Clinotrons as powerful sources of terahertz radiation

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Abstract: A series of clinotron tubes and clinotron based oscillators, which effectively operate throughout millimeter and sub-millimeter wavelength bands, have been developed at the Institute of Radio Astronomy. In this paper, the design and characteristics of these devices are discussed. Potentials of the clinotron for further upgrading efficiency, output power, and operating frequency are considered as well.

The THz frequency region is becoming increasingly attractive for researchers due to a number of current and potential scientific and practical applications of such frequencies. It is clear now that the development of this frequency region will have a dramatic impact on remote sensing, telecommunication, radio astronomy, plasma diagnostics, medical imaging, security screening, industrial-process monitoring, monitoring of atmospheric pollutions, spectroscopy and many other arias [1 - 5]. The main factor that still essentially contains the exploitation of the THz-frequencies is related with a lack of suitable THz-sources. Most of the applications call for compact, high-power, tunable, room-temperature oscillators. At present time, the sources of the terahertz radiation are direct multiplier-based sources, frequency mixers, the gyrotron, the backward wave oscillator (BWO), the far infrared laser, optically pumped lasers, free electron lasers, synchrotron type sources, single-cycle sources, and some others. Each of these sources has its own advantages and disadvantages, but none of them meets completely the formulated requirements.

As for the low-frequency part of the THz-region - up to about 3 THz, the BWO [6, 7] can be considered as the most suitable candidate for wide practical applications. The only disadvantage of this type of oscillators is related with a low power, which goes down to the microwatt level at frequencies about 1 THz.

In this presentation, we describe a THz-tube, called the clinotron, which can illuminate the indicated shortcoming of the BWO. The clinotron was invented by Ukrainian scientists [8, 9], and it has already proved its efficiency for the frequencies up to 500 GHz. The clinotron is similar to the BWO in the sense that it utilizes the interaction of an electron beam with spatial harmonic components of the electromagnetic field of a slow-wave structure. However, some essential modifications in the tube design were introduced. The distinguishing features of the clinotron are as following:

(i) The electron beam is inclined to the surface of a grating as illustrated in Fig. 1, where the schematic of the tube is given. By varying the tilt angle α, it is easy to optimize the length of the „effective“ interaction space without changing the geometry of the tube,

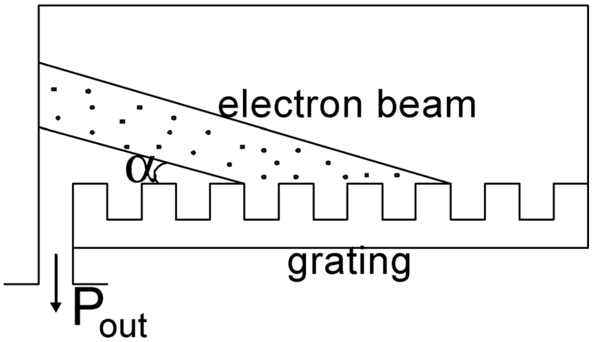

Fig. 1. Configuration of the beam, the grating, and the cavity in the clinotron.

(ii) The beam thickness is large compare to that in the conventional BWO,

(iii) The electrons are bunched in an exponentially growing field,

(iv) A wide electron beam is used, what enables for increasing the beam current and the output power as well, and

(v) The clinotron is usually built as a resonance device. Nevertheless, the electronic tuning of the operating frequency is large what is achieved by successive exciting the resonator modes with beam voltage variation.

The above approaches have resulted in the development of clinotron tubes for the frequency range from 30 GHz to 500 GHz [8, 9]. The output power level of these tubes is at least an order of magnitude greater than for conventional BWO's [6, 7]. For example, 300 GHz and 500 GHz tubes provide the power level of about 500 mW and 100 mW, respectively. Physical dimensions, weight, and the operating voltage of clinotrons are comparable with those of BWO's.

The energy output in the clinotron is arranged by means of a waveguide, as schematically shown in Fig. 1. However, tubes with a distributed energy output, where the energy is directly radiated via a transparent window, as shown in Fig. 2, have been developed and produced as well [8 - 10]. The output energy is brought out here by means of the Smith-Purcell radiation. Thus, such clinotron tubes acquire the solution used in orotron oscillators [11]. In the clinotron, this radiation is organized by using a two-periodic grating. Such clinotron tubes are easily matched with quasioptical transition lines and, therefore, this modification is especially interesting for applications in THz-systems.

Due to the unique characteristics, the clinotron tubes have been already used in various electronic systems, like plasma diagnostic instruments, short-range radars, local oscillators, etc. To meet the above applications, a compact, solid-state, high-

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voltage power supplies have been developed for the clinotron based oscillators [12]. These supplies feature a high efficiency and reliability. The possibility of the development of clinotron-based synthesized oscillators with the relative frequency stability of about 10^{-7} has been also demonstrated.

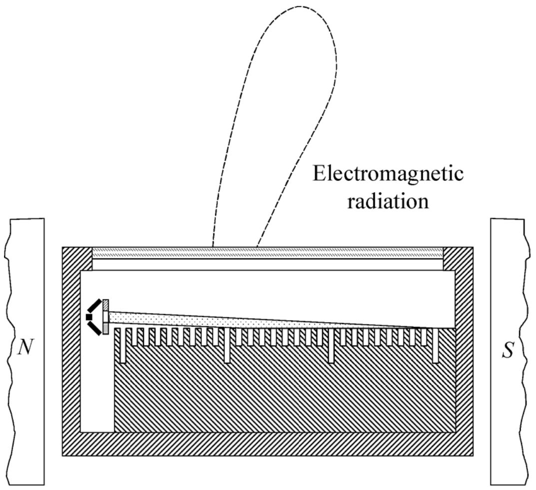

Fig. 2. Schematic view of the clinotron with distributed energy output.

The theoretical studies [13 - 15] indicate that the clinotron has a large potential for further increasing of both the operating frequency and the output power. In order to realize this potential, clinotron tubes with a denser and more intensive electron beam should be realized. It is important that the space charge and temperature effects do not impose serious limitations on an essential current density increase as compared with those values used in the present clinotron design. According to our recent simulation results, the output power levels of about 2 W and 70 W can be achieved at the frequencies around 1 THz in CW and pulsed operating modes, respectively. To realize such tubes, the beam current density should be increased to about 100 A/cm^2 for the CW mode and to about 1000 A/cm^2 for the pulsed mode. The beam cross section can be 0.05 mm x 2.5 mm, which is the same as in the already produced tubes. Characteristics of such further clinotron tubes, which are now under development, are summarized in Table 1. It should also be noted that the required beam current and the accelerating voltage are still relatively low.

Table 1. Characteristics of further clinotron tubes

	CW operation mode	Pulsed operation mode
Central frequency	1 THz	1 THz
Beam Current Density	100 A/cm^2	1000 A/cm^2
Beam Current	0.125 A	1. 25 A
Accelerating voltage	5 kV	5 kW
Beam cross-section dimensions	0.05 mm x 2.5 mm	0.05 mm x 2.5 mm
Efficiency	0.7 %	2.5 %
Output power	2 W	70 W

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