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Comment on "Guided modes in graphene waveguides" [Appl. Phys. Lett. 94, 212105 (2009)]

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It was shown[1] that the ground (third-excited) state is absent when the energy E of the incident electron is less (greater) than the potential V_0, with V_0 being the potential responsible for confining electrons in a graphene-based waveguides of width d. We claim that these states (or modes) actually exist and such conclusions are likely to be misleading. First, consider the case where $E<V_0$ which was denoted by the authors as the $ss'=-1$ case. In order to know whether the ground-state mode ($n=0$) is present or not, one should check the peaks in the *probability density function* $\rho(x) = |\psi_A(x)|^2 + |i\psi_B(x)|^2$. Each component of the spinor $[\psi_A(x) i\psi_B(x)]^T$ indeed presents unexpected nodes for $E<V_0$ but counting them in order to realize which confined state is present (or absent) leads to unlikely correct conclusions. In order to support our claiming, we did the same calculations as the authors but with a slightly different approach which has been used by other authors.[2] As a result of the continuity condition for the spinor at the potential edges, one is indeed able to write down a transcendental equation, which is easily solved by state-of-the-art numerical routines. For a given value of the incident energy E, there are several values (modes) for the reflection angle θ [or for the wave-vector $k_y = (|E|/\hbar v_F)\sin\theta$], which satisfies the transcendental equation *numerically*. We take into account those values of $\theta > \theta_c^n$ only, with θ_c^n being the critical angle for each mode n. We plot in Fig. 1(a) the dispersion relation $E_n(\theta)$ (solid curves) which comes from the computer, as well as the function $f(E) = \arcsin(|1 - V_0/E|)$ (dashed curves). Notice that the intersection of the dashed lines, $f(E)$, with each dispersion branch $E_n(\theta)$ determines the value of the critical angle θ_c^n. The horizontal red line at $E=33.86$ meV is drawn to suit the parameters taken in Ref. 1. For this value of E, there are only three reflection angles allowed as follows: (i) 1.33 rad; (ii)

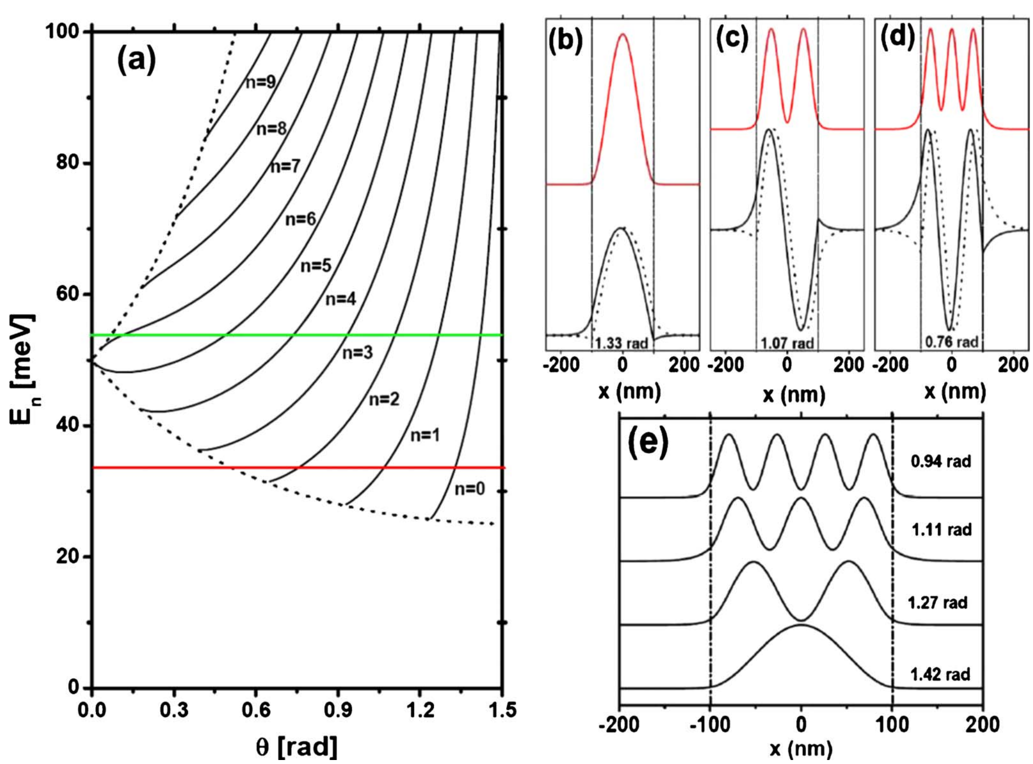

FIG. 1. (Color online) (a) The energy dispersion relation $E_n(\theta)$ for $V_0=50$ meV and $d=200$ nm. Right panel: the probability density function (red curves) for the three lowest modes ($E=33.86$ meV); (b) $\theta=1.33$ rad, (c) $\theta=1.07$ rad, and (d) $\theta=0.76$ rad. (e) The probability density function corresponding to the four lowest modes for $E=55$ meV.

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1.07 rad; and (iii) 0.76 rad, which are the same values of θ found by the authors. But, we plot in Figs. 1(b)–1(d) the function $\rho(x)$ (red curves), as well as the spinor components $\psi_A(x)$ (solid line) and $i\psi_B(x)$ (dashed line), corresponding to these angles, respectively. One easily sees that the *ground* ($n=0$), the first-excited ($n=1$), and the second-excited ($n=2$) modes are clearly present. We claim that there is no physical reason for the ground-state mode $n=0$ to be vanished. Consider now the situation where $E>V_0$, which was denoted by the authors as the $ss'=1$ case. The parameters taken by the authors for this case are really confusing. They lead to inconsistent values for k_1d, k_2d and $V_0=50$ meV when the given energy $E>V_0$ is assumed. Nevertheless, in Fig. 1(a) we draw the green horizontal line at $E=55$ meV and certify the existence of guided modes up to the sixth order for this value of energy. The existence of these modes is still verified for incident energies up to $2V_0$. For the sake of brevity, we plot $\rho(x)$ in Fig. 1(e) for the four lowest modes only. We also verified the situation where the potential $V_0=21.05$ meV and the incident energy $E=42.10$ meV. For this case, our numerical routine *does* find the third-excited mode with a reflection angle being of about 0.79 rad, which is greater than $\theta_c^{n=3}=0.22$ rad. Readers should be aware of the existence of this mode when doing the numerical calculations. We finally mention that this mode can still be considered as of infinite lifetime, since we are considering, as a first approximation, pure real values for E in solving our transcendental equation *numerically*.[2]

In summary, the dispersion relation showed in Fig. 1(a) is in agreement with those obtained and analyzed by other authors.[2] We emphasize that the physics studied in Ref. 1 is the same as that in Ref. 2, so the energy dispersion relation should not be different.

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