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Vacuum Electron Device Technology: Key of the Clean and Safe Energy Generation (SDG-7) for Climate Stabilization (SDG-13)

Anshu S. Singh [(1)], and Dragos Dancila [(1,2)]
(1) FREIA, Department of Physics and Astronomy, Uppsala University, Sweden
(2) Microwave Group, Department of Electrical Engineering, Uppsala University, Sweden

1. Introduction

Global warming and climate change affect the whole earth, from polar to tropical regions. In the Arctic circle, polar bears are starving due to the two-week early arrival of springs, and in the South Asian tropical region, farmers are committing suicide due to crop damage in extreme weather events. Temperature rise has disturbed the hydrological cycle, which can be seen as low agriculture productivity and a decaying ecosystem, leading to the food crisis and extreme poverty in developing countries amid high petrol prices. Green technologies implementation is the key not only to reducing carbon gas emissions but also indirectly addressing several sustainable development goals (SDGs) especially SDG-7 and SDG-13. It well known fact the all seventeen SDGs are interacting with one another Furthermore SDG-7 and SDG-13 are strongly coupled with each other. In present article, role of vacuum electron device technology has been discussed towards the realization dream of greener earth.

Besides our daily life's necessity, electricity becomes fuel for the economy. Clean energy generation to fulfil the global electricity demand is significant challenges as the carbon emission are gradually increasing global warming. Therefore, to follow the path of sustainable development in the competing cutthroat environment among the countries becomes difficult. Depletion of fossil fuels such as oil, gas and coal not only increase the cost of electricity generation but also become a significant burden on the economy of non-OPEC countries. These factors push the research towards nonconventional energy generation technique. However, the environment-friendly, well-developed solar and wind energy generation technology, is not suitable for enormous and constant energy demands of industry, especially as compared to the nuclear power reactor. Nuclear energy generation technique fission and fusion reactors are generating power with negligible greenhouse emission. Clean safe and enormous energy generation is an issue for sustainable development. Vacuum electron devices (VEDs) have a crucial role in nuclear power generation; it increases the safety in the nuclear fission reactor using the VEDs driven subcritical reactors as well as drives the nuclear fusion reactor using the Gyrotron oscillator.
Despite having colossal energy generation capabilities, nuclear fission reactor is not suitable due to safety issues. The uncontrolled chain reaction in fission process renders it as a potential threat to the nearby population as happened Chernobyl, USSR in 1986 and Fukushima, Japan in 2011. Apart from the uncontrolled chain reaction-based implosion, radiation from radioactive waste is another risk to humanity. A vacuum electron device mitigates the problem of safety in the nuclear fission-based reactor as well as provides the waste management of radioactive by-product/residue. Subcritical nuclear reactors drove by a particle accelerator in which a vacuum electron device accelerates the protons and fission process is stopped with the particle accelerator thus provides safety. This mechanism uses thorium (which is abundantly available in India), unlike uranium which is used in conventional nuclear reactors and accelerator-driven subcritical reactors use plutonium residue which is obtained from conventional nuclear reactors. Apart from making nuclear fission safer, VEDs are employed into the transmutation of radioactive waste generated from reactors and nuclear weapons. The transmutation is a conversion process that turned long-lived radioactive waste into short-lived waste and reduces the storage time. Presently the radioactive dump at Marshall Island and its neighbouring archipelago in the South Pacific Ocean is a crisis for the inhabitant. Vacuum electron devices are not only employed in safe nuclear fission-based energy generation but also efficiently manage radioactive waste.
Unlike the well-established fission based nuclear generation technology, thermonuclear fusion reactors can generate safe and clean energy to suffice the global energy requirement using the VED named gyrotron. This VED is a cornerstone in the development of artificial sun on earth through a thermonuclear fusion reactor which can fulfil the world energy demands without carbon emission.
One GW Fusion power plant needs less than 2 kg of fuel per day, but the major challenge is to increase the temperature up to millions of centigrade to fuse the deuterium and tritium. Plasma heating is a requirement of fusion reaction in TOKAMAK, toroid shaped vacuum vessel where strong magnetic field confinement restricts particles to collide with a wall. Early work of Russian scientists forges the path of a clean energy generation. Russian scientist Alikev has identified gyrotron are capable of increasing temperature from 250 eV to 490eV in 1977 and gyrotron was exposed top world at Saratov Russia in fifth inter-university microwave electronics conferences. Presently, scientific groups from the European Union, India, Japan, China, Russia, South Korea, Australia and the United States are working collaboratively to develop thermonuclear fusion reactor, projects named as International Thermonuclear Experimental Reactor (ITER). ITER will be installed at France in 2025 and will generate 500 MW up to 2035. Participating countries of ITER projects represent approximately 80 % of world GDP and rigorously working to achieve the ultimate energy solution.

Gyrotron Oscillator applications is not limited to energy generation through nuclear fusion, Its second popular applications in DNP/NMR applications as gyrotron presently most powerful RF source in terahertz region. Pharmaceuticals and chemistry research advancements are heavily dependent on high power THz gyrotrons.
For heating applications high power generation using vacuum devices have efficient way to transfer energy to object rather than conventional heating. In recent years, microwave technology extended its applications in material processing, rock comminution, activated carbon processing, syngas production, microwave assisted extraction of pharmaceutical and industrial contaminants, treatment of biohazardous waste, waste rubber recycling, radioactive waste management and much more. These all applications claim VED based technology as a key solution for fast economical and green manufacturing. Most of industrial applications are depending on Magnetron; Magnetron is the key for allied force's victory in World War II and now this veteran tube finds applications in heating from industrial to domestic purposes, particle accelerator from cargo scanning to radiotherapy, and RADAR from air traffic to weather. The services of magnetron over several decades in a multi-dimensional environment proves its efficiency, reliability, and ruggedness. These virtues of veteran magnetron tube render it as an energy efficient solution for industrial applications. The market of magnetron will reach up to 1 billion B$ by 2030 in addition to Industrial microwave heating1.8 B$ and Wireless power transfer 15 B$.

Similarly micro-VEDs are opening a new frontier in Terahertz which is the less explored frequency regime as lack of power sources. In early attempts, the gap between conventional vacuum electron devices (VEDs) and lasers was filled by fast-wave devices. The fast-wave devices and lasers are become bulky due to the required magnetic field system and cryogenic system, respectively. Compact solid-state devices (SSDs) such as resonant tunnelling diodes (RTDs) are available in the THz range, with microwatt power generation capabilities as the nature of conduction in solid-sate material limits the high-power operation. With the advent of microfabrication techniques, micro variants of conventional VEDs i.e., micro-VEDs generates high power per unit volume than SSDs and micro-VEDs started to infiltrate the THz frequencies. In 1960 several combinations of klystron and TWT were investigated to optimise the performance metrics and gave birth to hybrid VEDs such as EIK and twystron. EIK tube (VKS-8345), developed by Varian Inc, is commissioned in US AN/TPS RADAR in 1968 and currently, EIK tubes became an integral part of the space-borne transmitter. Similar to EIK, the micro-magnetron is fascinating THz sources for medical imaging technique as a non-ionizing alternative of X-rays as well as successful demonstration of THz imaging for dental purposes.

The Famous Scientist Freeman Dyson stated that most of recent scientific discoveries are instrument driven. Since the J. J. Thomson's discovery of electron, vacuum electron devices are the key for most of the scientific discoveries, despite the current partial replacement in industrial technology. The success of gyrotron will transform the whole world and will ease the path of Clean Energy Generation (SDG-7) and Climate Action (SDG-13). The vacuum electron devices such as klystron amplifier have potential to increase the safety of nuclear reactor power plant (SDG-7) using the VEDs driven subcritical accelerators. Magnetron oscillators are exploring the possibilities of microwave assisted processing for optimal industrial scale solution and hydrogen generation for clean energy generation. The implementation of vacuum electron device technology will strengthen the global action of climate stabilization.

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