# CONTROLLABLE SYNTHESIS OF ALIGNED CARBON NANOTUBE/ALUMINUM OXIDE HYBRID FIBERS BY ATOMIC LAYER DEPOSITION

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**Keywords:** Carbon nanotube fibers, Atomic layer deposition, Aluminum oxide, Mechanical properties, Thermal resistant properties

## ABSTRACT

Carbon nanotube (CNT) fibers have been the focus of significant research over the past decade due to their excellent mechanical, electrical and thermal properties.[1] However, the mechanical properties of CNT fibers are still far below those of individual CNTs and the structures of the pure fibers are vulnerable after exposure to high temperature.[2] An effective way to reinforce the CNT fibers is to fabricate the CNT/polymer fibers by polymer infiltration, but due to the insulating nature and poor thermal stability of polymers, the electrical performance of the CNT/polymer fibers is still limited and their application is restricted mainly at ambient temperatures.[3] Compositing the CNT fibers with thermal resistant ceramics is a facile, but scarcely explored method.[4] Compared to the polymers, aluminum oxide ($Al_2O_3$) is chemically inert and high temperature tolerant. Herein, with the aim of obtaining thermal resistant fibers with higher tensile strength, we synthesized the multi-functional aligned CNT/aluminum oxide ($Al_2O_3$) hybrid fibers involving CNT-based continuous fibers coated by $Al_2O_3$ through the atomic layer deposition (ALD). Trimethylaluminum (TMA) for the Al precursor and deionized water (DI $H_2O$) vapors for the reactant were introduced into the ALD reactor in an alternating sequence to perform ALD-$Al_2O_3$ with a growth temperature of 200 ºC.[5] The aligned CNT/$Al_2O_3$ hybrid fibers with various ALD-$Al_2O_3$ cycles (100, 500 and 1000 cycles) can be simply obtained by changing the ALD cycles. Surface morphologies of the hybrid fibers observed by scanning electron microscopy (SEM) shown in Figure 1 confirm the successful oxide coating on the CNT fibers. Single fiber tensile test and two-point method were employed to characterize the mechanical and electrical properties of the hybrid fibers, respectively. Compared with the pristine CNT fibers, the tensile strength of the aligned CNT/$Al_2O_3$ hybrid fibers raised with the increase of ALD-$Al_2O_3$ cycles, rising from 0.92 GPa to 1.1 GPa (Figure 2a), while the electrical conductivity of CNT/$Al_2O_3$ hybrid fiber (1000 cycles) decreased by 33% (Figure 2b). Furthermore, the tensile strength retentions of the CNT/$Al_2O_3$ hybrid fibers (1000 cycles) were increased by 11.6% and 13.2%, respectively, after 1 h treatment at 800 ºC and 1000 ºC in argon atmosphere, as illustrated in Figure 2c, evidencing enhanced thermal resistant properties. Due to its self-limiting characteristic which distinguishes itself from aqueous solution methods and other vapor deposition techniques, ALD has precise control in deposition at the atomic level and can facilitate the conformal and uniform coating of $Al_2O_3$ on the CNT fibers while preserving the alignment of the CNT bundles within the fiber. As a consequence, we believe this process can improve the mechanical and thermal resistant properties of the hybrid fibers, which is significant for meeting the mechanical and high-temperature needs in advanced fiber reinforced composites.

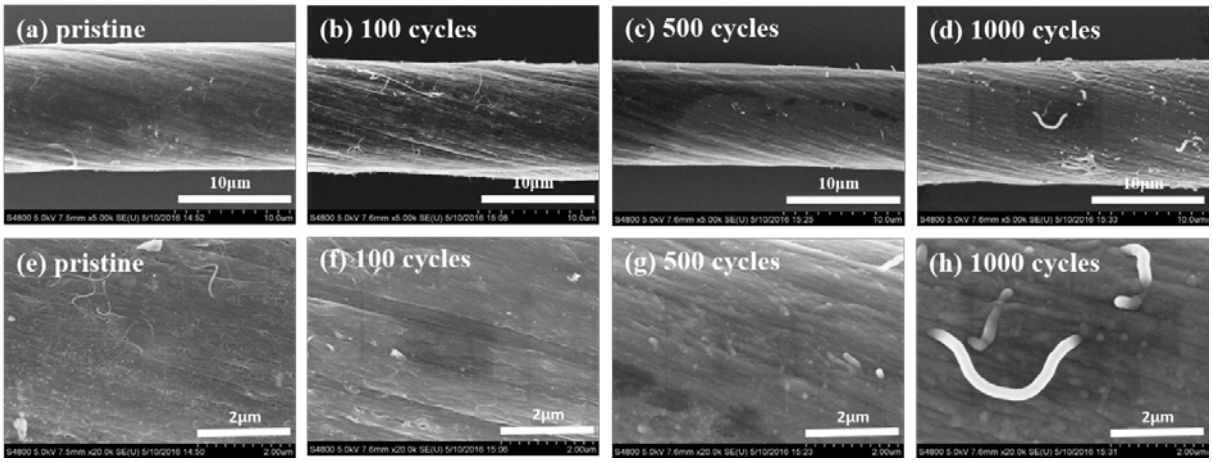


Figure 1: Surface morphologies of the aligned CNT/$Al_2O_3$ hybrid fibers with various ALD-$Al_2O_3$ cycles (0, 100, 500, 1000 cycles).

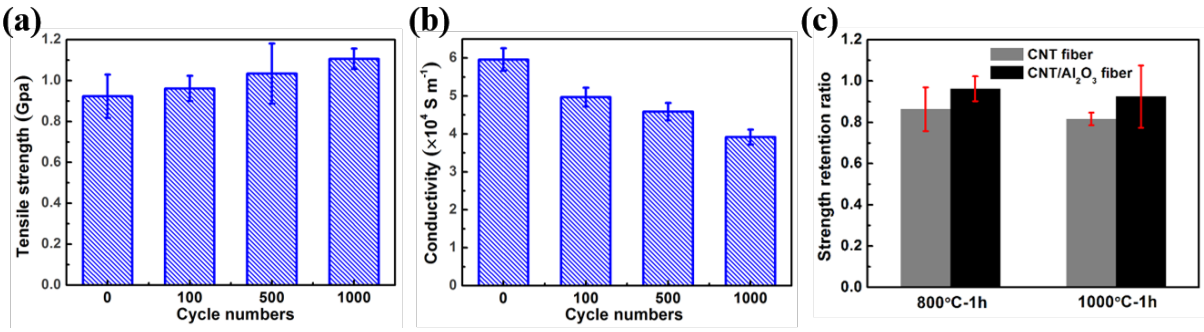


Figure 2: a, b) Mechanical and electrical properties of the aligned CNT/$Al_2O_3$ hybrid fibers with various ALD-$Al_2O_3$ cycles; (c) Tensile strength retentions of the CNT and CNT/$Al_2O_3$ fibers (1000 cycles) after 800 ºC and 1000 ºC heat treatment in argon atmosphere.

## REFERENCES

[1] W. Lu, M. Zu, J.H. Byun, B.S. Kim and T.W. Chou, State of the art of carbon nanotube fibers: Opportunities and challenges, *Advanced Materials*, **24**, 2012, pp. 1805-1833 (doi: 10.1002/adma.201104672).

[2] Z. Yang, X. Sun, X. Chen, Z. Yong, G. Xu, R. He, Z. An, Q. Li and H. Peng, Dependence of structures and properties of carbon nanotube fibers on heating treatment, *Journal of Materials Chemistry*, **21**, 2011, pp. 13772 (doi: 10.1039/c1jm12346g).

[3] Q.W. Li, Y. Li, X.F. Zhang, S.B. Chikkannanavar, Y.H. Zhao, A.M. Dangelewicz, L.X. Zheng, S.K. Doorn, Q.X. Jia, D.E. Peterson, P.N. Arendt and Y.T. Zhu, Structure-dependent electrical properties of carbon nanotube fibers, *Advanced Materials*, **19**, 2007, pp. 3358-3363 (doi: 10.1002/adma.200602966).

[4] M. Luo, Y. Li, S. Jin, S. Sang and L. Zhao, Oxidation resistance of multi-walled carbon nanotubes coated with polycarbosilane-derived sicxoy ceramic, *Ceramics International*, **37**, 2011, pp. 3055-3062 (doi: 10.1016/j.ceramint.2011.05.033).

[5] B.T. Quinton, K.D. Leedy, J.W. Lawson, B. Tsao, J.D. Scofield, J.N. Merrett, Q. Zhang, K. Yost and S.M. Mukhopadhyay, Influence of oxide buffer layers on the growth of carbon nanotube arrays on carbon substrates, *Carbon*, **87**, 2015, pp. 175-185 (doi: 10.1016/j.carbon.2015.02.015).