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Conduction state transition induced by solitons in a graphene junction at room temperature

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Abstract

The aim of this research was the study of the transition between high and low electrical resistivity states of two overlapped graphene layers when subjected to short electromagnetic pulses (soliton waves). These transitions have already been previously observed by the authors in experiments carried out with different conductors, separated by a tiny insulating layer. The choice of a highly ordered material, such as graphene, was justified by the attempt to achieve greater stability and reproducibility of these transitions. What has been observed is an instantaneous *reversible* transition of the graphene overlapped layers to/from a state of insulator with resistance in the order of Mohms from/to a state of resistance of few ohms or, in some cases, of zero ohms. The transition from a high resistance state to a lower one requires EM pulses of different polarity than the transition from a low resistivity state to a higher one. Some intermediate relatively stable states have also been observed.

Introduction

Physicist Pablo Jarillo-Herrero (M.I.T.), along with other researchers from the US and Japan [1], announced in 2018 that they had discovered how to induce superconductivity in a double layer of graphene. More precisely, they achieved this result by using two overlapped and suitably rotated graphene layers, at a temperature of less than two kelvin.
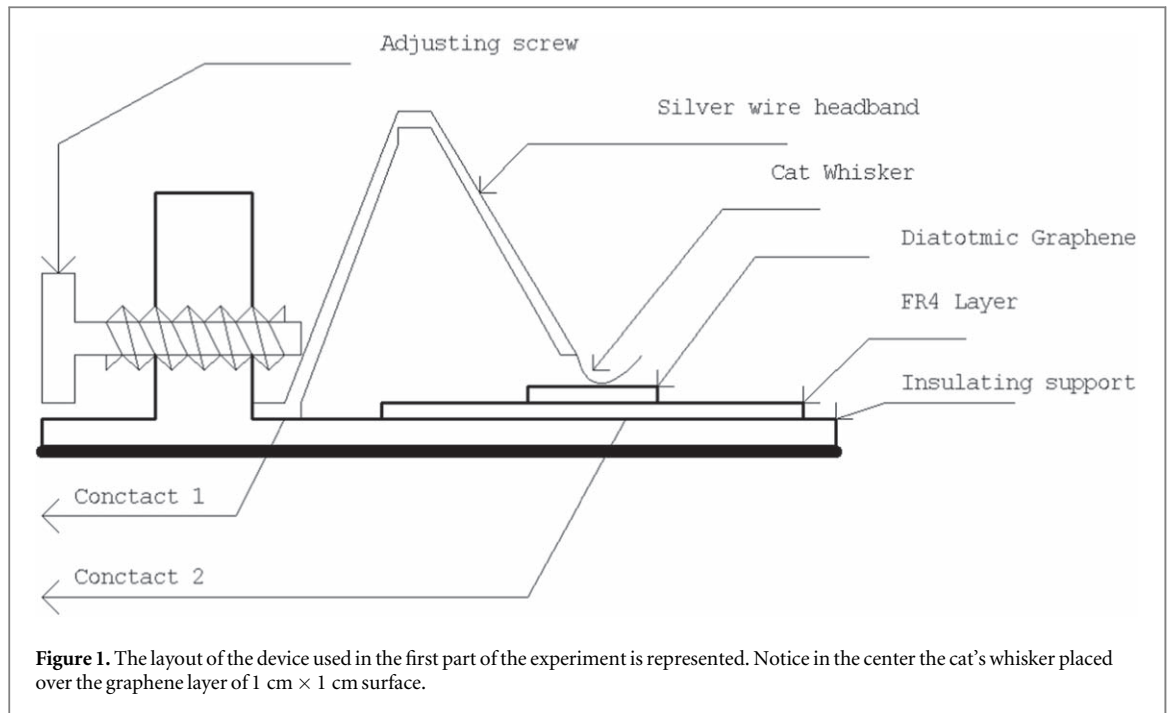
The discovery by Jarrillo Herrero's team has been replicated in several laboratories and aroused great interest among condensed matter physicists. As a matter of fact, a deeper understanding of superconductivity is a very important research target, not only for the possibility of new applications but also for the chance of reaching a better understanding of the conceptual foundations of theoretical physics.

Later, Chao Yang *et al* [2] highlighted the role of quantum phase coherence in the superconductor-metal-insulator transitions caused by quantum magneto-conductance oscillations in superconducting films at relatively high temperatures, noting that an intermediate bosonic metallic state occurs between the superconducting and insulating regimes.

In another experiment, Johan F Prins observed the formation of a superconducting bond at room temperature between two opportunely doped diamond electrodes. This kind of superconductivity cannot be modeled by the widely accepted BCS theory of Cooper pairs.

It's also interesting to remind that the transition, caused by electromagnetic pulses, between high and low resistivity states between conductors with a loose contact is a phenomenon observed and exploited since the very early years of radio communication [3]. Surprisingly, even today this interesting phenomenon lacks a fully satisfactory theoretical explanation.

We believe that all these phenomena are somewhat related, and this fact indicates the necessity of a new theory of superconductivity. For this purpose, among other possible theoretical paths, the authors believe it should be considered also the innovative electron model recently proposed by A. Kovacs, G. Vassallo, P. O'Hara,

Figure 1. The layout of the device used in the first part of the experiment is represented. Notice in the center the cat's whisker placed over the graphene layer of 1 cm × 1 cm surface.

Table 1. Effect of subsequent bright and/or dark solitons irradiations on the resistance of two overlapped graphene layers (under loose contact).

Initial value of R	Soliton A	Soliton B	Soliton C	Soliton D	Final value of R
245,560,000 ohm	101.234 ohm	23.410 ohm	12.67 ohm	8.42 ohm	8.42 ohm
458,330,000 ohm	87.397 ohm	87.397 ohm	87.397 ohm	7.481 ohm	7.481 ohm
Overload	4.048 ohm	4.048 ohm	4.048 ohm	4.048 ohm	4.048 ohm
850,200,000 ohm	37.733 ohm	32.941 ohm	21.335 ohm	5.155 ohm	5.155 ohm
Overload	93.104 ohm	54.297 ohm	43.333 ohm	35.891 ohm	12.449 ohm

F. Celani, A. Oscar Di Tommaso in 'Unified Field Theory and Occam's Razor: Simple Solutions to Deep Questions'—2022 - [4].

In this paper, the experimental setup, the observed data, and some preliminary hypotheses related to the possible physical mechanism involved are described.
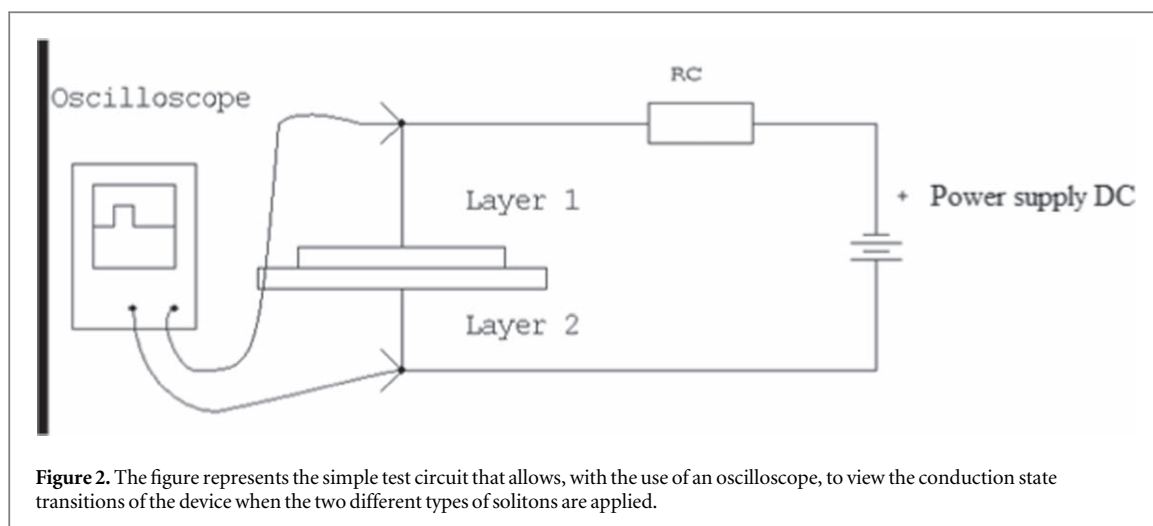
Tests performed and experimental setup

The experiment was carried out in two phases, using two different experimental setups.

Apparatus 1
The first apparatus was built to carry out a series of tests on the effects of the application of solitons generated by excitation with a remote high voltage electric soliton pulse generator. Both positive ('bright' solitons) and negative ('dark' solitons) pulses with a width of approximately 100 ns have been used. In the preliminary tests, a 10 mm × 10 mm single layer graphene film on an 18-micron thick copper foil (Digikey code 1767-1003-ND) has been used. The copper foil, in turn, was placed on an FR4 vetronite board, copper plated on both sides. A folded stylus (bow) was created out of a 1 mm silver-plated copper wire finishing with a so-called 'cat's whisker' made of 0.3 mm silver-plated copper wire. An adjusting screw on the axis of the bent stylus allowed to modify both the pressure and the position of the cat's whisker on the layer. A schema of the device is represented in figure 1.

The resistance values detected with the HP multimeter Mod.3456 A, measured on contacts 1 and 2 after the application of so-called bright and/or bright solitons, are shown in tables 1 and 2.

The above table should be read as follows: on the left, the initial measurement of the electrical resistance of the loose contact is reported, before irradiation with the soliton pulses. The realization of a loose contact is obtained by slightly moving the cat's whisker on the surface of the layer and increasing or decreasing its pressure on it. A point is therefore sought where the electrical resistance is not equal to the short-circuit resistance of the

Figure 2. The figure represents the simple test circuit that allows, with the use of an oscilloscope, to view the conduction state transitions of the device when the two different types of solitons are applied.

Table 2. Effect of subsequent bright and/*or dark solitons ir*radiations on the resistance of two overlapped graphene layers (under loose contact).

Initial Value of R	Soliton A	Soliton B	Soliton C	Soliton D	Final Value of R
100.944 ohm	389.99 ohm	389.99 ohm	2,303.0 ohm	77,994.0 ohm	580,662.0 ohm
980.274 ohm	1,287.742 ohm	5,488.236 ohm	10,077.0 ohm	874,882.0 ohm	21,339,000 ohm
25.710 ohm	28.744 ohm	86.05 ohm	2,699.197 ohm	5,528.744 ohm	80,274.0 ohm
39.402 ohm	39.402 ohm	39.402 ohm	39.402 ohm	overload	overload
8.708 ohm	399.411ohm	6,677.25 ohm	9,955.86 ohm	overload	overload

junction. Having found this position, it is verified that the electrical resistance is sufficiently high (from a few kohm to a few tens of Mohm) and that it is then also stable and does not vary excessively with respect to the resistance initially measured.

The labels 'Solitons A-B-C-D', indicate subsequent irradiations with 'bright' solitons. Said irradiations caused a progressive transition to a state having a final resistance value R for which subsequent pulses had no further effects. The tests were repeated several times and only the results of a few trials of significance for the preliminary part of the research are reported above in table 1.

The following table 2 shows the results of another series of tests where, starting again from a loose contact of the two graphene layers, an initial relatively low resistance state was previously obtained by emission of bright solitons. After that, the injection of dark solitons was started, and a progressive increase in the resistance value was observed.

In table 2 the values of R, measured after applying dark solitons, show a progressive increase in the electrical resistance of the device. The above measurements were carried out by an ohmmeter connected between Contact 1 and Contact 2, according to the configuration shown in figure 1. Then, an electrical circuit was created by connecting a 10 kohm load resistor to the contact of the upper layer (Layer 1) and connecting this to a stable 12 V power supply unit, while the contact of the lower layer (Layer 2) was grounded, according to the schema represented in figure 2 below.

The device was then connected to the oscilloscope and both 'bright' and 'dark' solitons were applied. The voltage at the ends of the device after the application of a dark and a bright soliton is shown in figure 3 below.

At the arrival of a dark soliton the electrical resistance rises, reaching a different stable value, increasing consequently the voltage measured at the ends of the device.
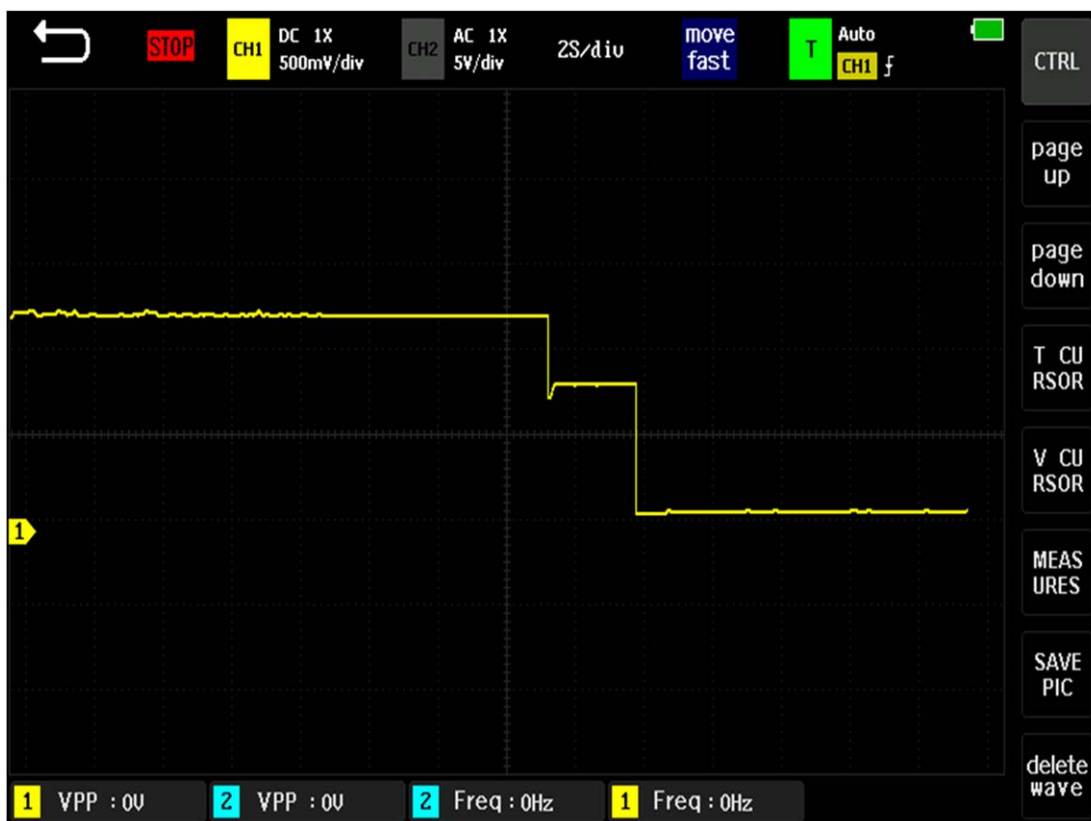
When a bright soliton is applied, the device instantaneously switches its electrical resistance to a lower value and the voltage at the ends of the device drops. The final result is a square wave like that visible in figure 3.

Figure 4 above shows the voltage drops obtained at the ends of the device after the application of two subsequent bright solitons. As can be seen, two different stable states draw a two-stepped figure.

Figure 5 below shows, instead, the switching of the device after the application of a dark soliton, and the slight oscillations that are produced only when an intermediate resistance has been reached. The peak visible on the step and rising upwards is induced by the sudden variation of the electric field produced by the remotely transmitted soliton wave.

Figure 3. A screenshot from the oscilloscope connected to the test device of figure 2. It represents the effect of a dark soliton irradiated on the device, which determines the immediate increase of the electrical resistance of the overlapped layers, causing the voltage at the insertion point of the RC load resistance to rise by about 600 mV. The subsequent irradiation, after 4 s, with a bright soliton causes the quick collapse of the electrical resistance and the return of the device to its initial state.

Figure 4. A screenshot taken from the oscilloscope connected to the test device in figure 2 is represented here. An initial voltage of about 1.5 volts is applied to the device and then the first irradiation with a bright soliton is applied. The quick collapse of the electrical resistance is thus determined up to an intermediate level with reference to the zero resistance which would lead the device to the reference of the ground plane indicated with number 1 on the left of the image. The application of a subsequent bright soliton, after about 3 s from the application of the first one, causes a collapse of the resistance of the device such as to bring its output to the ground plane. It is therefore evident the induction of stable intermediate levels of resistance between the two superimposed layers of graphene.
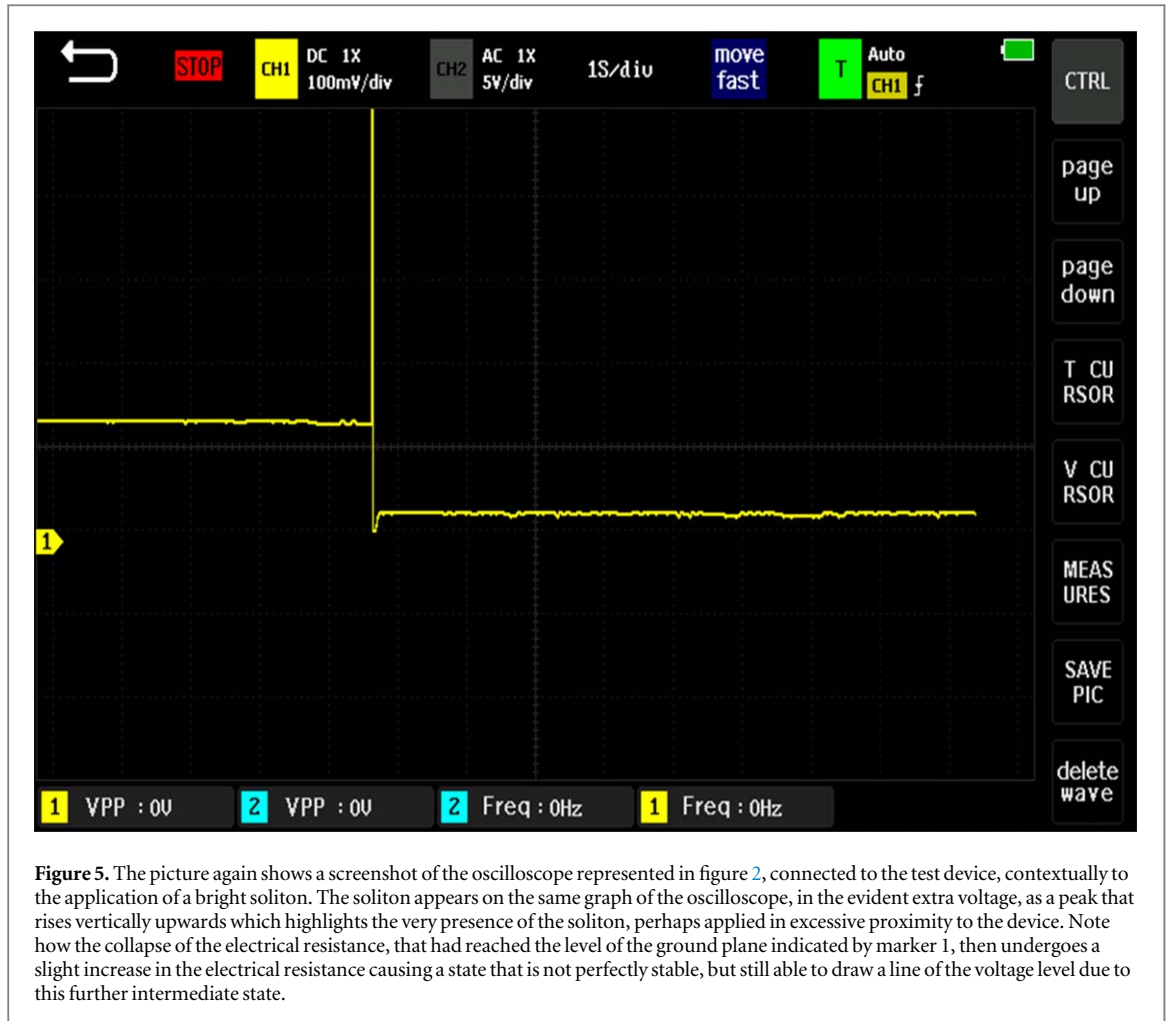
Figure 5. The picture again shows a screenshot of the oscilloscope represented in figure 2, connected to the test device, contextually to the application of a bright soliton. The soliton appears on the same graph of the oscilloscope, in the evident extra voltage, as a peak that rises vertically upwards which highlights the very presence of the soliton, perhaps applied in excessive proximity to the device. Note how the collapse of the electrical resistance, that had reached the level of the ground plane indicated by marker 1, then undergoes a slight increase in the electrical resistance causing a state that is not perfectly stable, but still able to draw a line of the voltage level due to this further intermediate state.

Apparatus 2

Successively, a different apparatus has been implemented.

The outline of the apparatus can be seen in figure 6. It includes two monoatomic layers of graphene, each of which is in contact with a 18 μm thick copper foil.

The resulting sandwich has two connection surfaces, the first one on the lower face and the other one on the upper face; both are made of copper, so it has been possible to make simple soldering to link the connections to the Hewlett Packard 3456 A ohmmeter. The lower surface of the Cu-graphene plate is 1 cm square, while the upper surface is 5 mm square.
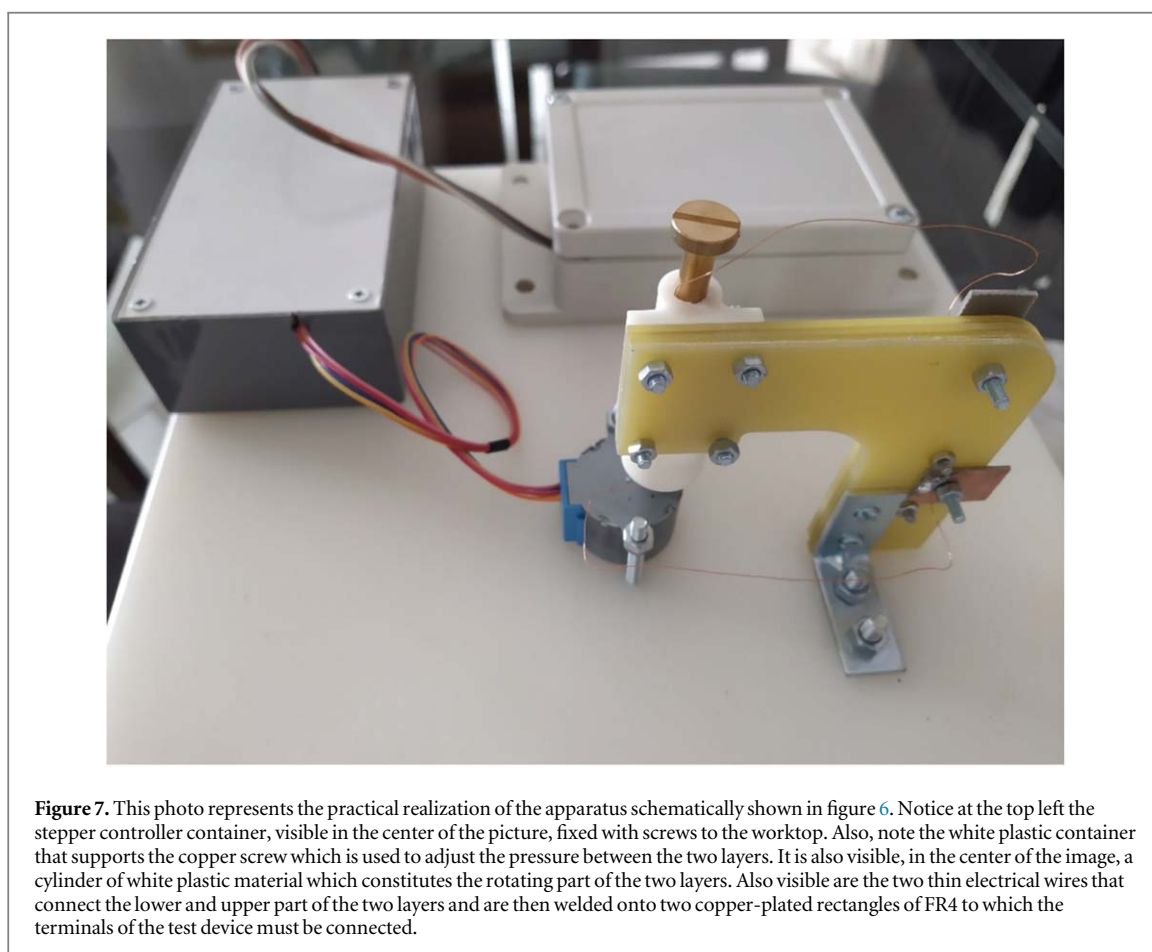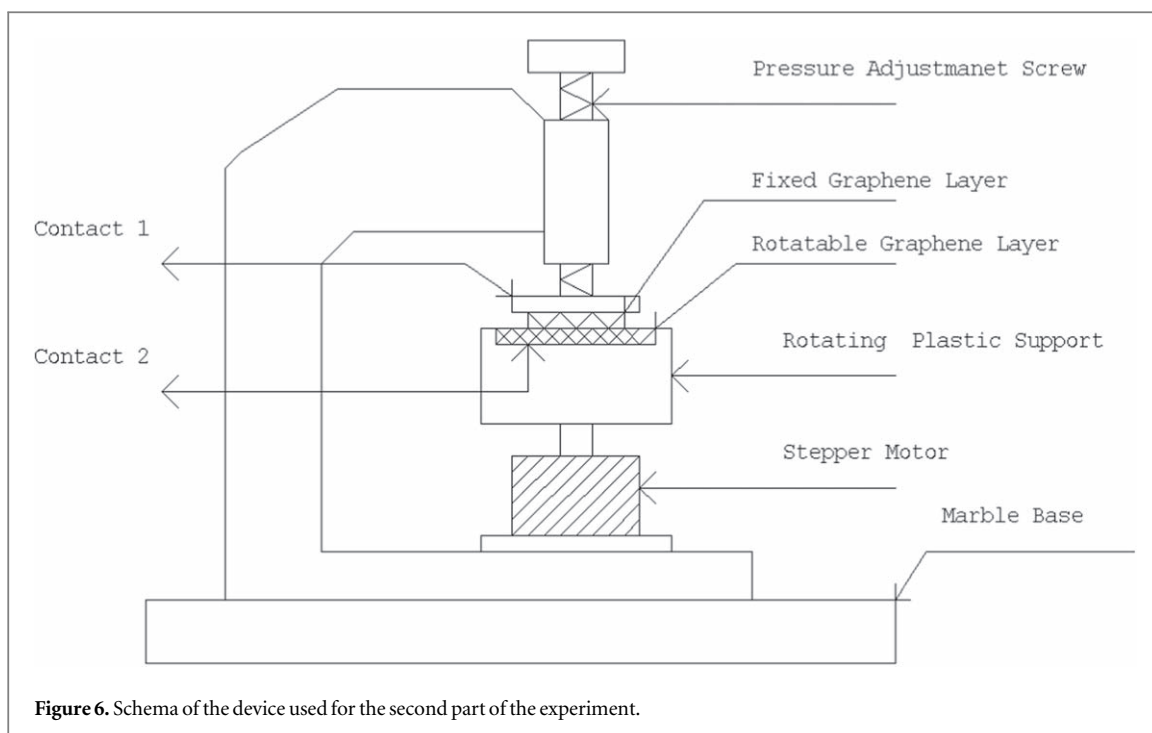
The upper layer is applied to a support (Contact 1), which is visible in figure 6, while the lower layer is connected to the axis of a 2048 steps stepper motor (every single step determines an angular variation of 0.176 degrees).

The lower and upper layers must be kept close to each other in such a way that a 'loose contact' is created between them, as described in the literature [5].

During the second phase of the experiment, a step-by-step rotation of the bottom plate was made using the stepper motor and its controller. The upper plate, on the other hand, remained fixed in the position where a loose contact was previously reached. In this case, to find the position that realizes the loose contact, it was chosen to irradiate the device with two different soliton emissions of bright and dark solitons and while adjusting the distance between the graphene layers with the appropriate screw, the operator expected a square wave similar to the one seen on the oscilloscope in figure 3, to appear at the ends of the device itself.

The device can be seen in figure 7, while the details of the inner parts are described in figure 6. It was connected to the Hewlett Packard ohmmeter in order to measure the electric resistance of the described structure following this procedure:

Adjusting the screw connected to the upper side of the wafer, a contact is made between the two plates (Cu-graphene plates). The contact is detectable by a very low resistance reading.

Figure 6. Schema of the device used for the second part of the experiment.

Figure 7. This photo represents the practical realization of the apparatus schematically shown in figure 6. Notice at the top left the stepper controller container, visible in the center of the picture, fixed with screws to the worktop. Also, note the white plastic container that supports the copper screw which is used to adjust the pressure between the two layers. It is also visible, in the center of the image, a cylinder of white plastic material which constitutes the rotating part of the two layers. Also visible are the two thin electrical wires that connect the lower and upper part of the two layers and are then welded onto two copper-plated rectangles of FR4 to which the terminals of the test device must be connected.

After this contact is made, the screw is rotated in the opposite direction, decreasing the pressure until a large increase in the electrical resistance is detected.

After that, the resistance reaches very high, unstable values (hundreds Mohm), but remains always in a range of high values.

Table 3. The effect of subsequent bright soliton irradiations on the resistance of two overlapped and suitably rotated one to the other, graphene layers (under loose contact).

Initial Value of R	Soliton A	Soliton B	Soliton C	Soliton D	Final Value of R
644,181,000 ohm	230,172 ohm	26.61ohm	9.410 ohm	2.29 ohm	1.750 ohm
254,564,000 ohm	359,227 ohm	8,621 ohm	148.772 ohm	51.326 ohm	0.021 ohm
Overload	14.999 ohm	14.999 ohm	14.999 ohm	0.000 ohm	0.000 ohm
278,994,000 ohm	278,994,000 ohm	278,994,000 ohm	278,994,000 ohm	0.343 ohm	0.343 ohm
864,220,000 ohm	31.003ohm	31.003ohm	31.003 ohm	0.003 ohm	0.003 ohm

At this point, after sending a bright soliton wave, the electrical resistance of the junction dropped instantaneously.

Then, the junction was subjected to a mechanical vibration that brought it back to its initial condition of very high R, albeit with a different value.

Since it is not currently possible to place the two graphene layers perfectly on top of each other and match the geometry of the lattice, an initial point (angle 0) of the rotation was established exploiting the perfectly horizontal axis of the sides of the two Cu squares including each a graphene layer.

At the beginning of each test, the controller displays the initial value of 0 degrees on the computer monitor. Successively, by pressing the control button it is possible to increase the rotation by 0.176 degrees. The controller also allows the rotation to be advanced by up to 10 steps in a single command when a first coarse search of a position with a great resistance drop is required. This coarse search is followed by a finer one.

After these preliminary operations, a series of tests and measurements has been carried out. The results are presented in table 3 below.

During this experiment, dark solitons were applied. The resistance R was measured while changing the relative rotation angle of the two graphene layers until the lowest R value was achieved. In several cases, an extremely low resistance value has been measured, in some cases below the sensibility of the instruments.

Only the acquisition of more sophisticated techniques will allow us to establish the exact angular conditions in which the apparent superconductivity phenomenon observed occurs, but this does not diminish the relevance of the results achieved during the presented experiments, since the phenomenon occurs in several angular axes and the exact identification of the angle/s will be done in the next future as a development of the present research.

The above table 3 should be read as follows: in the first column on the left side, the initial measurement of the electrical resistance of the junction is reported, where a loose contact had been created [5] before irradiation with bright EM solitons. In the columns 'Solitons A-B-C-D', the resistance values obtained after subsequent irradiations with bright solitons are shown. Said irradiations lead, as reported by the data of the tests, to a final resistance of the junction at which subsequent irradiations had no further effects.

As can be seen, in many cases the system went from a resistance level so high that it cannot be measured with the laboratory instruments, to a final level that was so small that, again, it could not be measured with the instruments currently available in the laboratory.

These tests were repeated many times and only a few trials of significance are reported in table 3 above.

Discussion

The present research began with the study of the behavior of the conductive lattice of a highly ordered surface. Having this objective in mind, a graphene film has been chosen, although similar behavior has been observed in other materials (aluminum, steel, copper) as well. It's important therefore to emphasize that the phenomena are not strictly related to the structure of the graphene but to the structure [6] of the electron. In the books 'The Physics Delusion - the urgent need to reinterpret modern physics -' and 'Superconductions at Room Temperature without Cooper Pairs', the author, Johan F Prins, describes an experiment where a superconducting bond made up exclusively of electrons is created at room temperature between two tiny diamond electrodes separated by a gap of many microns [7–9]. This kind of superconductivity obviously cannot be modeled by the widely accepted BCS theory of Cooper pairs. In the latest book [9], the author writes [pp. 304–305]: 'I was forced to conclude that the stable phase which forms between the two interfaces has to consist entirely of electrons. There is no other experimental explanation, and one must believe experimental evidence'. Surprisingly this bond is stable and does not disappear when there is no potential difference between the electrodes even when the potential is reversed. This behavior has also been observed in our experiment. This scenario rises however a key question: How is it possible that a structure consisting exclusively of electrons can be stable despite Coulomb repulsion?

Prins recognizes the importance of this problem writing [9]: 'why does it remain stable when the power supply is switched off?' 'There must be some other mechanism. This mechanism should also explain why the electrons do not repeal each other and 'fly out of the gap' when switching off the applied potential.' 'I have discovered this mechanism and found that it relates to the formation of a single macro-wave'. As we can see later, the lack of repulsion between coherent electrons can be explained by accepting an appropriate, realistic electron model. Recently a patent [10] for the creation of pure coherent electron beams has been awarded to the Lockeed-Martin Corporation. This patent claims the possibility of BEC condensates in a laser-like beam made-up of coherent electrons: 'Furthermore, unlike laser beams or the Bose–Einstein condensate (BEC) (e.g., a form of coherent matterwave), the subject technology may produce coherent matterwaves that allow both Fermions and Bosons to achieve coherence'. It's clear that also in this case Cooper Pair Mechanism cannot be invoked to explain these exotic matter beams.

Now it is important to note that the well-known London equation, which is considered the simplest description of the superconductive effects, can be very easily explained by a Zitterbewegung [6, 11, 12] electron model where the inertial mass has a pure electromagnetic origin, and the spin is related to an internal rotation, at speed of light, of the electron's charge [6]. According to this model, the current loop generated by the charge motion is at the very origin of the electron inertial mass, intrinsic angular momentum $\hbar$, magnetic moment, and spin.

The spin value $\pm \hbar/2$ is interpreted as the component of the electron's intrinsic angular momentum $\hbar$ aligned with the external magnetic field while the electron, like a tiny gyroscope, is subjected to Larmor precession. This interpretation of spin is in agreement with the well-known electron paramagnetic resonance effect [6].

This electron model does not exclude the possibility that the electrons' angular momentum may be aligned, in particular conditions, to the external magnetic field, so that electrons behave as elementary particles with unit spin. In this case, the formation of Bose–Einstein condensates made-up of pure electrons becomes a realistic possibility.

According to this model, the electron mechanical momentum $m_e v$ is equal to the product of elementary charge e and the component A_s of the vector potential, associated with the Zitterbewegung current, parallel to the electron velocity vector v:

$$m_e v = e A_s \tag{1}$$

hypothesizing a unique collective velocity v of the coherent electrons, the superconductive current density j_s can be written as:

$$j_s = n_s e v \tag{2}$$

where n_s is the superconductive carrier density. Merging the last two equations we have the London equations:

$$j_s = \frac{n_s e^2}{m_e} A_s \tag{3}$$

$$\nabla \times j_s = \frac{n_s e^2}{m_e} \nabla \times A_s = \frac{n_s e^2}{m_e} B \tag{4}$$

$$\frac{\partial j_s}{\partial t} = \frac{n_s e^2}{m_e} \frac{\partial A_s}{\partial t} = \frac{n_s e^2}{m_e} E \tag{5}$$

In this case, the coherent electrons' angular momentum must be aligned [spin ($\hbar = 1$), no precession] as described by [6]. It's interesting to note that this Zitterbewegung phase coherence might imply a possible force balance between Coulomb repulsion and Lorentz force F_L:

$$F_L(x) = ecB(x) = \frac{\mu_0}{4\pi} \frac{e^2 c^2}{x^2} = \frac{1}{4\pi\varepsilon_0} \frac{e^2}{x^2} \tag{6}$$

$$B(x) = \frac{\mu_0 ec}{4\pi x^2} \tag{7}$$

In the last equation, the magnetic field B is generated by the elementary charges e at distance x in the same light-cone and moving at light speed along parallel, phase coherent, circular orbits with a length equal to the electron Compton wavelength. It is reasonable to hypothesize that this force balance explains not only the lack of repulsion in the electron coherent phase seen by Prins but also the dense exotic charge clusters seen by Kenneth Shoulders [13].

As a preliminary conjecture, we hypothesize that a remote, short (~100 ns) voltage pulse (soliton) with fast rise time, may generate, in agreement with Aharonov–Bohm effect [14], a rapid, collective, and simultaneous variation of the Zitterbewegung phase that catalyzes the formation of superconductive bridges between the graphene layers. The coherent state can be destroyed by a further collective phase shift induced by a soliton with

Figure 8. The shape of a bright soliton.

Figure 9. The shape of a dark soliton.
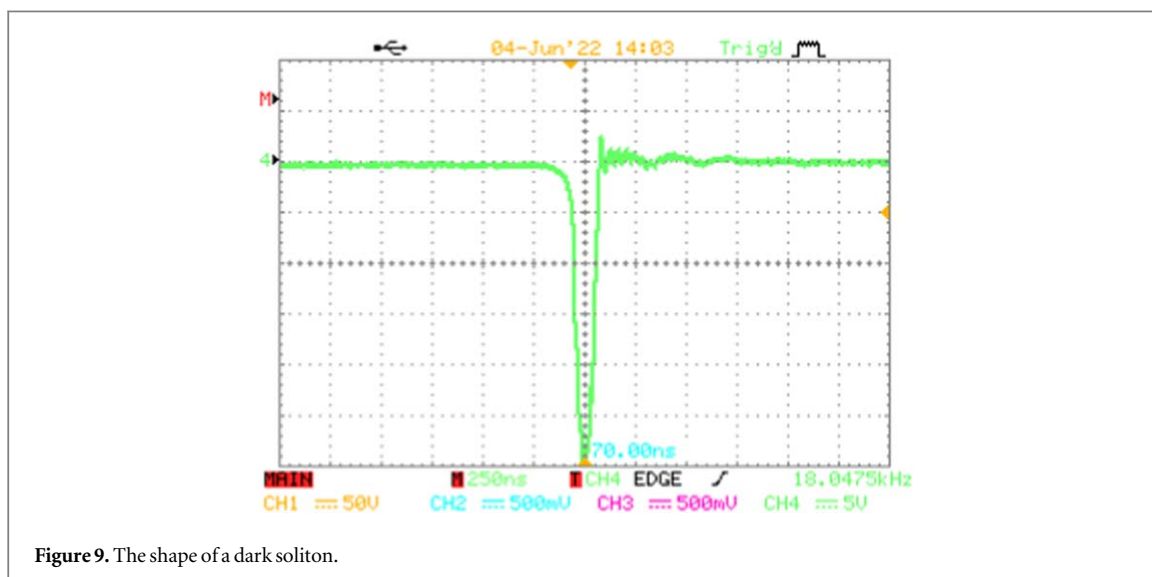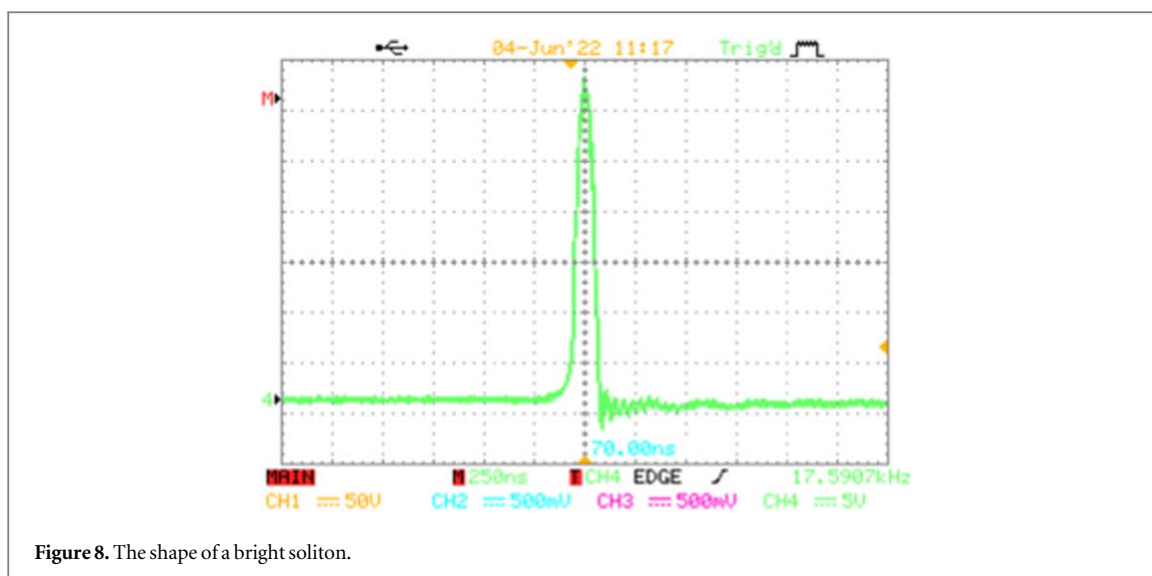
different polarity. We are aware that these considerations are not fully explanatory and only indicate a promising research direction.

The presented method represents an innovative method for the remote toggling of a switch and therefore also for designing new kinds of fast, low energy consumption transistors.

The data obtained also demonstrate that the degree of alignment of the lattice of the opposing graphene layers plays an important role in the degree of conductivity achieved.

As a result of the experimentation, it can now be stated that by using solitons of different defined types, it is possible to create or destroy the coherent bridges between the two layers.

Soliton generators used during the experiments

Two kinds of soliton generators have been used in the experiments. The first generator was simply used in proximity of the device, while the second one had a wire connection with the device. It should also be mentioned that during the experimentation, a laser beam (550 nm 100 mW) was set to hit the device at the same point at which the solitons produced by the electronic generator were applied by wire injection. In that case, the device switched its conductivity in a way that, unlike what happens with the application of electromagnetic solitons, persisted in the new state only for the duration of the exposure to the laser beam, switching back to its initial state immediately after the termination of said exposure.

Below, two screenshots are reported from the display of the oscilloscope showing a bright (figure 8) and a dark soliton (figure 9).

Conclusions

These results show the possibility, after appropriate improvements, to implement a system that allows an innovative remote control of an electric current. More in detail, the device object of the experimentation can be applied to the construction of high-breaking capacity switches that can become perfect conductors at room temperature. This research suggests the possibility to produce innovative devices that can be used in applications where remotely controlled switches with very low resistance are required and also for designing a new kind of fast, low energy consumption transistors.

A preliminary conjecture that hypothesizes the formation of coherent electron structures between the graphene layers has been presented.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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