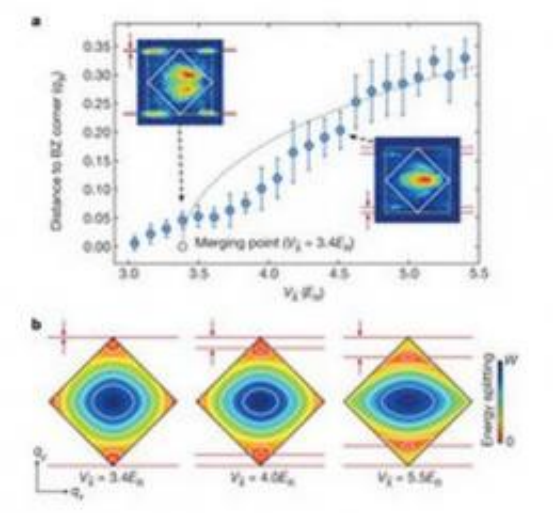
Research team finds way to simulate graphene Dirac points

March 15 2012, by Bob Yirka



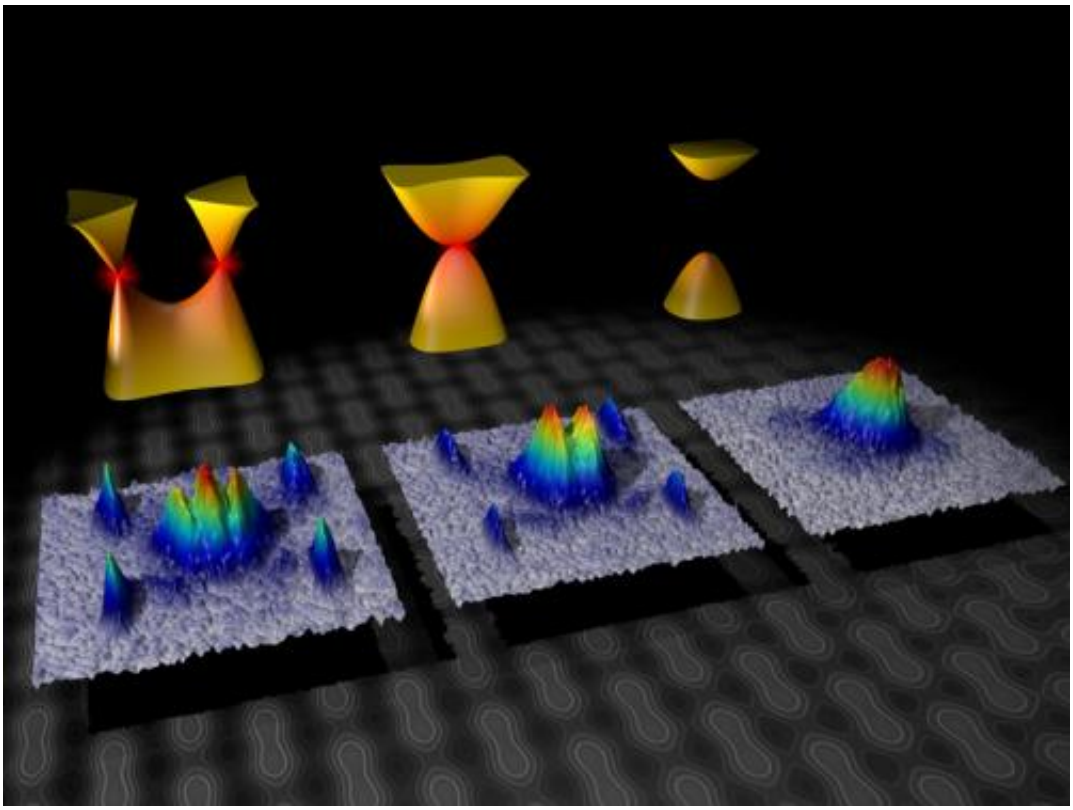
Movement of the Dirac points. Image (c) *Nature*, doi:10.1038/nature10871

(PhysOrg.com) -- As researchers continue to study graphene and its unique attributes, they find themselves fixated on different areas of its properties. One of those properties is that because of its lattice structure, graphene is a “zero-gap” semiconductor. This means that its conduction and electron valance bands actually touch each other at certain points, which means there is no energy gap between them, as is the case with current semiconductor materials. And this means that the momentum and energy association is very much like that of photons, which implies that electrons could move at speeds approaching the speed of light. These parts of graphene’s structure are known as Dirac points. Up until

now though, no one has been able to see any real world evidence of such points, much less manipulate them.

Now, Tilman Esslinger and his fellow researchers at the Institute for Quantum Optics at ETH Zurich have found a way to do just that by simulating graphene and its properties using a laser created lattice filled with potassium-40 atoms. They report on their findings in the journal *Nature*.

The experiment began by cooling potassium-40 atoms, leaving them lethargic so they wouldn't move away from within the lattice. Their role was to serve as stand-ins for electrons moving in graphene. Then, to create the lattice, the team fired one laser perpendicular to another causing the two to interfere with each other. A third laser beam with a slightly different wavelength was then added to create a standing wave. In this scenario, the square lattice that resulted could be adjusted by adjusting the third beam. The team then tested the lattice for Dirac points by speeding up the atoms and measuring their trajectories and found two of them by noting the momentum between the lattice cells didn't slow, meaning there wasn't any gap. Better yet, the team found that by adjusting the lattice they could manipulate the Dirac points, moving them around or even causing them to disappear completely.



The density distribution of the potassium atoms measured after acceleration through Dirac points (left and centre), and without Dirac point (right). The upper row shows the corresponding regions of the calculated bandstructure. (Image: Tilman Esslinger's Research Group / ETH Zurich)

In an interesting turn of events, another team taking a completely different approach has also managed to find a way to show the existence of Dirac points and to manipulate them as well by synthesizing a form of graphne and arranging it in the familiar chicken-wire lattice on top of a conducting substrate and then manipulating it with a tunneling microscope. They have also published their results in *Nature*.

Finding ways to show how Dirac points can be manipulated will help to find ways of using graphene in real world applications that could result in new exotic materials with unique electronic properties, leading to end

products that in some cases can't even be imagined yet.

More information: Creating, moving and merging Dirac points with a Fermi gas in a tunable honeycomb lattice, *Nature* 483, 302–305 (15 March 2012) doi:10.1038/nature10871

Abstract
Dirac points are central to many phenomena in condensed-matter physics, from massless electrons in graphene to the emergence of conducting edge states in topological insulators. At a Dirac point, two energy bands intersect linearly and the electrons behave as relativistic Dirac fermions. In solids, the rigid structure of the material determines the mass and velocity of the electrons, as well as their interactions. A different, highly flexible means of studying condensed-matter phenomena is to create model systems using ultracold atoms trapped in the periodic potential of interfering laser beams. Here we report the creation of Dirac points with adjustable properties in a tunable honeycomb optical lattice. Using momentum-resolved interband transitions, we observe a minimum bandgap inside the Brillouin zone at the positions of the two Dirac points. We exploit the unique tunability of our lattice potential to adjust the effective mass of the Dirac fermions by breaking inversion symmetry. Moreover, changing the lattice anisotropy allows us to change the positions of the Dirac points inside the Brillouin zone. When the anisotropy exceeds a critical limit, the two Dirac points merge and annihilate each other—a situation that has recently attracted considerable theoretical interest but that is extremely challenging to observe in solids10. We map out this topological transition in lattice parameter space and find excellent agreement with ab initio calculations. Our results not only pave the way to model materials in which the topology of the band structure is crucial, but also provide an avenue to exploring many-body phases resulting from the interplay of complex lattice geometries with interactions.

Press release