Off-resonance magnetoresistance spike in irradiated ultraclean 2DES

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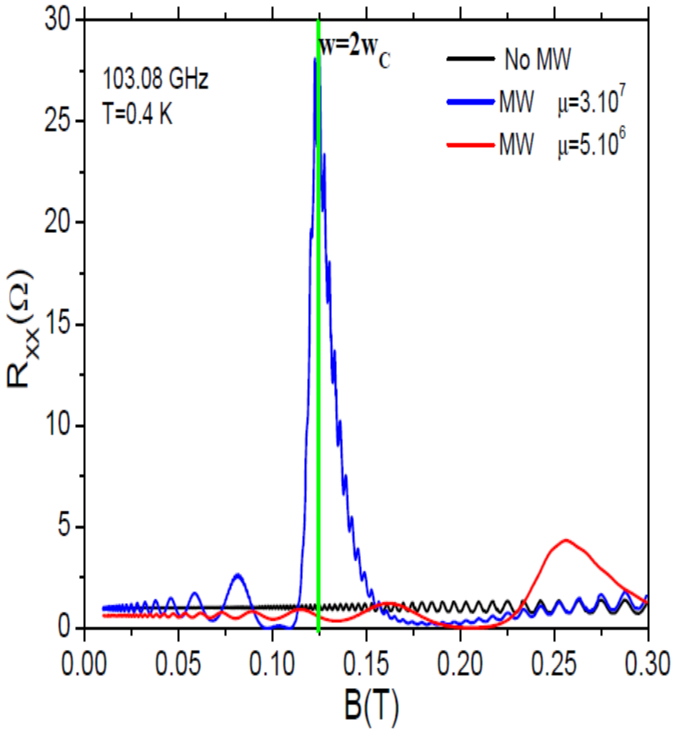
When a Hall bar (a 2DES with a uniform and perpendicular magnetic field (*B*)) is irradiated with microwaves, some unexpected effects are revealed deserving special attention: microwave-induced (MW) resistance oscillations (MIRO) and zero resistance states (ZRS) [1]. These remarkable effects show up at low *B* and high mobility samples, especially ZRS where very clean samples are needed. Different theories have been proposed to explain these striking effects but the physical origin is still being under debate. To shed some light on the physical origin, a great effort has been made, especially from the experimental side, growing better samples and adding new features to the basic experimental setup.

Very recently an even more striking experimental result on this field, has been obtained when using ultraclean samples, i.e., samples with extremely high mobilities [2]. These results show a colossal spike in the manetoresistance of the 2DES under MW radiation and weak magnetic field. But the most striking and unexpected feature is that the spike shows up on the second harmonic of the MW frequency, i.e., at $w=2w_c$, where w is the MW frequency and w_c is the cyclotron frequency. The large spike was expected to show up at the cyclotron resonance condition, $w=w_c$. To date there has not yet been presented any theoretical approach to try to explain such a surprising effect.



In this work, we theoretically study magnetoresistance of a Hall bar being illuminated with MW radiation when the Hall bar is supported on a ultra-clean GaAs sample. We apply the theory developed by the authors, the MW-driven electron orbits model [3], which we extend to an ultra-clean or high mobility sample. According to this theory, when a Hall bar is illuminated, the electron orbit centers of the Landau states perform a classical trajectory consisting in a harmonic motion along the direction of the current. Thus, the 2DES moves periodically at the MW frequency altering dramatically the scattering conditions and giving rise eventually to MIRO and ZRS. An ultra-clean sample implies that the Landau levels are very narrow or that the quantum life time is very long. This has an important influence in our theory. On the one hand, our theory proposes an acoustic phonon emission (inelastic process) which damps the electron motion. But ultra-clean samples give rise to a acoustic phonon emission bottleneck effect. Then, when electrons are damped by the interaction with phonons do not have final states where to get to due to the extremely narrow Landau levels. This produces the bottleneck effect and the damping decreases giving rise to the colossal spike.

On the other hand, these samples produce an increase in the scattering rate of electrons with charged impurities, (this is an elastic process with mainly supports the current). And it is due to the increase in the final states of the scattering process when Landau levels are very narrow.

The outcome is a smaller transport scattering time that it is perceived by the scattered electrons as a smaller MW frequency. Importantly, the spike is shifted to smaller magnetic fields and MIRO and ZRS are shifted too. According to our theory, in the very high mobility samples used in experiments the shift corresponds to the conditions of $w=2w_c$. In our calculated results we have obtained the spike at the experimental obtained position but also, when the sample is less clean (lower mobility) we obtain MIRO and ZRS in the older positions [1] (see Fig.). Finally, the calculated results are in reasonable agreement with experiments.

References

[1] R. G. Mani et al., Nature(London), 6, 420, 646 (2002)
[2] Yanhua Dai et al., Phys. Rev. Lett., 105, 246802, (2011); A.T. Hatke et al., Phys. Rev. B 83, 121301(R), (2011)
[3] J. Inarrea and G. Platero, Phys. Rev. Lett. 94, 016806, (2005); J. Inarrea and G. Platero, Phys. Rev. B 72,193414 (2005)