

Support information

XPS analysis

For the figures S1-S7: C1 is assigned to sp^2 -C (284.4 eV), C2 to π -plasmon excitations (290.9 eV), C3 to sp^3 -C (285.0 eV), C4 to epoxy groups C-O-C (286.6 eV), C5 to carbonyl groups C=O (287.5 eV) and C6 to carboxyl groups -COOH (288.8 eV).

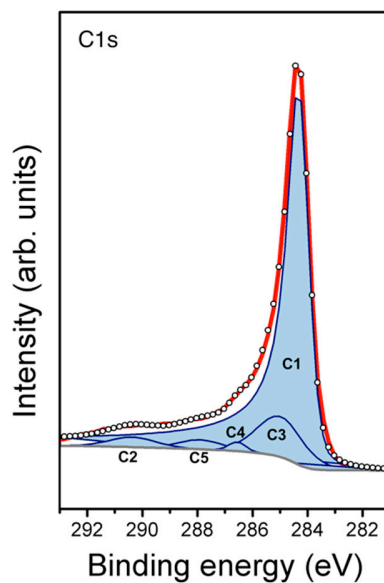


Figure S1. XPS analysis of C1s spectrum of v-CNTs after 1 minute of ion implantation with 1 keV of ion kinetic energy.

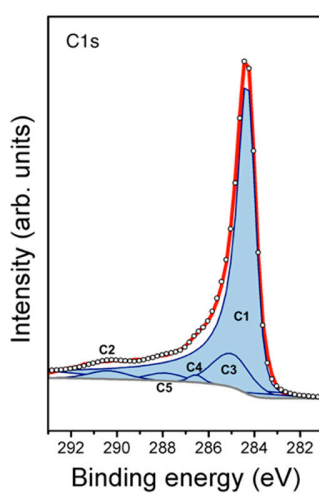


Figure S2. XPS analysis of C1s spectrum of v-CNTs after 2.5 minutes of ion implantation with 1 keV of ion kinetic energy.

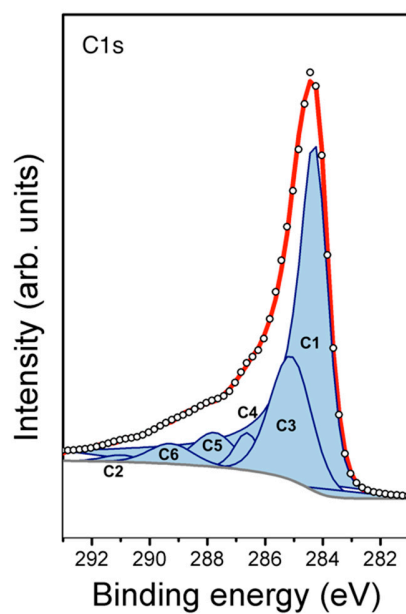


Figure S3. XPS analysis of C1s spectrum of v-CNTs after 5 minutes of ion implantation with 1 keV of ion kinetic energy.

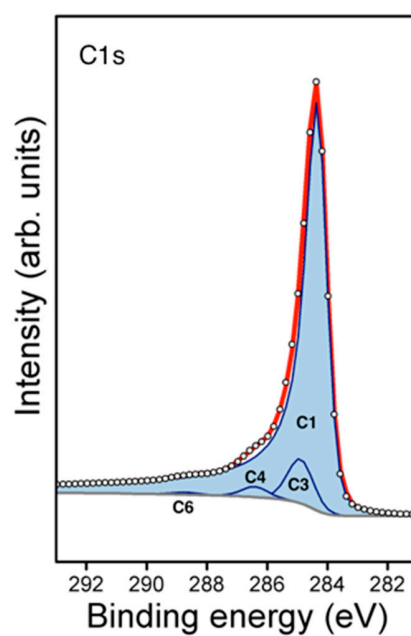


Figure S4. XPS analysis of C1s spectrum of v-CNTs after 5 minutes of ion implantation with 0.1 keV of ion kinetic energy.

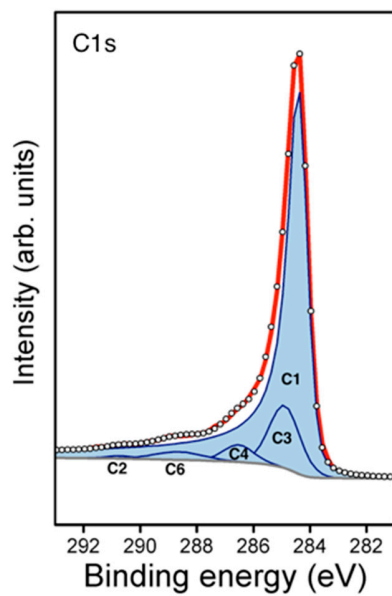


Figure S5. XPS analysis of C1s spectrum of v-CNTs after 5 minutes of ion implantation with 0.25 keV of ion kinetic energy.

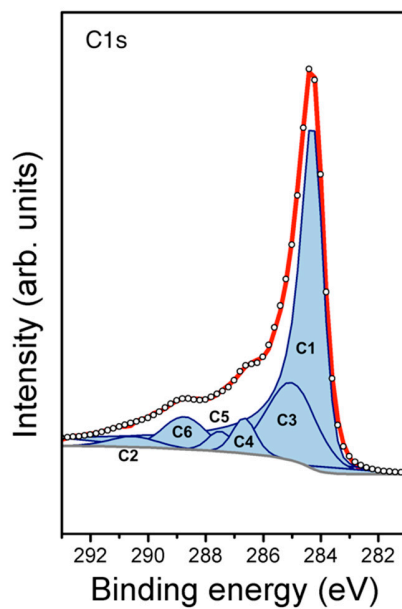


Figure S6. XPS analysis of C1s spectrum of v-CNTs after 5 minutes of ion implantation with 0.5 keV of ion kinetic energy.

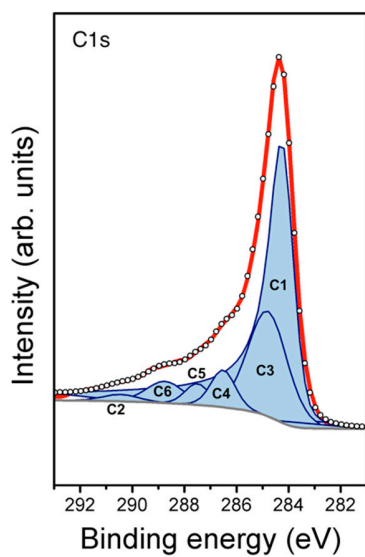


Figure S7. XPS analysis of C1s spectrum of v-CNTs after 5 minutes of ion implantation with 1.5 keV of ion kinetic energy.

Table S1. Relative area and standard deviation of the components present in the C1s XPS analysis spectrum.

Sample	Component	Relative area (%A)	St. Deviation (%)
Pristine	sp^2 -C	96.3	0.5
	Plasmon	3.7	0.5
1min/1keV	sp^2 -C	86.2	2.9
	sp^3 -C	9	1.2
	C-O-C	0.7	0.5
	C=O	1.9	1.4
	Plasmon	2.2	1.7
2.5min/1keV	sp^2 -C	83	5.5
	sp^3 -C	11.5	1.4
	C-O-C	1.7	0.8
	C=O	2.4	0.8
	Plasmon	1.4	5.5
5min/1keV	sp^2 -C	71.7	4.2
	sp^3 -C	16.8	3.6
	C-O-C	3.1	1.3
	C=O	4.7	1.5
	COOH	2.9	1.1

10min/1keV	Plasmon	0.8	4.8
	<i>sp</i> ² -C	72.7	2.7
	<i>sp</i> ³ -C	19.9	2.2
	C-O-C	4.5	1.3
	C=O	3.8	1.2
	COOH	7.2	0.9
	Plasmon	1.9	1.7
5min/0keV	<i>sp</i> ² -C	85.2	4.3
	<i>sp</i> ³ -C	8.8	3.1
	C-O-C	5.5	1.7
	Plasmon	0.5	0.4
5min/0.1keV	<i>sp</i> ² -C	92.9	1.4
	<i>sp</i> ³ -C	5.5	1.45
	C-O-C	1.3	0.5
	COOH	0.3	0.2
	Plasmon	0	0
5min/0.25keV	<i>sp</i> ² -C	84.2	4
	<i>sp</i> ³ -C	9.8	1.5
	C-O-C	2.6	1.5
	COOH	1.9	1.9
	Plasmon	1.5	2.3
5min/0.5keV	<i>sp</i> ² -C	71.2	3.6
	<i>sp</i> ³ -C	15.7	2
	C-O-C	3.3	0.7
	C=O	2	1
	COOH	5.7	1
	Plasmon	2.1	4.2
5min/1.5keV	<i>sp</i> ² -C	69.7	3.1
	<i>sp</i> ³ -C	18.9	2.1
	C-O-C	4.2	0.9
	C=O	2.4	0.7
	COOH	3.7	0.9
	Plasmon	1.1	3.4
5min/2keV	<i>sp</i> ² -C	72	2.9
	<i>sp</i> ³ -C	15.5	2.1
	C-O-C	3.9	0.8
	C=O	4.2	1.3
	COOH	2.7	0.7
	Plasmon	1.7	3.5

For the figures S8-S16: O1 is assigned to C-O-C, O2 to C=O and O3 to COOH.

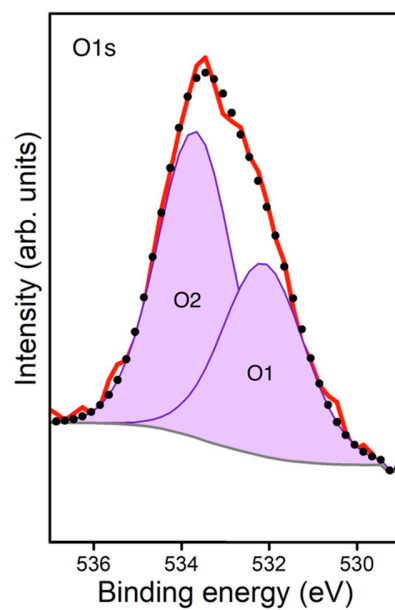


Figure S8. XPS analysis of O1s spectrum of v-CNTs after 1 minute of ion implantation with 1 keV of ion kinetic energy.

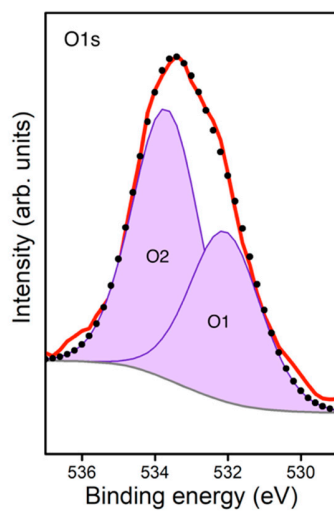


Figure S9. XPS analysis of O1s spectrum of v-CNTs after 2.5 minutes of ion implantation with 1 keV of ion kinetic energy.

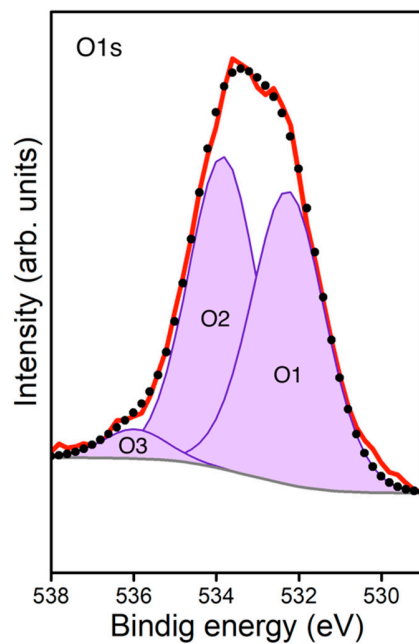


Figure S10. XPS analysis of O1s spectrum of v-CNTs after 5 minutes of ion implantation with 1 keV of ion kinetic energy.

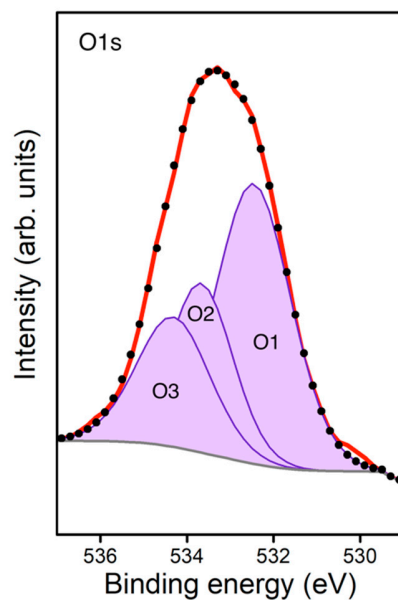


Figure S11. XPS analysis of O1s spectrum of v-CNTs after 10 minutes of ion implantation with 1 keV of ion kinetic energy.

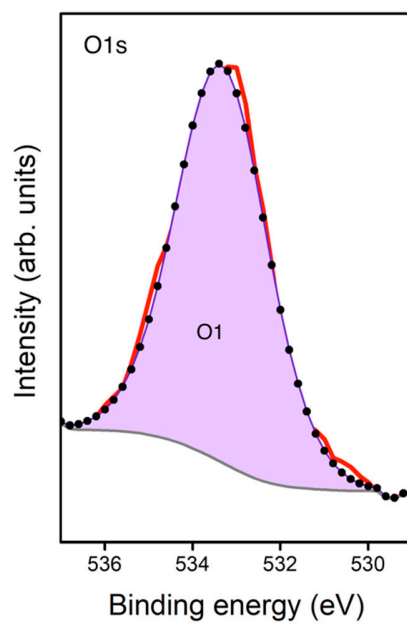


Figure S12. XPS analysis of O1s spectrum of v-CNTs after 5 minutes of ion implantation with 0 keV of ion kinetic energy.

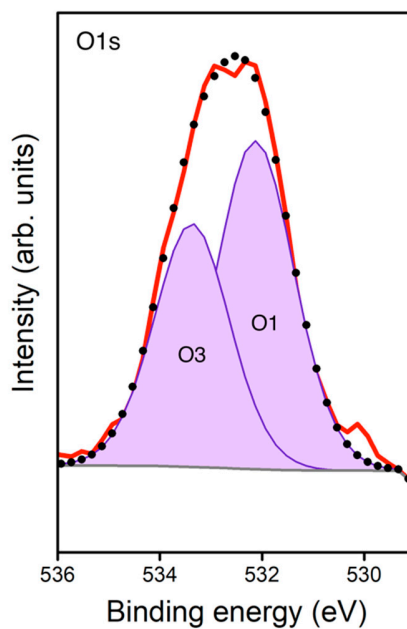


Figure S13. XPS analysis of O1s spectrum of v-CNTs after 5 minutes of ion implantation with 0.1 keV of ion kinetic energy.

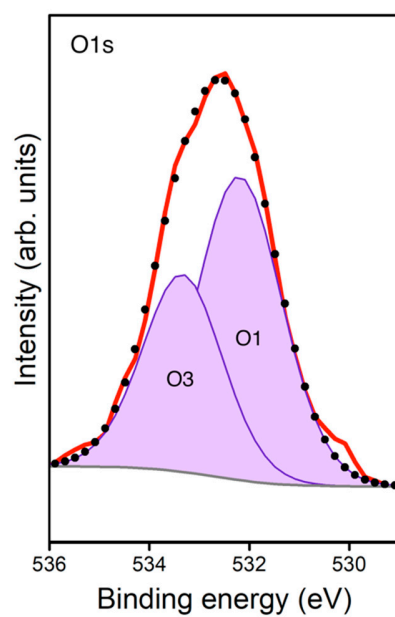


Figure S14. XPS analysis of O1s spectrum of v-CNTs after 5 minutes of ion implantation with 0.25 keV of ion kinetic energy.

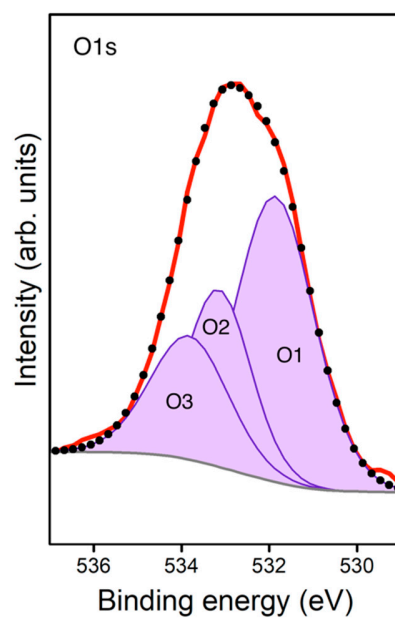


Figure S15. XPS analysis of O1s spectrum of v-CNTs after 5 minutes of ion implantation with 0.5 keV of ion kinetic energy.

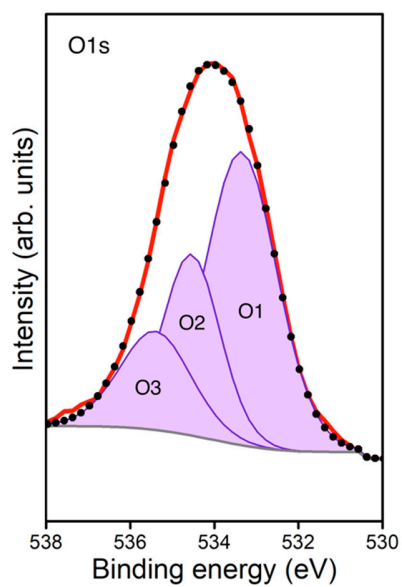


Figure S16. XPS analysis of O1s spectrum of v-CNTs after 5 minutes of ion implantation with 1.5 keV of ion kinetic energy.

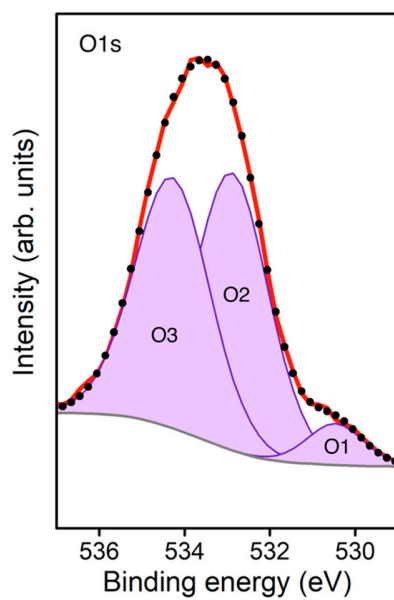


Figure S17. XPS analysis of O1s spectrum of v-CNTs after 5 minutes of ion implantation with 2 keV of ion kinetic energy.

Table S2. Relative area and standard deviation of the components present in the O1s XPS analysis spectrum.

Sample	Component	Relative area (%A)	St. Deviation (%)
1min/1keV	C-O-C	40.5	12.6
	C=O	59.5	12.6
2.5min/1keV	C-O-C	39.7	5.7
	C=O	60.3	5.7
5min/1keV	C-O-C	47.6	4.9
	C=O	48.3	5.7
	COOH	4.1	2
10min/1keV	C-O-C	50.9	16.7
	C=O	26	19.9
	COOH	23.1	15.7
5min/0keV	C-O-C	100	0
5min/0.1keV	C-O-C	58.2	24.8
	COOH	41.8	24.8
5min/0.25keV	C-O-C	61.9	16.6
	COOH	38.1	16.6
5min/0.5keV	C-O-C	51.5	12.3
	C=O	26.2	14.3
	COOH	22.3	14.2
5min/1.5keV	C-O-C	54.6	16.1
	C=O	27.1	20.7
	COOH	18.3	16
5min/2keV	C-O-C	5.6	1.5
	C=O	48.8	8.2
	COOH	45.6	8.2

Raman analysis:

The Raman data presented is “as-recorded” with no peak normalization, all spectra obtained for the same laser intensity (523 nm) and recording time. Figure S18a shows that with increasing oxygen ion implantation time, there is a gradual increase in peak intensity and notably the intensity of the D-peak band at $\sim 1350\text{cm}^{-1}$ increases significantly faster than the G-peak at $\sim 1580\text{cm}^{-1}$. This increase in the relative intensity of the peaks (or peaks area ratio) is a direct indication that the oxygen irradiation is damaging the CNT samples. The variation of the intensity with varying ion-energy is somewhat subtler: overall there is the same general trend of increasing I_D/I_G ratio however the initial step from

pristine to 0keV shows a slight decrease in this ratio. We anticipate that this decrease comes from the oxygen plasma acting to preferentially etch amorphous carbon on the nanotube surfaces, effectively cleaning the carbon material. CNTs synthesized at low temperatures as the one used in this work are known to have a high amount of amorphous carbon at the surface. There is a similar small change in the ratio of the principal G-peak with its higher frequency G⁺-shoulder. While the G⁺ comes purely from the nanotubes themselves, the G-peak will also feature a contribution from aromatic sp²-bonded carbon species. Hence etching the amorphous carbon from the CNT surface decreases its contribution to the G-peak, changing the G:G⁺ peak ratio as observed, consistent with this explanation. For increasing oxygen ion kinetic energy, the intensity of both peaks drop indicating that the CNTs are significantly degraded. Therefore, the Raman spectroscopy results verify the XPS results showing an increase in the defect/oxygen associated components for increasing irradiation ion kinetic energy.

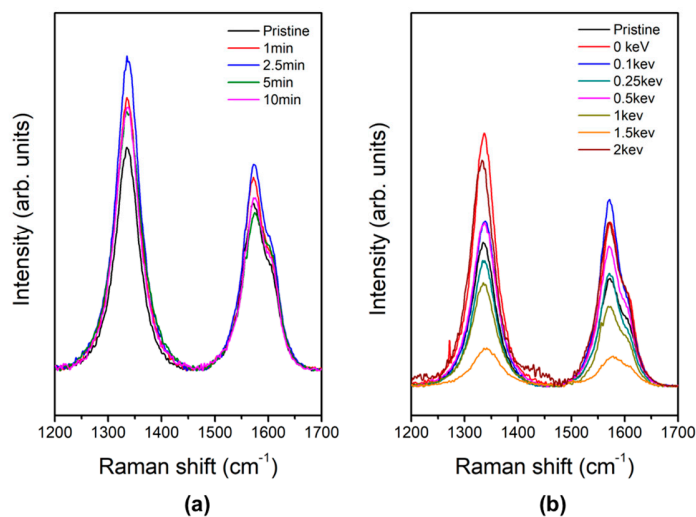


Figure S18. Raman spectrum of v-CNTs functionalized with low kinetic energy oxygen ion irradiation with different treatment time (a) and ion kinetic energy (b).