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Wafer-scale, massively parallel carbon nanotube arrays for realizing field effect transistors with current density exceeding silicon and gallium arsenide

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Calculations have indicated that aligned arrays of semiconducting carbon nanotubes (CNTs) promise to outperform conventional semiconducting materials in short-channel, aggressively scaled field effect transistors (FETs) like those used in semiconductor logic and high frequency amplifier technologies. These calculations have been based on extrapolation of measurements of FETs based on one CNT, in which ballistic transport approaching the quantum conductance limit of $2G_o = 4e^2/h$ has been achieved. However, constraints in CNT sorting, processing, alignment, and contacts give rise to non-idealities when CNTs are implemented in densely-packed parallel arrays, which has resulted in a conductance per CNT far from $2G_o$. The consequence has been that it has been very difficult to create high performance CNT array FETs, and CNT array FETs have not outperformed but rather underperformed channel materials such as Si by $6x$ or more. Here, we report nearly ballistic CNT array FETs at a density of 50 CNTs um^{-1}, created via CNT sorting, wafer-scale alignment and assembly, and treatment. The on-state conductance in the arrays is as high as 0.46 G_o per CNT, and the conductance of the arrays reaches 1.7 mS um^{-1}, which is $7x$ higher than previous state-of-the-art CNT array FETs made by other methods. The saturated on-state current density reaches 900 uA um^{-1} and is similar to or exceeds that of Si FETs when compared at equivalent gate oxide thickness, off-state current density, and channel length. The on-state current density exceeds that of GaAs FETs, as well. This leap in CNT FET array performance is a significant advance towards the exploitation of CNTs in high-performance semiconductor electronics technologies. *Brady GJ, Way AJ, Safron NS, Evensen HT, Gopalan P, Arnold MS, Quasi-ballistic carbon nanotube array transistors with current density exceeding Si and GaAs, SCIENCE ADVANCES, 2 (9), e1601240 (2016)