EMERGENCE OF TOPOLOGICAL DEFECTS IN A BILAYER OF MULTIWALLED CARBON NANOTUBES IRRADIATED BY GAMMA-RAYS

H. Grushevskaya, A. Timoshchenko, I. Lipnevich
Physics Faculty, Belarussian State University, Minsk, Belarus

grushevskaja@bsu.by

I. INTRODUCTION

Among applications of graphene-like materials in nuclear technologies the development of radiation-resistant materials and of protective shielding nanostructured coatings is in a great demand. Graphene is stable to irradiation because the knocked-on neutral carbon atoms reside on the graphene plane. The radiation resistance of graphene can be caused by an interaction of gamma-quanta with the graphene charge vortical carriers of the pseudo-Majorana type [1,2]. A mechanism of the interaction between gamma-quanta and the pseudo-Majorana charge carriers in the graphene plane leading to a Compton scattering on super-dense fluxes of the pseudo-Dirac charge carriers has been not ascertained yet.

In the paper we will study gamma-ray scattering on rolled graphene atomic layers of high-ordered multiwalled-carbon-nanotubes (MWCNTs) which organized a bilayer. Our goal is to reveal radiation high-energy topological defects of a type of pseudo-Majorana pairs “vortex–antivortex” in graphene electron and hole densities.

II. MATERIALS AND METHODS

MWCNT bundles decorated by the organometallic complexes were fabricated utilizing Langmuir--Blodgett (LB) nanotechnique. The two MWCNT LB-monolayers were deposited on the interdigital structure of aluminium electrodes, on the surface of which a layer of nanoporous anodic alumina (pores with a diameter of 10 nm) were previously formed as an insulator coating.

The standard low-intensive source of ionizing radiation (IRS) ^{137}Cs (CsJ) was utilized. We registered about 9200 events. MWCNTs were exposed to radiation for 1 hour.

An analysis of secondary electrons spectra has been performed by a lab-quality radiation spectrometric facilities "Nuclear Physics" (BSU, Minsk, Belarus). The scintillation crystal thallium-activated sodium iodide, NaI(Tl) (a diameter of 25 mm, a height of 40 mm)) was utilized as a detector crystal.

III. RESULTS AND DISCUSSION

Response functions of the detector with and without the absorber are shown in Figure 1. The IRS response function R_{Cs} features peaks of photoelectric absorbtion (photopeak) and a characteristic X-ray at the lower and highest pulse heights respectively. The characteristic X-ray photons are emitted by free electrons filling non-occupied electron *K*-shells in atoms of the lead collimator. The radiation spectrum of CsJ is a typical one recorded from the NaI(Tl) scintillation detectors. The photopeak appears at the energy of original ^{137}Cs gamma-ray photon. A Compton scattering gives rise a single Compton continuum of energies and multiple-Compton-scattering events in the IRS spectra. The multiple Compton scattering occurs due sufficiently large size of the detector crystal. One observes also a peak caused by the bremsstrahlung generated in stopping the beta particles by the IRS shield and the backscatter peak caused by photons Compton scattered at large angles in materials immediately surrounding the scintillator crystal (see Figure 1a).

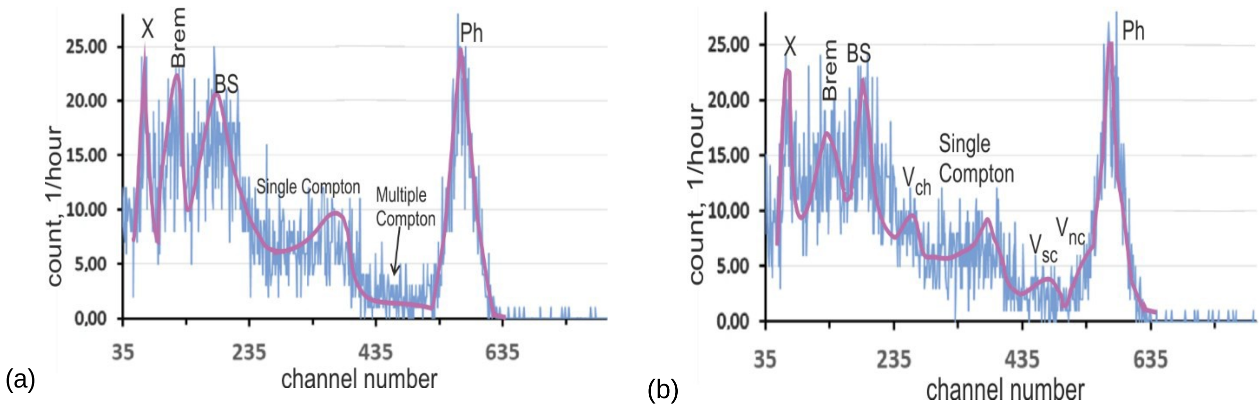

Figure 1. Pulse height spectra R_{Cs} (a) and R_{CsG} (b) for photons beam incoming from IRS ^{137}Cs through the collimator without and with the absorber, respectively, and scattering on the detector crystal; a radiation background has been subtracted from original distributions.

In Figure 1 the backscatter peak, the photopeak, the characteristic X-ray peak, and the contribution from the bremsstrahlung are labeled by ``BS'', ``Ph'', ``X'', and ``Brem'', respectively; the absorber escape peaks of the pseudo-Majorana chiral, semichiral, nonchiral fermions, which are created at the interaction between graphene and gamma-ray, are called as "V_{ch}", "V_{sc}", and "V_{nc}", respectively. The single Compton continuum and area of multiple Compton scattering are labeled by ``Single Compton'' and ``Multiple Compton'', respectively.

Let us analyze MWCNT effects on the incoming ^{137}Cs gamma-quanta beam. After placing the electromagnetic-radiation absorber with the bilayer of ordered MWCNT bundles decorated by the organometallic compound into the collimator, three additional peaks reveal themselves in the ^{137}Cs-radiation spectrum of secondary electrons along with the photopeak, the single Compton continuum, the backscatter peak, the X-ray escape peak, and the bremsstrahlung. The spectra indicate narrowing of the ^{137}Cs-radiation peaks. The shape of the single Compton continuum of ^{137}Cs-radiation spectrum with maximum being approximately in 360th channel after placing of the MWCNT sample into the collimator. Maxima of the three new peaks are approximately in 260th, 460th and 535th channels. It testifies that in creating pairs of charge carriers in the graphene the gamma-quanta escape from the detector. Collisions between the radiation graphene defects and the photons from the bremsstrahlung process leads to decreasing of the peak ``Brem''.

Now we will utilize the experimental data to elucidate a pseudo-Majorana nature of the graphene charge carriers. To do it we offer a following mechanism of graphene radiation resistivity through creation of neutral vacancies V_0 with knocked-on neutral carbon atoms C^0 fixed on the graphene monolayer by radiation defects of a pseudo-Majorana type. The gamma-rays can escape from the detector crystal owing to a production of radiation-defect pairs in a form of topologically nontrivial defects of delocalized electron (hole) density in a one part of the graphene monolayer plane and topologically nontrivial defects of hole (delocalized electron) density in another graphene part. The pseudo-Majorana vortex-antivortex pairs are created at the Compton scattering of the gamma-rays on the MWCNT graphene planes. Accordingly, the radiation defects decrease the energy deposited in the detector and it results in the appearance of the additional peaks V_{ch}, V_{sc} and V_{nc} in the response function R_{CsG} (see Figure 1b). At colliding with C atoms the free pseudo-Majorana fermions are de-excited and confined by hexagonal symmetry near the Dirac touching valent and conductivity graphene bands. Meanwhile the graphene pseudo-Majorana band structure is degenerated and, accordingly, the vortex pairs transit from the flat area to conical one of the graphene band. It signifies that the branches of the vortex begin to move inconsistently. The vortex decay leads to an emergence of an electron-hole avalanche.

III. CONCLUSIONS

So, scattering in MWCNTs the 661.7-keV gamma-rays create pairs of topologically nontrivial radiation defects and antidefects. These high-energy graphene pairs of scattering centers are pseudo-Majorana vortical and antivortical fermions. Annihilating and scattering on carbon electron density the pseudo-Majorana quasiparticles avalanche-likely produce electron-hole configurations of graphene charge density.

REFERENCES

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