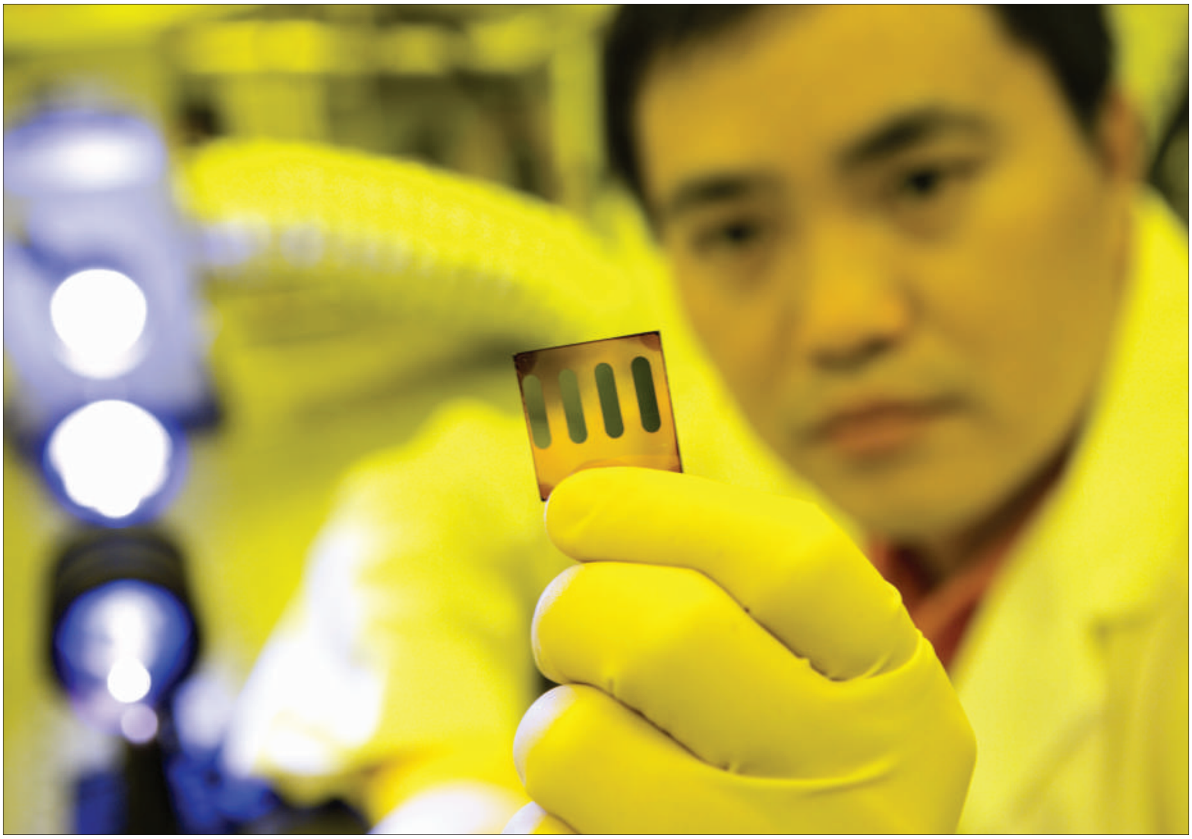

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Diamond Detectors Provide a Glimpse Into Artificial Suns

Unique Cherenkov detectors for measurements of electron beams in thermonuclear installations of the tokamak type are being developed at the Institute for Nuclear Studies in Swierk. Tests conducted this year in the Tore Supra tokamak in Cadarache, France revealed that the device constructed by Polish physicists might be useful for investigating the extreme physical conditions inside the largest present-day installations, which will form the basis of future fusion energy reactors, commonly known as Artificial Suns.

Cherenkov detectors for measurements of electron beams constructed at the Institute for Nuclear Studies (IPJ) in Œwierk underwent tests in the French Tore Supra tokamak at the research centre in Cadarache, this year. Concluded several days ago, a recent series of experiments revealed that the scientists from IPJ are the only ones in the world who can built Cherenkov detectors that might be useful for investigating the extreme physical conditions in the immediate vicinity of plasma almost as hot as the one inside the Sun. Thermonuclear fusion is the energy source of the stars. The synthesis process consists in the merging of the nuclei of light elements, usually isotopes of hydrogen, to create heavier nuclei. The resulting products have a lower mass than the sum of the masses of the constituents. The excess mass is converted to large amounts of energy, as stated in the famous Einstein's formula. To conduct controlled thermonuclear fusion would be to ensure energy security for thousands of years to come. It is worthy of note that the energy would be both clean and safe. For atomic nuclei to fuse, the electrostatic repulsion between them must be overcome. To that end, hydrogen fuel needs to attain the same temperature as the plasma inside the stars -- that is the temperature of at least hundreds or so million degrees.

Attempts are currently being made to produce controlled thermonuclear fusion in tokamaks -- devices with a toroidal (donut-shaped) vacuum chamber surrounded by strong magnetic fields. Plasma, which consists of free electrons and the nuclei of isotopes of hydrogen stripped of electrons, is compressed by the magnetic field. An electric current of intensity exceeding one million amperes is driven through the plasma. The magnetic field of the electric current along with the magnetic field generated by the coils of the tokamak form a magnetic trap to confine the plasma in the torus. The difficult technical issue of controlling such plasma has long exercised the minds of physicists. There are a great many problems to solve -- one of the most pressing being the electron beams generated during discharge. The uncontrolled electron beams that escape the plasma region have already caused severe damage to chamber walls in experimental reactors in operation. Hence, physicists and constructors are seeking ways to gain direct insight into the reaction area, which would allow to gain a better understanding of the processes that occur during the reactions and provide solutions to the adverse phenomena.

Several years ago the scientists from the Institute for Nuclear Studies in Œwierk put forward a proposal to construct detectors that would apply Cherenkov effect to investigate electron beams that escape the plasma region in tokamaks. "Cherenkov radiation is emitted when a charged particle passes through a medium at a speed greater than the phase velocity of light in that medium," explains Jaroslaw Zebrowski, PhD, from IPJ. The particle -- for example an electron losing energy -- travels at such a high speed that the crests of the light waves it emits begin to overlap in the medium. The formed front is the electromagnetic equivalent of the shock wave that occurs when an aircraft exceeds the speed of sound in the air. In the case of an electromagnetic wave in a medium such as water or diamond, the front may be visible as a blue-green glow -- Cherenkov radiation. It was first observed in 1934. As the physical conditions inside a tokamak are extremely adverse to measuring devices, the materials used to construct Cherenkov detectors need to be characterized by high melting temperature and high thermal conductivity. At the same time, their high refractive index would ensure that Cherenkov radiation is emitted even by relatively low-energy electrons. Therefore, the physicists from IPJ opted for diamond crystals to construct a detector for the French Tore Supra tokamak.

The extreme working conditions of the detector posed plenty of difficulties for the constructors. It proved necessary to develop special methods for fixing the position of the crystals (in the present-day version of the detector there is a set of four diamonds operating), connecting the crystals to optical fibres leading to photomultipliers and screening the diamonds from other sources of radiation that could affect the precision of electron beam measurements. "Yet the problems do not end here. The signals need to leave the reactor chamber, which is characterized by high vacuum, and be transmitted at a distance of several dozens of meters to the control room. There they need to be registered by photomultipliers and electronic systems with a short reaction time," stresses Lech Jakubowski from IPJ, PhD, the Head of the project.

The Polish detector crystal has a size of millimetres, good spatial resolution and extremely short response time of approximately several billionths of a second. The aforementioned features allow to take precise measurements of electron beam parameters. The device is mounted on a 3 meters long movable probe. The probe is inserted through a diagnostic port into the vicinity of the plasma for a period as short as 0,1 s. Having been removed and cooled down, the probe may be reinserted. "One discharge in the Tore Supra tokamak may last six minutes. During this period, our detector can take up to over a dozen measurements," reveals Professor Marek Sadowski from IPJ.

Research into the application of Cherenkov radiation in investigating the conditions prevailing in tokamak chambers has been conducted at the Institute for Nuclear Studies in Œwierk for over six years. The idea has been tested in increasingly larger tokamaks, initially in the CASTOR tokamak in Prague, at a later stage in the ISTTOK tokamak in Lisbon and presently in the Tore Supra in Cadarache. The results of the first measurements in the French tokamak have already been published in the journal, Review of Scientific Instruments.

Data analysis of the most recent measurement session is currently under way. "The tests conducted this year reveal that we are the only ones who can construct Cherenkov detectors that might be useful for investigations in the most powerful tokamaks in the world," concludes Marek Rabiñski, PhD, the Head of the Department of Plasma Physics and Material Engineering IPJ. The experience gained in the recent years in increasingly larger tokamaks allows Polish physicists to be optimistic about the prospects of constructing at the Institute for Nuclear Studies in Œwierk detectors intended for the future thermonuclear reactor ITER developed in Cadarache at a cost over 10 billion euros.

Research into Cherenkov detectors for measurements in tokamaks conducted at IPJ is funded by EURATOM, an organisation, governed by the EU institutions, coordinating European research into controlled nuclear fusion.

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