Carbon chains are sp-hybridized strings of carbon atoms; they may be considered as the elements of a one-dimensional phase of carbon. Atomic carbon chains have been proposed since a long time until they were observed by electron microscopy. According to theory, the chains may be bonded by either alternating single/triple carbon-carbon bonds (polyyne) or by double bonds throughout the chain (cumulene). Their electrical and mechanical properties and their stability have been subject of many theoretical studies; however, no experimental information has been available. Now, by using an STM stage (Nanofactory) in a TEM in an in-situ study, carbon atom chains have not only been made but also characterized electrically [1]. The chains were obtained by establishing a contact between a metallic tip and graphene ribbons. Retracting the tip while an electrical current flowed through the contact led to the unraveling of carbon atoms from the graphene ribbons. Figure 1 shows the simplified principle of the experiment and figure 2 the development of a typical carbon chain, spanning here between two graphene filaments. The electrical conductivity of the chains could be measured in such a way and was found to be much lower than predicted for ideal chains. Figure 3 shows the measured current-voltage characteristics of a chain. Theory predicts that strain in the chains determines their conductivity in a decisive way. Indeed, carbon chains are always under varying non-zero strain that transforms their atomic structure from cumulene to polyyne, thus inducing a tunable band gap. The modified electronic structure and the characteristics of the contact to the graphitic periphery explain the conductivity of the locally constrained carbon chains. New experiments show the local chemistry and the bonding at contacts between metals and carbon chains as well as characteristic current-voltage curves, depending on the type of contact. Dedicated experiments show qualitatively that the chains have an outstanding mechanical strength, in accordance with theory. The results show a perspective toward the synthesis of carbon chains and their application as the smallest possible interconnects or even as one-dimensional semiconducting devices.


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Fig. 1: Unraveling an atomic carbon chain from a graphene ribbon by passing a current through the junction and retracting the STM tip.

Fig. 2: Formation of a carbon chain between two graphene ribbons (FLG). The time scale as well as the length of the chain are indicated. In (f) the chain is broken.

Fig. 3: Carbon chain (arrowed) and its current-voltage characteristics.