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Review Article

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Synchrotron Facilities for Advanced Scientific Oriented Research

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ABSTRACT. Synchrotron radiation (SR) is emitted from moving driven charged particles on linear path which are accelerated in circular accelerators to produce a wide range of light wavelengths. Since the first observation of SR, accelerator technologies have been developed to provide synchrotron facilities, which have significant roles for developments of science and technology in the world. Fundamental scientific benefits in addition to industrial services have made synchrotron facilities at the top rank of advanced facilities to provide better quality for life. To this aim, SESAME has been built up for users of Middle East countries and two other ones TAC and ILSF have been also planned to build up to stimulate developments in science and technology. It is worth to note that applicability in various fields of science and engineering areas made SR based facilities as a necessary plan for different countries worldwide in spite of its expensive installation cost.

Keywords: Crystal structure; Electronic structure; Synchrotron radiation.

INTRODUCTION

Almost novel synchrotron radiation (SR), with a half-century of history, is emitted from moving driven charged particles on linear path, which are bended under high magnetic fields.[1] In the SR facilities, the charged particles are accelerated in circular accelerators to produce a wide range of light wavelengths.[2] The first observation of SR was made in the research laboratory of General Electric in 1947 during the detection of the visible light region in the continuous spectrum.[3] Furthermore, the first generation of SR laboratories have been used for producing high energy levels by the physics researchers to determine the basic properties of the substances.[4] Indeed, SR has been originally built up by particle accelerators physics. The electronic and structural features of substances are always important problems for evaluations by the scientists, in which so many efforts have been also dedicated in the computational analysis of structures.[5-8] To this point, the generated SR could yield a broad spectrum of electromagnetic radiation including X-ray to be used in high accuracy electronic and structural analysis.[9] Immediately after this important development, SR has begun to be used as a pioneering technique to investigate the initial structural characteristics of substances. The construction of SR to produce this special light and to develop its applications has been continued without slowing down in many parts of the world for around 60 years. "Storage ring" (Fig. 1) is one of the major components of SR facilities allowing to propagate in a narrow cone tangent to the orbit of the moving electron.[10] It would be an increase in the kinetic energies of the electrons as the ring cone narrows that the energy of the electrons will be increased in such situation and the emitted spectrum will be shifted to shorter wavelengths. Therefore, the progress in the energy harvesting techniques/instrumentation could provide an immense development in use of the SR-based experimental research techniques.[11] The so called “wiggler and undulator” are the special magnetic structures to build up the 2nd and 3rd generations of storage rings for advanced application of SR facilities.[12] These special magnets could produce special-shaped magnetic fields forcing electrons to oscillate for polarized light creation that move linearly or circularly in a spiral orbit. Circular orbit acts as a source of

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radiation when deflecting electrons are passing through magnets; therefore, the emitted light is seen as intense as the brightness of laser emotion. These dominant features such as high polarization, high brightness and wide range of energy spectrum have made the SR light facilities unique for advanced studies.[13] Moreover, extra features such as high coherence and high current have made the SR beam privileged.

Besides the benefits of produced light, some novel techniques diagnosis techniques such as XAFS (X-ray Absorption Fine Structure Spectroscopy) could be only applicable in the SR facilities not in any conventional laboratory.[14] Moreover, several other novel techniques such as XMCD/XMLD (X-ray Magnetic Circular/ Linear Dichroism), WAXS/SAXS (Wide/Small Angle X-ray Scattering) could be provided by the SR facilities. Up to now, more than fifty of 3rd generation SR facilities have been used by more than 15000 expert researchers worldwide (http://www.lightsources.org).

As the importance described above, this study is aimed to discuss the benefits of SR facilities for building a powerful scientific environment, especially in the Middle East region gathering people from different cultures and social backgrounds to do with a common SR laboratory. In this sense, SESAME (Synchrotron-light for Experimental Science and Applications in the Middle East) (Fig. 2) has been built up in Jordan for the scientific users from all of the Middle East countries (www.sesame.org.jo).[15]

Fig. 1: Storage ring, obtained from the website of SESAME.

ACCELERATOR CONCEPT

Accelerator systems are those devices used to increase charged particle bunches (electron, positron, anti-proton, positron) to high energy levels for fundamental purposes of forming particles beams and providing accelerating and radiating resources (SR or free electron laser).[16] More than 300 particle accelerators are distributed worldwide to be used in the research fields of neutron source, SR, radiotherapy, nuclear medicine, materials science, nanotechnology, genetics, food safety, environmental waste disposal, archeology, energy production, mining, especially basic particle physics and nuclear physics.[17] Such accelerator systems are divided into two groups of linear accelerators and circular accelerators. The main function of accelerator systems is to accelerate The already formed electron beams in the linear direction, which could be used in LINAC (Linear Accelerator) regions bringing the electron beams to their initial speed in synchrotrons; circular accelerators. Four working techniques are available in circular accelerators: synchrotron, betatron, cyclotron, and microtron, to generally accelerate a charged particle around a circular orbit.[18] Magnetic field forces are applied perpendicular to the orbit motion so that the particle motion could be remained in the circular orbit obtaining great benefits of particle accelerating in a circular orbit repeatedly.[18]

Fig. 2: SESAME building, obtained from its website.

Historically, discovery of the photoelectric event was the first description of matter and light interactions yielding scattering, absorption, and pair creation occur.[19] Elastic (coherent or Rayleigh) and inelastic (incoherent) are two types of scattering process as a results of matter and light interactions. Elastic scattering is occurred by interaction of an incoming photon with the valence electrons of atoms, in which the total wavelength of the scattered photon is equal to the wavelength intensity of the incoming photon. In contrast, inelastic scattering is occurred when there is a difference between wavelengths of incoming and reflected photons. Two fundamental events are occurred in an atom by absorbing the emitted photon from a light source: i) the photoelectric effect ii) the Auger effect.[20] While a photon is coming with very high energy, it will be able to stimulate the inner electrons and reach the inner orbits of the atom to transfer its energy. SR could provide such situation. Comparing with the conventional X-ray tubes, SR could provide 10^5 times brighter light emitted in circular accelerators with wide range of electromagnetic spectrum; called as continuous spectrum starting from radio waves and extending to soft and hard X-ray for various applications.[21-25]

RESULTS AND DISCUSSION

SR facilities are almost located at the central heart of advanced scientific developments leading high technologies due to their superior features. In this case, building up the 3rd and 4th generation of SR facilities have become one of the important developing plans for many countries resulting several SR facilities worldwide with different characteristics such as, energy range beam brightness. ESRF (France), APS (USA), SPring-8 (Japan), ALS (USA), CLS (Canada), LNLS (Brazil), SLS (Switzerland), Australia Synchrotron (Australia), ANKA (Germany) are examples of those favorite SR centers for researchers of Middle East (http://www.lightsources.org). Inside the Middle East, SESAME has been built up in Jordan to provide SR facilities for researchers of this local region and also attracting researchers worldwide (www.sesame.org.jo). SESAME has gathered almost the Middle Eastern countries under a scientific umbrella to work at the highest level of research and technologies. The first step of SESAME construction was taken in 1980s as a cooperation of the neighboring countries of the Middle East region in direct collaboration with international scientific organizations and SR facilities worldwide. SESAME, as a 2.5 GeV electron synchrotron of 3rd generation facilities, provides Infrared (IR), Ultraviolet (UV), soft and hard X-ray for the researchers of several fields of materials science and engineering. It is governed by an International Council funded by the member states, which has been officially opened since May 16, 2017 as a bridge between member countries to have scientific and cultural interactions.

Currently, three beamlines of SESAME are operating to provide X-ray absorption spectroscopy, X-ray diffraction and Infrared spectroscopy facilities for researchers. However, the beam time allocation is based on proposal system submissions to provide required services of those available beamlines in addition to three upcoming under developing beamlines including soft X-ray photoelectron spectroscopy, hard X-ray tomography and imaging, and a macromolecular crystallography beamlines. Up to 18 beamlines are planned be constructed for full operations of SESAME. Engineering and industry related applications such as automotive, archeology, polymer, petroleum, materials, geology, defense, nuclear physics, food sterilization, radiology, environmental, nanotechnology, pharmacology, medicine, and so many other ones are provided by synchrotron facilities in addition to fundamental scientific applications.

Turkey, a member of SESAME, has also stepped to build up a national synchrotron facility so called "Turkish Accelerator Center -TAC" as a joint university collaboration for scientific research and technological developments (http://tac.en.ankara.edu.tr). TAC has been conceptually planned as electron, positron and proton accelerators with different GeV scales to perform experimental studies in basic and applied sciences. The synchrotron facility so called TURKAY is actually the second phase of the TAC project, which is planned as a 3rd generation of light sources with a 3 GeV electron beam. TAC have scientific collaboration agreements with CERN (Switzerland), DESY, Euro XFEL, HZB and HZDR (Germany), ESS (Sweden), Cockcroft Institute (England), INFN-NLS (Italy) and IHEP (China) to use the experiences of the well-known accelerator laboratories during the local construction processes .

Iran, a member of SESAME, has also decided to build up the "Iranian Light Source Facility - ILSF" as a synchrotron light source facility for stimulating improvements in science and technology (http://ilsf.ipm.ac.ir). Awaring of huge benefits of SR-based collaboration, Iran has organized many scientific activities both to promote science, to upgrade the knowledge of Iranian scientist in synchrotron light using techniques, as well as to provide an awareness to scientist on the precious outcomes of the synchrotron light. Planning to construct of ILSF is a result of this carfeul awareness of SR benefits.

CONCLUSION

Accelerator technologies, including synchrotron facilities, have significant roles for developments of science and technology in the world. Industrial related services providing, in addition to fundamental scientific benefits, have made synchrotron facilities at the top rank of advanced facilities to yield better quality for life.

To this aim, SESAME has been built up for users of Middle East countries and two other ones TAC and ILSF have been also planned to build up to stimulate developments in science and technology. As a conclusion, applicability in various fields of science and engineering areas made SR based facilities as a necessary plans for different countries worldwide in spite of its expensive installation cost.

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