Department of Physics and Photon Science at GIST

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INTRODUCTION TO GIST

GIST (Gwangju Institute of Science and Technology) is a small, but strong research-oriented university in Gwangu, Korea, which is fully supported by the Korean government. It was founded in 1990s and it began to accept graduate students in 1995. In the beginning, it started with a graduate school for M.S. and Ph.D. programs, but it was expanded to include an undergraduate school in 2010. Now GIST has about 1,400 graduate students and 800 undergraduate students. GIST has high-level education and strong research activities in the fields of physics, chemistry, biology, electrical engineering and computer science, mechanical engineering, material science, and earth science/ environmental engineering. According to the 2017 QS(Quacquarelli Symonds) World University Ranking, GIST is ranked 3rd in the world in the area of number of paper citations per faculty. This fact shows that GIST is very strong in research. GIST is still expanding in size and the success of GIST in quality education and research will continue in the future.

Fig. 1: Overview of the GIST campus.

DEPARTMENT OF PHYSICS AND PHOTON SCIENCE

Fig. 2: Building of the Department of Physics and Photon Science at GIST.

The Department of Physics and Photon Science in the graduate school of GIST was officially formed in the fall of 2012 and we aim at high quality education and research in physics. It has a very short history, but it has made a remarkable success in recent years. The number of graduate students in the M.S. and Ph.D. programs has increased sharply to 110 and now 15 faculties are working for education and research in physics. These numbers will continue to increase for the time being as the history is so short.

Our department is focused on 4 main research fields which include optics, plasma physics, condensed matter physics, and particle physics. Intensive researches in those areas are performed by laboratories and centers of the department, and some international collaborations between our department and foreign laboratories are also under way. For those purposes, diverse research grants from the Korean government and industries are used.

RESEARCH ACTIVITIES

The Department of Physics and Photon Science at GIST has four main research fields including optics, plasma physics, condensed matter physics, and particle physics. Their activities are briefly described below.

Optics Group

The optics research group in the Department of Physics and Photon Science conducts researches on various topics in ultrafast nonlinear optics and ultrahigh intensity physics. When the light field is confined in extremely small space and short time, the intensity of the light can be greatly increased and the light matter interaction becomes ultrafast and highly nonlinear. Understanding light- matter interaction in such extreme condition is the main research goal of the optics groups. There are four research laboratories in the optics group. They are Laboratory for Ultrafast Nonlinear Optics, Mathematical Physics Research Laboratory, Attosecond Science Laboratory and Center for Relativistic Laser Science.

In the Laboratory for ultrafast nonlinear optics, ultrafast laser development and its measurement techniques, Laguerre-Gaussian beam and Bessel beam developments being controlled angular momentums, ultrafast spectroscopy and microspectroscopy, quantum optics by using an ion-trapping, and linear and nonlinear optic-devices manufacturing and its applications are under research.

In the Mathematical Physics Research Laboratory, the main thrust of this year's projects of the group is lined up along the following areas: Photonic crystal device theory, simulation and fabrication, and development of a prototype semiconductor LED with a significantly enhanced light-extraction efficiency. The group will be interested computer simulations of the relativistic effects of multi-photon interaction of light and matter such as multiphoton ionization, laser acceleration, pair-plasma production, relativistic self-focusing and electron- positron creation electrodynamics.

The Attosecond Science Laboratory is focused on understanding of ultrafast electron dynamics in a variety of materials such as atoms, molecules, and solids with the purpose of future applications. The laboratory studies ultrashort laser development, ultrafast pump-probe spectroscopy, high harmonic spectroscopy, attosecond pulse generation and characterization, and the strong field plasmonics.

The Center for Relativistic Laser Science (CoReLS) of Institute for Basic Science (IBS) was launched in December 2012 based on the femtosecond (fs), petawatt (PW) laser facility located at Gwangju Institute of Science and Technology (GIST). The CoReLS has 6 research groups – laser, low-density laser-plasma, high-density laser plasma, laser plasma theory, high energy density physics and attosecond science. The CoReLS has 70 research and technical staffs including graduate students. Since 2017, CoReLS has been operating 4 PW laser and using the ultrahigh intensity lasers, explores novel physical phenomena in superintense laser-matter interactions, such as laser-driven particle acceleration, strong field quantum electrodynamics, nuclear photonics and laboratory astrophysics. The ongoing research at CoReLS includes development of femtosecond high power lasers with intensities exceeding 10^{23} W/cm^2, laser-driven acceleration of charged particles, such as electrons and protons, generation and characterization of ultrashort light pulses and ultrafast atomic and molecular dynamics using attosecond XUV pulses.

Fig. 3: Laser facilities with 1.5 PW and 4 PW in the Center for Relativistic Laser Science.

Plasma Physics Group

High power lasers are unique tools for concentrating energy into matter, which leads to a plasma state. The interaction of laser light with plasma has been an extremely rich topic with many applications. The GIST plasma physics group conducts research utilizing several state-of-the-art high power laser systems at various scales (a terawatt ~ four petawatts). The research subjects of three laboratories are unique and range from understanding on fundamental physics to high-tech applications.

In the Laser-Plasma Acceleration Laboratory, the laser-plasma acceleration research is conducted using a home-built 20 TW laser system. The ultrastrong laser electric field is converted into a highly nonlinear plasma wave and the plasma wave can accelerate charged particles to very high relativistic energies (~GeV) over a very short distance (~cm). They are also interested in fundamental laser-matter interactions and developing novel radiation sources and plasma diagnostics.

In the High Energy Density Physics Laboratory, they try to understand how plasmas and materials behave under extremely high temperature and pressure conditions, *a.k.a.* high energy density (HED, > 10^{11} J/m^3) states. HED conditions are created via intense optical lasers, and probed using ultrafast optical and x-ray techniques. Not only high-power optical laser, but also X-ray Free Electron Laser (XFEL) is an important experimental tool in this group. We develop new techniques to apply XFEL to HED science.

In the Laser Fusion Laboratory, small-scale nuclear fusion experiments are conducted with high power lasers. Here, they study not only fundamental physics necessary to achieve fusion ignition, but also material properties in extreme states, such as equation-of-states of warm and dense matters.

Condensed Matter Physics Group (Theory)

The condensed matter theory group is specialized in the computational research fields of quantum many-body phenomena and strongly-correlated material system. Main research topics are quantum magnetism, superconductivity, and superfluidity using various computational tools such as the dynamical mean-field approximation, the dynamical cluster approximation, exact diagonalization, quantum Monte-Carlo method. Two faculties are in charge of the theory group.

Condensed Matter Physics Group (Experiment)

The condensed matter experiment group with 5 faculties studies X-ray for nanoscale phenomena, X-ray photoelectron spectroscopy, optical spectroscopy, nano-hybrid quantum devices, and nanoscale electronics devices. Their researches include the followings: coherent X-ray diffraction imaging and X-ray nano-patterning, surface and interface characteristics of next-generation energy-related materials, including battery, catalyst, and fuel cell, the Mott metal-insulator transition and its device applications, and terahertz/ultraviolet spectroscopy for spintronic devices, quantum electronic transport in mesoscopic systems, and superconducting/spintronic quantum device applications of various nanostructures, the suspended FET devices and electronic transport in low-dimensional materials. The main equipments are listed here: the synchrotron undulator beamlines (APS 8-ID, PAL 11A) and X-ray laser beamline in APRI (Advanced Photonics Research Institute), the angle-resolved photoemission, THz/UV optics, ultra-low temperature and high-magnetic field cryostats and scanning electron microscopy.

Fig. 4: 150 TW laser target chamber and x-ray detectors.

Fig. 5: PLS-II synchrotron GIST beam line at Pohang Accelerator Laboratory, Korea.

The department has an important research center named Center for Advanced X-ray Science (C-AXS), which was selected as a Science Research Center (SRC) project supported by the Korean National Research Foundation in 2015. By utilizing ultrashort coherent bright X-ray sources from high-performance synchrotron radiation and x-ray free electron laser facilities, it aims to establish a research platform to investigate ultrafast physical properties at atomic and molecular scales. To achieve this goal, the center develops ultra-fast X-ray diffraction, nano-scale x-ray imaging, and in-operando spectroscopic techniques that utilize various advanced x-ray sources. These advanced x-ray techniques will be applied to reveal and understand the nature of dynamical and static behaviors various materials. Five faculty members of the Physics and Photon Science including the director Prof. Do Young Noh participate in the C-AXS. Total of 13 core members from various institutes in Korea run the center.

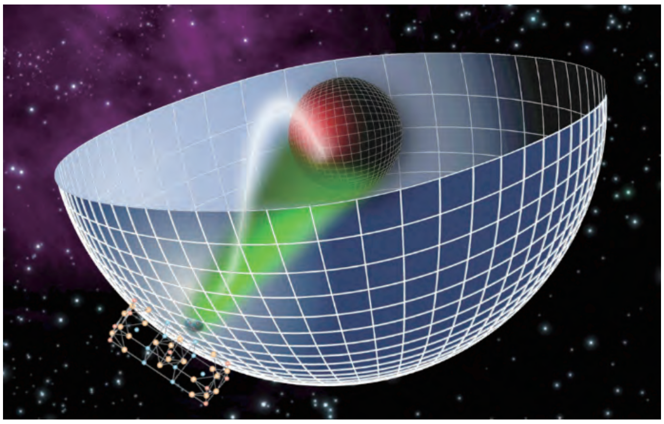

Fig. 6: Holographic Principle: The lattice structure at the left bottom of the blue surface represents some condensed matter system. The space inside the blue surface corresponds to the holographic realization of the condensed matter system, where the red sphere represents the black hole and the green and white 'hairs' visualizes matter fields supporting geometry.

Quantum Field and Gravity Theory Group

The quantum field and gravity theory group seeks the fundamental structures of the nature by investigating quantum fields, classical and quantum gravitational theory including string theory. The group has been working on various issues in theoretical physics: biophysics, nuclear physics, condensed matter physics, field theory and string theory. Recent research focuses on the gauge/gravity duality, AdS/CFT correspondence or holographic principle. The gauge/gravity duality (or AdS/CFT correspondence) has been developed from the string theory. It provides a novel tool for studying strongly coupled systems by mapping difficult strong coupling problems to tractable classical gravity problems in higher dimensions (so holographic principle or holography, see Fig.1). The group studies both the formal aspects of the gauge/gravity duality and its practical applications to diverse systems. In particular, strongly coupled phenomena, such as color confinement, chiral symmetry breaking, high Tc superconductor, and non-Fermi liquid are long and outstanding unsolved problems in physics. The group is trying to solve these intricate problems in terms of gravitational or geometric picture.

The group also studies the quantum information theory such as quantum entanglement entropy, Reni entropy, entanglement negativity and quantum complexity by using the holographic principle. Based on these researches they want to understand how space-time could emerge from quantum entanglement. Ultimately, they aim at understanding quantum gravity and the evolution of our universe by the holographic principle.

Acknowledgements: This material is a combined version of some faculties' contributions in our department (especially Byung-ik Cho, Keun-Yong Kim, Yong-Joo Doh, and Kyungtaec Kim). Their contributions are really appreciated.

Hyyong Suk is the chair of the Department of Physics and Photon Science at GIST. He got a Ph.D. degree in plasma physics at the University of Maryland, College Park, in the U.S. He worked as a postdoctor and a research scientist at UCLA. After that, he returned back to Korea and worked as a center director at KERI (Korea Electrotechnology Research Institute) . In 2007, he joined GIST and has been working on laser plasma with a high power laser.