Ta$_2$Pd$_3$Se$_8$ crystal as base for new naturally one-dimensional semiconducting nanostructures

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Since the discovery of carbon nanotubes the one dimensional or quasi one dimensional materials attract high interest as a possible base of future nanoelectronics. Still, to obtain pristine atomic scale single-crystal structure is difficult and very limited examples were presented, such as 1D nanotubes or nanowires. Indeed, there are many groups of materials that are highly anisotropic in their bulk crystal structure with bonding strength differs significantly even up to 100 times. This makes it possible that one can mechanically separate the bulk into high quality low dimensional crystals directly, and the pristine quality from the exfoliated crystals assures that its intrinsic properties can be studied. As have been demonstrated in 2D graphene, exfoliated from graphite, many quantum effects can be observed even at room temperature. Lately, the same micromechanical exfoliation technique was applied to the group of transition metal dichalcogenide and exotic optical properties and high electronic switching performance has been revealed on their 2D crystals. Such technique can be applied for the extraction of 1D structure from its bulk counterpart if it will consist of lengthful parts connected by physical or weak chemical bonds. The successful realization of such procedure can allow to get access to naturally one-dimensional objects of high crystalline quality and small width distribution. Here, we will show that, by avoiding chemical synthesis, a new truly one dimensional single crystal material Ta$_2$Pd$_3$Se$_8$, can be exfoliated using simple mechanical exfoliation technique due to weakly bonding between Pd atom and Se atom from neighbor ribbon unit. Transmission electron microscopy study clearly shows the evidence that the diameter of TPS crystal can be reduced down to lower than 2 nm and preserve good crystal quality. Comprehensive density functional theory simulation revealed the nature of the chemical bonding in the structure, the theoretical analysis of the energies of Ta$_2$Pd$_3$Se$_8$ surfaces allowed to construct the nanowires models which corresponded well with experimental data. Our band structure calculations indicated the trend of expanding band gap from bulk crystal to single ribbon, when the diameter of TPS crystal keeps decreasing. Also, it turns into direct band gap for single fiber
while thicker crystals are not. Based on TPS crystal with different diameters, we fabricated field effect transistor with a back gate electrode. FETs with TPS crystal ranges from 10 nm to 30 nm perform best with an on/off ratio reaching $10^4$ and mobility near 80 cm$^2$V$^{-1}$s$^{-1}$. Our results demonstrate a truly one dimensional atomic chain material which presents opportunities in areas including low dimensional physics, optoelectronics and energy harvesting. P.B.S. acknowledges the financial support of the Ministry of Education and Science of the Russian Federation in the framework of Increase Competitiveness Program of NUST "MISiS"(No. K2-2015-033) and Grant of President of Russian Federation for government support of young PhD scientists MK-6218.2015.2 (project ID 14.Z56.15.6218-MK).