Fundamental Studies and Applications

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Abstract: Laser derivatization is proposed as an advanced diagnostic method for identifying and distinguishing the sources responsible for generating soot during combustion processes. This method enhances the ability to uniquely connect carbon black particle structure to formation conditions within the reactor. Laser derivatization has been shown to trace soot back to specific fuel types or combustion conditions, which is essential for source attribution, pollution control, and improving air quality management strategies. The pulsed laser (Nd:YAG) used for heating the carbon does not allow for normal graphitization of the carbon because pulse duration is too short (~ 10 nanoseconds) while particle size provides for rapid cooling, unlike a graphitization furnace. When carbons are laser-heated, all structural changes across all length scales are activated simultaneously in comparison to the sequential graphitization in an ordinary thermal furnace. Limitations in chemistry, resulting from nanosecond heating and microsecond cooling durations, underscore these initial compositional and structural distinctions, which are influenced by the specific formation conditions for the carbon. In all cases presented here, nanostructure changes are evaluated by HRTEM. For carbon blacks produced from different feedstocks variations in lamellae length, stacking, and especially in the core-to-shell radial structure are noted. Conversely for soots produced from biomass sources the similarity in derivatized nanostructure originates from the similarities in the fuel chemistry of biomass-based sources. In this study, three hydrocarbons were used as precursors to form three carbon black analogues with seemingly similar nanostructure after furnace graphitization. In stark contrast quite different nanostructures were realized when the carbons were laser-heated, despite both methods having similar peak temperatures (2,500 ℃). This research demonstrates that laser-based heating can serve as an analytical method for distinguishing carbon blacks and combustion-produced soot based on formation conditions and/or fuel type, by determining the optimal laser operational parameters for derivatization.