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A Practical Polariton Laser

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The report of an electrically pumped polariton laser that operates at room temperature and relies on an inversionless lasing scheme holds promise for realizing a new breed of very low threshold semiconductor lasers. Academician Sveatoslav Moskalenko has predicted a phenomenon that led to the development of a new type of laser

Dedicated to the 70^{th} anniversary of the foundation of first research institutions of the ASM

The exciton represents an electron-hole pair which can be excited in semiconductors by light. Moldavian physicist S. A. Moscalenco and professor from USA M. A. Lampert predicted in 1958, independently from each other, the existence of biexcitons, i.e. of exciton molecules, representing bound states formed by two electrons and two holes. The biexcitons and multi-exciton complexes have been discovered experimentally later on. For these achievements a group of collaborators of the Russian Academy of Sciences and the collaborator of the ASM Sveatoslav Moskalenko were awarded the State Prize of USSR in 1988. The biexcitons are used nowadays as an efficient source for the generation of entangled photons in quantum information processing.

About 55 years ago, when studying the properties of excitons in semiconductors, the young doctor of sciences Sveatoslav Moscalenco predicted for the first time the phenomenon of Bose-Einstein condensation of the excitons and their superfluidity in semiconductors and described the reversible optico-hydrodynamical processes which can occur in a nonideal exciton gas under the conditions of its Bose-Einstein condensation. The work published in 1962 in the journal "Физика Твердого Тела" (vol.4, p.276) triggered the development of a new direction in the solid state physics - the Bose-Einstein condensation of excitons and biexcitons.

Over the years, this new direction attracted an increasing number of researchers in different scientific centers of the world, who not only confirmed experimentally the phenomenon predicted by academician Sveatoslav Moscalenco, but also demonstrated its importance for practical applications. Particularly, at the Institute of Applied Physics of the Academy of Sciences of Moldova the phenomenon of Bose-Einstein condensation of excitons and biexcitons was investigated over more than 50 years with the participation of several generations of researchers, more than 1000 papers having been published, including 10 monographs, about 40 PhD theses and 6 doctor habilitat theses having been defended. The results obtained in different scientific centers worldwide in the period of 1962-2000 were reflected in the monograph of S.A. Moskalenko and D.W. Snoke, Bose-Einstein condensation of excitons and biexcitons and coherent nonlinear optics with excitons, Cambridge University Press (2000).

The physics of high density excitons and biexcitons demonstrated a rising development. If the exciton-photon conversion process takes place reversibly and repeatedly, a new type of elementary excitation half-matter/half-light is formed, known as polariton. The phenomenon of Bose-Einstein condensation of such excitations became the basis for the development of a new type of lasers - the polariton laser.

While most of electrons must be in a high energy state (with inversion of the population) for functioning of a usual laser, the polariton laser can work without fulfilling this condition. Among the main advantages of the polariton laser, one can mention an extremely low threshold current density necessary for the diode excitation. Apart from this, the polariton laser emission can be modulated at much higher frequencies as compared to usual lasers (in other words, this type of lasers can be switched on and off much faster).

The discovery of the polariton laser is of particular importance for Moldavian scientists, since the basic theoretical concepts that brought to this scientific and technological success belongs to academician Sveatoslav Moscalenco. We are pleased that the phenomenon predicted by our scientist many years ago not only was confirmed experimentally, but also leads nowadays to the discovery of new lasers, more efficient and cost-effective than the existing ones.

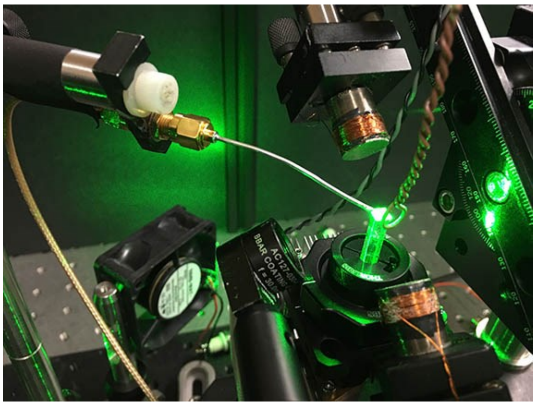
A Leap Forward for Diamond-Defect Nuclear Magnetic Resonance

With a hundredfold improvement in frequency resolution, the technique can now identify the spectral fingerprints of molecular structure.

Ashley G. Smart

NV centers—point defects in diamond in which two neighboring carbon atoms are substituted with a nitrogen atom and a vacancy—are exquisitely sensitive magnetometers. That's because an NV center's fluorescence response depends on its spin state, which, in turn, is sensitive to external magnetic fields. Embedded a few nanometers deep inside a diamond, the defect can detect fields as small as a few nanotesla at the surface.

Five years ago, researchers showed that the diminutive magnetometers could be used to perform nuclear magnetic resonance spectroscopy. (See *Physics Today*, April 2013, page 12.) In NMR, the nuclear spins of molecules in a target sample—say, a soup of proteins—are polarized and manipulated with RF pulses to produce a faint magnetic signal. Typically, that signal is detected with induction coils. But due to their limited sensitivity, such coils require micron-scale or larger samples. With NV-center magnetometers, the researchers could detect NMR signals from nanometer-scale samples. Unfortunately, however, the technique's spectral resolution wasn't good enough to identify the key markers of molecular structure: scalar couplings and chemical shifts.



Credit: Ronald Walsworth

Now a Harvard University team led by Mikhail Lukin, Hongkun Park, and Ronald Walsworthhas improved the resolution of NV-center NMR a hundredfold. The trick was to synchronize the NMR pulses and measurements to an external clock, which made it possible to average thousands of repeat measurements on the same sample—and thereby achieve effective measurement times orders of magnitude longer than the NV center's millisecond spin-coherence time. Combined with a noise-minimizing device design, the scheme delivered spectral resolution sharp enough to detect scalar couplings and chemical shifts in all three organic samples the team tested. (The accompanying image shows the device in action.) The group anticipates that the technique could one day be used to perform NMR spectroscopy on single living cells. (D.R. Glenn et al., *Nature* 555, 351, 2018.)

Unconventional Superconductivity in Graphene Bilayers

When two carbon sheets are misaligned by a mere degree, striking changes result.

Johanna L. Miller

Much of the appeal of the two-dimensional materials zoo—which includes graphene, hexagonal boron nitride, molybdenum disulfide, and many others—lies in the multitude of ways the atomically thin sheets can be stacked and combined to create new structures with novel properties. (See the article by Pulickel Ajayan, Philip Kim, and Kaustav Banerjee, *Physics Today*, September 2016, page 38.) Compounding the number of potential arrangements is the possibility of tuning the twist angle between successive layers. Now MIT's Pablo Jarillo-Herrero and colleagues have shown that the twist angle between two sheets of graphene can be exploited to dramatic effect: At a so-called magic angle of approximately 1.1°, the two-layer stack becomes a superconductor.

A graphene monolayer's electronic properties are dominated by the electrons' kinetic energy. Free to roam the honeycomb lattice, the electrons behave quasi-relativistically. In the magic-angle bilayer, on the other hand, electrons are largely concentrated on the regions (shown in yellow in the figure) where the hexagons in the two layers line up. Confined to such close quarters, the electrons' Coulomb interactions dominate over their kinetic energy. The physics of strong correlations comes to the fore—just as it does in the cuprates and other unconventional superconductors.

The graphene bilayer has a critical temperature T_c of just 1.7 K, which seems low in absolute terms. But in light of the material's minuscule charge-carrier density, which limits how many carriers can pair and condense into a superfluid, it's actually unexpectedly high. And as a platform for studying the notoriously mysterious high-T_c superconductivity, graphene offers a big experimental advantage over more standard high-T_c superconductors such as the cuprates and the pnictides.

In a material family such as the cuprates, tuning the carrier-doping level requires fabricating a new material of slightly different composition. In contrast, doping a graphene bilayer with charge carriers is as simple as applying a small gate voltage, so researchers can explore the whole phase diagram with a single sample. (Y. Cao et al., *Nature*, in press, doi:10.1038/nature26160.)