2021
Impact Factor
5.634

THE AMERICAN JOURNAL OF APPLIED SCIENCES

Crossref doi

10.37547/tajas

VOLUME-03

THE AMERICAN JOURNAL OF APPLIED SCINCES

(TAJAS)
SJIF-5.634
DOI-10.37547/tajas

Volume 3 Issue 01, 2021

ISSN 2689-0992

The USA Journals, USA
www.usajournalshub.com/index.php/tajas

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Website: www.usajournalshub.com/index.php/tajas

Email: editor@usajournalshub.com

Publisher Address: 304 S. Jones Blvd #5245 Las Vegas, NV 89107 USA

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The American Journal of Applied sciences
(ISSN – 2689-0992)
Published: January 30, 2021 | **Pages:** 69-78
Doi: https://doi.org/10.37547/tajas/Volume03Issue01-12

IMPACT FACTOR
2021: 5. 634
OCLC - 1121105553

Journal Website: http://usajournalshub.com/index,php/tajas

The Role Of Quantum Electronics In Alternative Energy

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ABSTRACT

The article deals with Quantum electronics, as a field of physics that studies methods of amplification and generation of electromagnetic radiation based on the phenomenon of stimulated radiation in nonequilibrium quantum systems, as well as the properties of amplifiers and generators obtained in this way and their application, a description of the structure of the most important lasers is given, physical foundations of quantum electronics, which are reduced primarily to the application of Einstein's theory of radiation to thermodynamically nonequilibrium systems with discrete energy levels.

The article is intended for undergraduates of the Department of Physics, Radio Engineering, who have interests in the field of research and applications of laser radiation, and is aimed at giving them the minimum necessary for that initial information on quantum electronics.

KEYWORDS

Quantum electronics, Einstein's theory, generation of electromagnetic radiation, laser radiation, maiser, thermodynamic nonequilibrium.

INTRODUCTION

Electronics and electronic devices play a huge role in today's world. Today, all electrical engineering has become as commonplace as biological. Moreover, today some

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schoolchildren have never seen a live chicken or horse, but they have all seen and are well aware of the computer and the Internet. This is not at all paradoxical, just a few decades ago the situation was radically different. But today it is difficult to imagine how humanity did without computers, the Internet, and simple electric bulbs. The use of advanced technologies has allowed humanity to reach a new level of existence. This science is the future – the electronic means will allow the creation of such things as electric cars or new generations of computing devices - ultra-powerful computers and laptops.

The concept of electronics includes such a vast area of human activity that just a simple listing of its sections would take too much space. However, all these sections have one thing in common: the physical basis of electronics is the motion of electrons and the laws of this motion. Electronics is the most important component of modern technical civilization; it is difficult even to imagine what our world would look like without electronic devices (ED). EDs calculate train schedules and scientific research results, operate automatic machines and car assemblies, accumulate information and transform it into a form that is convenient for human perception.

But, perhaps, the field of application of electronics closest to all of us is the transmission of information. Today it seems absolutely natural that blue TV screens light up in every house in the evenings, that you can turn on the radio to find out the latest news and weather reports, that a tape recorder makes it possible to hear recordings of performances of your favorite singers and musicians, which is always there in all corners of our vast Motherland today's newspapers and that telegrams all over the world take a few hours. All this is achieved thanks to the flawless operation of ED - transmitters and receivers of information. Communication lines are complex and diverse, they include numerous intermediate information processing points, including those located on artificial earth satellites.

The exit of humanity into near-earth space is also inextricably linked with electronics. EIs exercise control over the preparation of spacecraft for launch and their flight, ensure the docking of spacecraft in orbit, landing and search for descent vehicles. In the latter case, special EDs are used - radars that periodically send radio waves, that is, beams of electromagnetic energy, and by their reflection from objects determine the direction of movement of space objects and the distance to them.

MATERIALS AND METHODS

In recent years, new classes of EDs have appeared, based on the laws of so-called quantum electronics. These are well-known lasers - generators of coherent light and radio waves. The range of application of lasers is very wide - from the study of the lunar surface to very precise welding of metals in industry or ultra-precise operations on the retina in medicine.

The appearance of lasers in the mid-60s is also associated with the advent of lasers. a new direction in the field of electronics - optoelectronics, which uses optical (photonic) communication to transmit information. Optical communication has several advantages over electrical communication. Due to the electrical neutrality of photons in the optical communication channel, electric and magnetic fields accompanying the flow of electric current are not excited. In other words, photons do not interfere with communication lines.

The transmission of information using a light beam is not accompanied by the accumulation and dissipation of electromagnetic energy in the line, and this ensures the speed of information transmission and the minimum level of its distortion. The high frequency of optical vibrations (10m - 1015 Hz) determines both a large amount of information and its speed, and a short wavelength (up to 10 ~ 4 - 10 5 cm) provides an opportunity for microminiaturization of transmitting and receiving devices. The main elements of optoelectronics: light sources (lasers, LEDs), optical media (active and passive) and photodetectors. A new promising field of electronics is functioning - the creation and application of acoustoelectronic devices in various branches of technology.

Speaking of electronics, one cannot but mention the particularly important role of electronic computers. Computers are increasingly penetrating all spheres of human activity, carrying out a true revolution in them due to the high accuracy of information processing and tremendous speed: modern computers are capable of performing several million operations per second. They not only free a person from the laborious work of collecting and processing information, but also make it possible to obtain fundamentally new results of labor. An example is the use of computers in factories for the production of highly pure materials, which are the basis of the modern electronic industry: not a single person - an operator - would be able to cope with the management of the most complex technological processes.

Electronics is the most rapidly developing area of human activity, and in modern conditions the success of scientific and technological progress largely depends on the level of its development.

Electronics comprises three areas of research:

- Vacuum electronics;
- Solid state electronics;
- Quantum electronics.

Each area is subdivided into a number of sections and a number of areas. The section unites complexes of homogeneous physical and chemical phenomena and processes, which are of fundamental importance for the development of many classes of electronic devices in this area. The direction covers the methods of designing and calculating electronic devices, related in the principles of operation or in the functions they perform, as well as the methods of manufacturing these devices.

RESULTS AND DISCUSSIONS

Quantum electronics is a branch of physics, the main content of which is the study of methods of amplification and generation of electromagnetic radiation by using the effect of induced emission of radiation in thermodynamically nonequilibrium quantum systems, the properties of amplifiers and generators obtained in this way and their application. The most famous devices in quantum electronics are masers and lasers. Therefore, in the narrow sense of the word, one can speak of quantum electronics as the science of masers and lasers, bearing in mind that masers are quantum amplifiers and generators of coherent electromagnetic radiation in the radio frequency (microwave) range, and lasers belong to the optical range.

A high degree of concentration of light energy in a very narrow solid angle and a small spectral interval, i.e., high directivity and monochromaticity of radiation, is the main characteristic feature of lasers and significantly distinguishes them from conventional light sources. Adjacent to this is the ability of lasers to concentrate large energy in extremely short periods of time. In turn, maser-generators differ from ordinary sources of radio emission by a high stability of the generation frequency, and masers-amplifiers differ from classical electronic radio amplifiers by a low noise level.

All this is due to the fact that the effect of stimulated emission of radiation is used to amplify radiation in quantum electronics, which is precisely reflected in the well-established terminology. The term "maser" ("laser") is formed from the initial letters of the English expression microwave (light) amplification by stimulated emission of radiation, which means amplification of a microwave radio wave (light) by the effect of stimulated emission of radiation.

The basis of quantum electronics as a science as a whole is the phenomenon of induced radiation, the existence of which was postulated by A. Einstein in 1916. In quantum systems with discrete energy levels, there are three types of transitions between energy states: transitions induced by an electromagnetic field, spontaneous transitions and nonradiative relaxation transitions. The properties of stimulated radiation determine the coherence of radiation and amplification in quantum electronics. Spontaneous emission causes the presence of noise, serves as a seed impulse in the process of amplification and excitation of oscillations, and, together with nonradiative relaxation transitions, plays an important role in obtaining and maintaining a thermodynamically nonequilibrium radiating state.

During induced transitions, a quantum system can be transferred from one energy state to another (Fig. 1) both with the absorption of the energy of the electromagnetic field (this is a transition from a lower energy level to an upper one), and with the emission of electromagnetic energy (this is a transition from an upper level to a lower one).

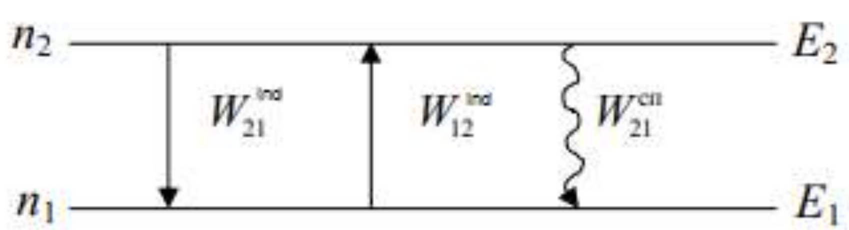

Fig. 1 Diagram of two energy levels

Published: January 30, 2021 | Pages: 69-78
Doi: https://doi.org/10.37547/tajas/Volume03Issue01-12
IMPACT FACTOR
2021: 5. 634
OCLC - 1121105553

In quantum generators, the internal energy of microsystems - atoms, molecules, ions - is used to create electromagnetic oscillations.

Quantum generators are also called lasers. The word laser is made up of the initial letters of the English name for quantum generators - light amplifier by creating stimulated emission.

The principle of operation of a quantum generator is as follows. When considering the energy structure of matter, it was shown that the change in the energy of microparticles (atoms, molecules, ions, electrons) does not occur continuously, but discretely - in portions, called quanta (from the Latin quantim - quantity).

The Microsystems in which elementary particles interact with each other are called quantum systems.

The transition of a quantum system from one energy state to another is accompanied by the emission or absorption of a quantum of electromagnetic energy hv: E2 - Ei = hv, where E1 and E2 are energy states: h is Planck's constant; v is the frequency.

It is known that the most stable state of any system, including an atom and a molecule, is the state with the lowest energy. Therefore, each system seeks to occupy and maintain the state with the least energy. Therefore, in the normal state, the electron moves along the orbit closest to the nucleus. This state of the atom is called ground or stationary.

Under the influence of external factors - heating, lighting, electromagnetic field - the energy state of the atom can change.

If an atom, for example, hydrogen interacts with an electromagnetic field, then it absorbs energy E2 - E1 = hv and its electron goes to a higher energy level. This state of the atom is called excited. An atom can be in it for a very short time, called the lifetime of an excited atom. After that, the electron returns to the lower level, i.e., to the ground stable state, giving up excess energy in the form of a radiated energy quantum - a photon.

The emission of electromagnetic energy during the transition of a quantum system from an excited state to the ground state without external influence is called spontaneous or spontaneous. In spontaneous emission, photons are emitted at random times, in an arbitrary direction, with arbitrary polarization. Therefore, it is called incoherent.

However, under the influence of an external electromagnetic field, the electron can be returned to the lower energy level even before the expiration of the lifetime of the atom in the excited state. If, for example, two photons act on an excited atom, then under certain conditions the electron of the atom returns to the lower level, emitting a quantum in the form of a photon. In this case, all three photons have a common phase, direction and polarization of radiation. As a result, the energy of the electromagnetic radiation is increased.

Radiation of electromagnetic energy by a quantum system with a decrease in its energy level under the influence of an external electromagnetic field is called forced, induced or stimulated.

The induced radiation coincides in frequency, phase and direction with the external radiation. Hence, such radiation is called coherent (coherence — from the Latin cogerentia - cohesion, connection).

Since the energy of the external field is not spent on stimulating the transition of the system to a lower energy level, the electromagnetic field is amplified and its energy increases by the value of the energy of the emitted quantum. This phenomenon is used to amplify and generate oscillations using quantum devices.

Currently, lasers are made from semiconductor materials.

A semiconductor laser is a semiconductor device in which electrical energy is directly converted into radiation energy in the optical range.

For a laser to work, that is, in order for the laser to create electromagnetic oscillations, it is necessary that there are more excited particles in its substance than unexcited ones.

But in the normal state of a semiconductor, there are fewer electrons at higher energy levels at any temperature than at lower levels. Therefore, in the normal state, the semiconductor absorbs electromagnetic energy.

The presence of electrons at one level or another is called the level population.

The state of a semiconductor in which there are more electrons at a higher energy level than at a lower level is called a state with an inverted population. Inverse population can be created in various ways: by injection of charge carriers with direct switching on of the p - n junction, by irradiating the semiconductor with light, etc.

The energy source, creating an inversion of populations, performs work, transferring energy to the substance and then to the electromagnetic field. In a semiconductor with an inverted population, stimulated emission can be obtained, since it contains a large number of excited electrons that can give up their energy.

If a semiconductor with an inverse population is irradiated with electromagnetic oscillations with a frequency equal to the frequency of the transition between energy levels, then electrons from the upper level are forced to move to the lower one, emitting photons. In this case, stimulated coherent radiation occurs. It is enhanced. Having created a positive feedback circuit in such a device, we obtain a laser - an auto-generator of electromagnetic oscillations of the optical range.

For the manufacture of lasers, gallium arsenide is most often used, from which a cube is made with sides a few tenths of a millimeter long.

CONCLUSION

The birth date of quantum electronics can be considered 1954, when N.G. Basov and A.M. Prokhorov in the USSR and independently J. Gordon, H. Zeiger and CH Townes in the United States created the first quantum generator (maser) on ammonia molecules. Generation in it occurs at a wavelength of 1.25 cm, which corresponds to transitions between the states of molecules with a mirror-symmetric structure. Population inversion is achieved due to the spatial separation of excited and unexcited molecules in a strongly inhomogeneous electric field (see the Stark effect). The sorted molecular beam is passed through a cavity resonator for feedback.

Subsequently, other molecular generators were created, for example, a maser on a beam of hydrogen molecules.

The next important step in the development of quantum electronics was the three-level method proposed in 1955 by N. G. Basov and A. M. Prokhorov, which made it possible to significantly simplify the attainment of inversion and to use optical pumping for this purpose. On this basis, in 1957-1958, H. E. D. Scovil and others created quantum amplifiers based on paramagnetic crystals (for example, ruby), which operated in the radio range.

The idea of using open resonators (a system of parallel mirrors, as in a Fabry-Perot resonator), which are extremely convenient for pumping, turned out to be important for advancing quantum generators into the optical frequency region. The first ruby crystal laser, emitting radiation at a wavelength of 0.6934 µm, was created by Th. Maiman in 1960. Optical pumping in it is realized using pulsed gas-discharge lamps. The ruby laser was the first solid-state laser; neodymium glass lasers and neodymium garnet crystals (wavelength 1.06 µm) also stand out. Solid-state lasers have made it possible to generate high-power short and ultrashort light pulses in Q-switching and cavity mode locking.

Soon A. Javan created the first gas laser based on a mixture of helium and neon atoms (wavelength 0.6328). It is pumped by electron impact in a gas discharge and by resonant energy transfer from the auxiliary gas (in this case, helium) to the main gas (neon). Other types of gas lasers include powerful carbon dioxide lasers (wavelength 10.6 µm, auxiliary gases nitrogen and helium), argon lasers (0.4880 and 0.5145 µm), cadmium laser (0.4416 and 0.3250 µm), copper vapor laser, excimer lasers (pumping due to the decay of molecules in the ground state), chemical lasers (pumping due to chemical reactions, for example, the chain reaction of the combination of fluorine with hydrogen).

In 1958, NG Basov, BM Vul and Yu. M. Popov laid the foundations for the theory of semiconductor lasers, and already in 1962 the first injection laser was created [R. Hall (R. N. Hall), W. L. Dumke (W. L. Dumke), etc.] Interest in them is due to the simplicity of manufacture, high efficiency and the possibility of smooth frequency tuning in a wide range (the radiation wavelength is determined by the band gap). A significant result is also the creation in 1968 of lasers based on semiconductor heterostructures.

In the late 1960s, lasers based on organic dye molecules were developed and created, which have an extremely wide gain band, which makes it possible to smoothly tune the generation frequency when using dispersive elements (prisms, diffraction grating). A set of several dyes covers the entire optical range.

- Masers have made it possible to improve the sensitivity and stability of the operation of radio devices, which has found application in radio astronomy (the discovery of relic radiation and interstellar hydrogen) and space communications.
- Lasers made it possible to achieve electric field strengths comparable to intra-atomic ones, at which the properties of a substance begin to depend on the intensity of the light wave: the effects of nonlinear optics are manifested. They make it possible to study matter and control the characteristics of a light beam

(multiphoton processes, saturation and resonance clearing phenomena, generation of harmonics, sum and difference frequencies, parametric generation of light, self-focusing phenomena, stimulated light scattering, etc.)

- Lasers are used to create and control high-temperature plasma, including for the purpose of thermonuclear fusion.
- Quantum electronics has led to a significant increase in the resolution of spectroscopic systems (laser spectroscopy).
- Monochromaticity of laser radiation makes it possible to selectively influence a substance, which finds application in photochemistry and photobiology, laser cleaning and laser isotope separation.
- The use of quantum electronics in metrology to create quantum standards for frequency and time, laser rangefinders, remote chemical analysis systems, laser ranging.
- Lasers are widely used in optical communication and information processing systems, which combine the principles of fiber and integrated optics.
- A high degree of coherence of laser sources made it possible to implement the idea of holography and holographic devices.
- Lasers find many applications in medicine (surgery, ophthalmology, etc.) and technology (welding, cutting, etc.).

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