European Physical Society
Condensed Matter Division

The European Physics Society
2020 EPS Condensed Matter Division Europhysics Prize
Long Citation

The 2020 EPS Condensed Matter Division Europhysics Prize is awarded to Jörg Wrachtrup for his pioneering studies on quantum coherence in solid-state systems, and their applications for sensing, and, in particular, for major breakthroughs in the study of the optical and spin properties of nitrogen vacancy centres in diamond.

The Prize will be presented on Wednesday September 2nd, 2020, during the Awards Session of the 28th General Conference of the EPS Condensed Matter Division – CMD 2020 GEFES[1], to be held **online** from September 1st to 4th, 2020 together with the Meeting of the Condensed Matter Group GEFES of the Spanish Royal Physics Society RSEF.

Jörg Wrachtrup is professor for experimental physics, institute director at Stuttgart University and Max Planck Fellow at the Max Planck Institute for Solid State Research in Stuttgart. His research has established an entirely new and highly successful area of research at the interface between solid-state physics and quantum optics with unexpected impact in quantum sensing, ranging from material science to biomedical research.

The foundation for this had been laid with his pioneering work on the optical detection of single spins in solids. By adapting techniques from spin resonance, he manifested precision control of single electron and nuclear spins in solids already in the early 1990's. A decade later, these methods became the foundation of solid-state quantum control. These achievements also count as one of the starting points for the research area now called quantum spintronics. The field advanced tremendously when Wrachtrup identified individual paramagnetic nitrogen vacancies in diamond, called NV centres, as a promising platform for quantum nanoscience. Wrachtrup was the first to recognise the importance of NV centres for quantum information technology, metrology and biomedical imaging. Being inspired by his early work, the field has meanwhile grown into a worldwide research area with regular dedicated conferences and symposia on all major meetings. Wrachtrup has published more than 290 papers that are cited close to 5000 times per year. Since 2014 he is continuously enrolled in the ISI Highly Cited Researcher list.

Diamond quantum spintronics has made spectacular progress in quantum information technology. Exquisite spin control has resulted in first demonstration of basic quantum functionality, and spurred expectation of integrated room temperature

[1] http://www.cmd2020gefes.eu/28512/detail/2020-joint-conference-of-the-condensed-matter-divisions-of-eps-cmd-and-rsef-gefes.html

quantum devices. This is largely based on worldwide research into the development of the diamond material and of diamond nano-structuring technology inspired and furthered by Jörg Wrachtrup. The preparation of ultrapure diamonds and the nano-positioning of defects are research achievements that have inspired solid-state nanotechnology as a whole. Furthermore, Wrachtrup's research has prompted his group and those of his colleagues to systematically search various solid state spin systems - which finally resulted in the discovery of quantum defect spins in materials like silicon carbide, GaN or recently two-dimensional materials such as graphene, boron nitride or MoS_2. Over the past years Jörg Wrachtrup has continuously made landmark contributions to the field by, *e.g.*, demonstrating entanglement between nano-positioned defects and electron and nuclear spins, the first non-destructive quantum measurements on solid state spins, or the recently achieved error correction based on nuclear spin clusters. International collaborations have led to the construction of hybrid quantum systems combining solid-state spins and other quantum structures like superconductors, photonic systems or mechanical oscillators.

The impact of Jörg Wrachtrup's research goes far beyond solid-state physics and quantum optics into material- and life sciences. The development of fluorescent nano-diamonds for labelling bio-molecules has likewise been made possible by NV centres. The nominee and his group were among the first to point out the impressive possibilities of nano-diamonds for nano-analytics in biomedical research and fluorescence imaging applications. An exciting example is the outstanding photostability of NV centres, which was used to maximise the resolution of fluorescence microscopy. As a result, there is now intense work on the fabrication of ultra-small nano-diamonds, giving birth to another new research area concentrating on the physical and chemical properties of mesoscopic-sized carbon clusters. Such clusters promise to form a new class of carbon nanomaterials with outstanding properties.

Finally, yet importantly, the nominee's research work laid the foundation of diamond-based sensors. Owing to the outstanding spin relaxation properties of diamond, spin methods from quantum and atom optics can be used for precision sensing. Wrachtrup and his group once again pioneered the field by demonstrating nanoscale precision sensing of magnetic fields. The approach has generated a worldwide wave of excitement among researchers. Diamond sensor capabilities have been extended to precision measurement of electric fields, temperature and strain. Proposals for precision time measurement, gyroscopes and force measurements have been published. Diamond based magnetic field sensors are now making an impact in various disciplines in solid-state physics and material science. Applications in nano-magnetism have started to unravel its unparalleled sensitivity and resolution. Its ability to measure various parameters in superconductors is being explored and the recent demonstration of integrated quantum detectors in high-pressure cells promises to establish an entirely new tool in solid-state physics.

Further on, it has been realized that sensor capabilities reach outstanding values even under ambient conditions. As a result, diamond sensors promise to be of significant value for biomedical applications. Thanks to landmark contributions by Jörg Wrachtrup, high-resolution imaging of bio-magnetic fields has now been reported. Meanwhile, a whole wealth of applications has been identified. Among those are novel methods for detection and imaging of neuronal activities with significant impact for e.g. the understanding of neuronal networks and complex systems such as brain functions.

Using diamond spin sensors Jörg Wrachtrup and his group recently succeeded in detecting the nuclear magnetic resonance signal of a few hundred proton spins, thereby increasing the sensitivity of the method by almost 16 orders of magnitude. As nuclear magnetic resonance is the most used method in chemical analytics and biochemical structure analysis, this achievement promises a revolution in these areas. In cooperation with partner groups he already could show the detection of single proteins with his methods. First reports on the structural analysis of single proteins or protein clusters, even in their cellular environment, are underway.

Magnetic resonance imaging (MRI) is the most used diagnostic method in medicine. Wrachtrup's research is advancing and potentially revolutionizing this method in two respects. His group recently demonstrated MRI with nanoscale resolution, basically taking the methods to nano-science and allowing unprecedented insight into complex structures ranging from material science to biomedical research. In addition, his research has lead towards enhancing the sensitivity of MRI in clinical applications by paving the way to new routes towards spin polarized nanoparticles as contrast agents for medical applications. The method promises versatile application and has marked the starting point of intense international research activities. As a consequence, new nation-wide research centres addressing the subject have recently been established in the UK, China and Japan as well as in the US.

In conclusion, the research activities of the nominee have initiated an entirely new research field with surprising and unexpected impact on a whole variety of different areas of science and impressive prospects for application, ranging from fundamental physical science to medical diagnostics.