MEGASCIENCE: THE OECD FORUM

UNIQUE RESEARCH FACILITIES IN RUSSIA

For technical reasons, OCDE/GD(95)81 has been split into 9 parts. This is the Part 8.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris 1995
CHAPTER 7. HIGH ENERGY MICROWAVE FACILITIES
CHERENKOV PLASMA RELATIVISTIC
MICROWAVE OSCILLATOR
General Physics Institute

Date of commissioning: 1988.

Field of science
Physics (plasma physics, electron beam–plasma interaction, and microwave generation).

Fields of research
• Control of the radiation frequency spectrum of a plasma relativistic microwave oscillator.
• Investigation of multi-particle excitation of waves in plasma, driven by a relativistic electron beam (REB).
• Elaboration of a plasma relativistic microwave amplifier with the power of 100 MW and frequency band of 8–15 GHz.

Main characteristics
The Cherenkov plasma oscillator uses three high-power electron accelerators:

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<tr>
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<th>Terek-2</th>
<th>Terek-3</th>
<th>Terek-3W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energy, keV</td>
<td>500</td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td>Beam current, kA</td>
<td>5</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Pulse duration, ns</td>
<td>30</td>
<td>2 000</td>
<td>120</td>
</tr>
<tr>
<td>Plasma density, cm(^{-3})</td>
<td>(10^{11}–5\cdot10^{14})</td>
<td></td>
<td></td>
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<tr>
<td>Magnetic field, kG</td>
<td>15–30</td>
<td></td>
<td></td>
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<tr>
<td>Microwave power, MW</td>
<td></td>
<td></td>
<td>up to 300</td>
</tr>
<tr>
<td>Frequency band, GHz</td>
<td></td>
<td></td>
<td>5– 40</td>
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</tbody>
</table>

Major advantages
The advantages of plasma microwave radiators in comparison with relativistic vacuum-electronics devices are:

• Controlling radiation frequency by varying plasma density.
• Using the beam current beyond its limiting vacuum value.
• Possible to build microwave noise radiators with a frequency band-width of the order of the mean frequency.
**Current research**

Under investigation are:

- Frequency spectrum of the plasma relativistic high-band microwave oscillator for various plasma densities, beam currents, and plasma radii.
- Possibility to design a plasma relativistic microwave amplifier.

**Possible research**

- Improving plasma diagnostics.
- Improving the frequency spectrum diagnostic of a microwave high-power (~ 100 MW) single pulse (>30 ns) with time resolution.
- Designing new methods for preparation of plasma, which is radius-limited and homogeneous along the axis and azimuth.

**Main scientific results**

- For the first time a relativistic plasma microwave oscillator of monochromatic radiation has been built with the power of 40 MW (10% efficiency) and radiation wavelength tuneable from 2 to 3 cm.
- For the first time a relativistic plasma microwave noise oscillator has been built with the power of 250–350 MW, efficiency of ~ 20%. The mean radiation frequency is tuneable from 8 to 17 GHz, and the frequency band width of radiation is of the order of the mean frequency.
- Theory as well as numerical methods have been developed to explain the main regular features of the plasma microwave oscillator operation.

**Basic papers**


**Current financial support**

International Science Foundation and Russian Foundation for Basic Research Grant: Theoretical and experimental investigation of mechanisms of stimulated electromagnetic radiation of dense relativistic electron beams in a spatially bounded plasma.
Scientific and technical personnel
6 researchers and 5 technicians.

Possibilities for international exchange
One foreign specialist for four months a year from Ecole Polytechnique, France, at the set-up.
It is possible to receive one man per year for joint work.
Vacancies for accommodation of foreign scientists: 2 man-year.

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HIGH-POWER MICROWAVE BEAM-PLASMA Interaction System KROT
Institute of Applied Physics

Date of commissioning: 1984.

Field of science
Physics (high-frequency relativistic electronics, propagation of radio waves, physics of low-temperature plasma, space-plasma physics, and physics of the atmosphere).

Field of research
- Generation of pulsed microwave radiation of gigawatt power on the basis of high-current relativistic electron beams.
- Transportation of quasi-optical beams of super-powerful microwave radiation and control of their parameters.
- Free-localised gas discharge in focused beams of super-powerful microwave radiation.
- Interaction of super-strong microwave fields with plasma.
- Laboratory modelling of plasma processes in the atmosphere and outer space, including active experiments.

Main characteristics
The facility consists of two parts: a relativistic microwave generator (KROT-M) and a large-volume vacuum plasma chamber (KROT-P) with the plasma source and set of diagnostics.

KROT-M includes:
- High-current electron accelerator:
  - particle energy, MeV up to 2
  - beam current, kA up to 20
  - current pulse duration, ns up to 200
  - operation regime single pulses
- Set of microwave generators:
  - operating frequency, GHz up to 2
  - output power, GW up to 2
  - microwave pulse duration, ns up to 100

KROT-P includes:
- large-volume vacuum plasma chamber with a magnetic system (length 10 m, diameter 3 m, vacuum to $10^{-6}$ Torr);
- magnetic-field system providing the mirror-machine configuration of a straight magnetic trap with confining magnetic field up to 3 kOe in significantly smaller plasma volume (distance between the magnetic mirrors is 2.5 m, and plasma diameter at the middle of the trap 1.5 m);
• RF generators (inductors) producing plasma with a total power up to 4 MW at the frequency of 5 MHz and pulse duration up to 1.5 ms. Density of the produced plasma may be varied from $10^4$ to $10^{12}$ cm$^{-3}$;
• electrodynamic line for transportation of radiation in the form of a weakly converging Gaussian beam from the microwave generator to the plasma chamber, and a system for focusing the beam that makes it possible to achieve record densities of microwave-power flux in the beam (up to $5 \times 10^7$ W·cm$^{-2}$);
• diagnostics complex (multi-channel energy analysers for electrons, ions, and neutrals; various controlled probes and antennas, multi-channel microwave interferometers, systems for active and passive optical diagnostics, systems of collective scattering of millimeter radiation and radiation of a CO$_2$ laser);
• system for automated acquisition and processing of data.

**Major advantages**

The main feature that makes KROT a unique installation is aggregation in an integral system of microwave generators with record powers, a vacuum plasma chamber of exceptionally large volume to produce highly homogeneous plasma with no interaction with the walls of the chamber, and a wide range of diagnostics. All the elements of the installation are unique. As a whole, the KROT facility has no foreign analogues.

**Current research**

• Development of sources producing microwave radiation of gigawatt power and based on generating and amplifying systems.
• Study of the dynamics of a free localised discharge into the atmosphere that may be used to restore ozone in the upper atmosphere.
• Study of the dynamics of low-hybrid gas breakdown and formation of an ionised region in the field of a coil with current, which models satellite experiments on an active effect on the Earth’s magnetosphere.

**Possible research**

• Investigation of non-linear processes in super-strong microwave fields (non-linear plasma self-transparency, frequency up-conversion and reflection-free propagation of a powerful electromagnetic pulse in the ionised medium, generation of relativistic and ultra-relativistic electrons in gyroresonant interaction with strong RF fields).
• Laboratory modelling of the processes in space plasma and the upper atmosphere (re-switching of magnetic field lines, dynamics of the geomagnetic trap, radioemission of shock waves in the corona of solar wind, collective interaction of radiation with aerosol plasma, etc.).
• Laboratory tests and adjustment of on-board equipment and antenna units of artificial satellites and rockets.

**Main scientific results**

A series of microwave generators operating in the cm wavelength band with output power up to 2 GW was designed on the basis of spatially distributed electrodynamic systems using efficient methods for coherence of the output radiation.
For the first time the nanosecond microwave discharge in various gases was experimentally studied when generated by a super-strong field of the wave beam, in which the oscillatory energy 1.2–3.5 keV of electrons significantly exceeded the potential of atom ionisation.

A series of experiments on modelling the antenna radiation in magnetosphere plasma demonstrated highly efficient energy deposit into plasma when a coil with current served as the antenna. The experiments showed the possibility of producing strong and easily controlled plasma, of generating intense fluxes of accelerated electrons and of exciting electromagnetic whistler waves efficiently.

A world-first study of the dynamics of the evolution of the microwave discharge on pure dielectric targets (glass, organic glass, teflon) was performed at radiation intensity up to 25 MW·cm$^{-2}$ in a quasi-optical beam of electromagnetic waves. It was shown that the discharge plasma may serve as a source of powerful UV and x-ray radiation.

The experiments of air breakdown with nanosecond microwave radiation under pressures corresponding to heights of 15–35 km demonstrated predominant formation of ozone (accompanied by minimum formation of nitrides). Due to low energy loss for ozone formation (10–50 eV per molecule), we propose to use a nanosecond microwave discharge in the atmosphere to restore ozone in the region of local ozone “holes”.

**Basic papers**


**Current financial support and co-operative projects**


ISF Grants: NR 86000 and NR 8X000.

Joint project with Thomson-Shorts-Systèmes (France): Parametric Study of a High-Power 10 GHz TWA
Scientific and technical personnel
18 researchers and 20 technicians.

Possibilities for international exchange
Possibilities for foreign scientists to work at the facility: five man-year.
Vacancies for accommodation of foreign scientists: one man-year.

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GENERATOR OF POWER ELECTRICAL PULSES GIT-16
High-Current Electronics Institute

The device is a system uniting 16 modules. The GIT-4, a pilot four-module device has been in operation since 1990. The basic device now in operation consists of 8 modules.

Field of science
Physics (physical and technical problems of power, electro-physics and electrical power).

Field of research
The device is designed for experimentation at the terawatt level. The aim is to develop a new type of pulsed power generator, matching the generator circuit to a load, measuring the pulse parameters, etc.

Main characteristics
Energy storage (8-module construction), MJ up to 4
Current of an intermediate inductive store, MA up to 5
Duration of the current rise, $\mu$s 1.2

Major advantages
The idea of the generator is to charge directly inductive storage from the Marx generators, excluding the conventional forming-water-line technology. A key element of the GIT-16 is the plasma opening switch (POS), which delivers energy into the load. The POS of GIT-16 operates at 5 MA current rising in $1.2 \mu$s. The ACE-4 installation at the Maxwell Labs, operating at 4 MA current, is the world's closest analogue to GIT-16.

- The high-current POS with a microsecond conduction time reduces significantly the total cost of new multi-module generators. That is why the GIT-16 is used for joint experiments on POS physics in collaboration with foreign scientists.

Possible research
- The GIT-16 device can be used to investigate production of dense high-temperature plasma emitting high-power pulsed bremsstrahlung x-radiation. While operating in a liner load mode with GIT-16 provides, at optimum conditions, as much as 200 kJ of the kinetic energy for a collapsing shell.
• The GIT-16 device was designed to generate high-power nanosecond pulses to perform investigations in z-pinch plasma physics as well as to study under laboratory conditions the resistivity of some equipment to irradiation by high-power x-ray pulses.

**Main scientific results**

Experiments have demonstrated the working capacity of the plasma opening switch with a conduction time of the order of \(1 \mu s\) for switching a current over 5 MA from the inductive energy store into a load of the liner type. This allows the “Marx generator–inductive energy store–plasma opening switch–load” concept to be used to develop of super-powerful pulsed generators based on a new principle which does not require the traditional costly water-line technology.

**Scientific and technical personnel**

4 researchers and 5 technicians.

**Possibilities for international exchange**

The Institute has experience in international co-operation with several research institutions in the United States, France, the United Kingdom, and China and it is ready to consider proposals of joint research from any interested organisations.

The working and living terms for foreign specialists can be specified by a concrete co-operation agreement.

**General information**

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