A high harmonic gyrotron with an axis-encircling electron beam and a permanent magnet

著者	IDEHARA Toshitaka, OGAWA Isamu, MITSUDO Seitaro, IWATA Yousuke, WATANABE Satoru, ITAKURA Yutaka, OHASHI Ken, KOBAYASHI Hideki, YOKOYAMA Tomonori, ZAPEVALOV Vladimir E, GLYAVIN Mikhail Yu, KUFTIN Andrey N, MALYGIN Oleg V, SABCHEVSKI Svilen P
journal or publication title	IEEE Transactions on Plasma Science
volume	32
number	3
page range	903-909
year	2004-06
URL	http://hdl.handle.net/10098/1603

A High Harmonic Gyrotron With an Axis-Encircling Electron Beam and a Permanent Magnet

Toshitaka Idehara, Isamu Ogawa, Seitaro Mitsudo, Yousuke Iwata, Satoru Watanabe, Yutaka Itakura, Ken Ohashi, Hideki Kobayashi, Tomonori Yokoyama, Vladimir E. Zapevalov, Mikhail Yu. Glyavin, Andrey N. Kuftin, Oleg V. Malygin, and Svilen P. Sabchevski

Abstract—A gyrotron with an axis-encircling electron beam is capable of high-frequency operation, because the high-beam efficiency is kept even at high harmonics of the electron cyclotron frequency. We have designed and constructed such a gyrotron with a permanent magnet. The gyrotron has already operated successfully at the third, fourth, and fifth harmonics. The frequencies are 89.3, 112.7, and 138 GHz, respectively, and the corresponding cavity modes are TE_{311} , TE_{411} , and TE_{511} . The permanent magnet system is quite novel and consists of many magnet elements made of NbFeB and additional coils for controlling the field intensities in the cavity and electron gun regions. The magnetic field in the cavity region can be varied from 0.97 to 1.18 T. At the magnetic field intensities, the output powers at the third and the fourth harmonics are 1.7 and 0.5 kW, respectively. The gyrotron is pulsed, the pulse length is 1 ms and the repetition frequency is 1 Hz. The beam energy is 40 kV and the beam current is 1.2–1.3 A. Beam efficiencies and emission patterns have also been measured. In this paper, the experimental results of the gyrotron are described and compared with computer simulations.

Index Terms—Axis-encircling electron beam, gyrotron, high harmonic, permanent magnet.

I. INTRODUCTION

THE development of gyrotrons is being advanced in two ways. One is the development of high-power, millimeter-wave gyrotrons. At the present time, a gyrotron with a diamond window has achieved 2 MW output power at 170 GHz in a pulse several seconds long [1]. Such high-power gyrotrons are being used for the electron cyclotron heating of fusion plasmas. The other is the development of high-frequency, medium-power gyrotrons as millimeter-to-submillimeter-wave radiation sources for a broad range of applications.

Manuscript received July 22, 2003; revised November 13, 2003. This work was supported in part by a Grant in Aid from the Japanese Society for Promotion of Science (JSPS) and carried out in the framework of the collaboration among five institutions in Japan, Russia, and Bulgaria.

T. Idehara, S. Mitsudo, S. Watanabe, and Y. Itakura are with the Research Center for Development of Far-Infrared Region, Fukui University, Fukui 910-8507, Japan (e-mail: idehara@fir.fukui-u.ac.jp).

I. Ogawa is with the Cryogenic Laboratory, Faculty of Engineering, Fukui University, Fukui 910-8507, Japan.

Y. Iwata was with the Research Center for Development of Far-Infrared Region, Fukui University, Fukui 910-8507, Japan. He is now with Mitsubishi Electric Company, Hyogo-ken 670-0993, Japan.

K. Ohashi, H. Kobayashi, and T. Yokoyama are with Shin-Etsu Chemical Company, Ltd., Fukui 915-8515, Japan.

V. E. Zapevalov, M. Yu. Glyavin, A. N. Kuftin, and O. V. Malygin are with the Institute of Applied Physics, Russian Academy of Science, Nizhny Novgorod 603600, Russia.

S. P. Sabchevski is with Institute of Electronics, Bulgarian Academy of Science, Sofia 1784, Bulgaria.

Digital Object Identifier 10.1109/TPS.2004.827614

Our gyrotrons developed in the Research Center for Development of Far-Infrared Region at Fukui University (FIR FU) belong to the second type. In FIR FU, we have developed the Gyrotron FU Series which consists of nine gyrotrons. The gyrotron series has achieved frequency tunability over a wide range (from 38 to 889 GHz). With output powers ranging from several tens of watts to several tens of kilowatts. The highest frequency corresponds to a wavelength of 337 μm . This is a current record for high-frequency operation of gyrotron [2].

In order to develop such high-frequency gyrotrons, we usually require high magnetic fields generated by superconducting magnets [3] and/or operation at high harmonics of the electron cyclotron frequency [4], [5]. For FU IVA, for example, [6] a 17 T superconducting magnet is used. Operation with a superconducting magnet is complicated, because we need to transfer liquid helium from a container to cryostat, recover the evaporated helium, and liquefy it and so on.

Recently, we have developed a high harmonic gyrotron with an axis-encircling electron beam and a permanent magnet instead of a superconducting magnet. Operation is much simplified [7], but the field intensity is quite low compared with a superconducting magnet. It is only around 1 T. We have to use higher harmonic operation in order to obtain high frequencies. A gyrotron with an axis-encircling electron beam [a so-called large orbit gyrotron (LOG)] is capable of n th harmonic operation, employing the TE_{n11} cavity mode. In this case, the frequency of electromagnetic wave f is equal to n times the electron cyclotron frequency f_c and the axis-encircling electron beam feels n cycles of alternating electric field during one the electron gyration, and the interaction between an electron and electromagnetic wave is optimized and highly efficient operation is expected. In addition, the mode competition is minimal, because only the TE_{n11} cavity mode is excited when $f = nf_c$ [8].

In the case of the conventional gyrotron, higher harmonic operation is difficult to realize. The Gyrotron FU Series easily achieved second harmonic operations but third harmonic operation was very rare [9]. Efficiency decreases with harmonic number. On the other hand, in the case of LOG, higher harmonic operation ($n = 3, 4, 5$) is easily excited [10], [11].

In this paper, the design of a LOG with a permanent magnet, construction and the results of preliminary tests are described.

II. OPERATION MECHANISM AND ADVANTAGES OF LOG

The LOG is characterized by the trajectory of the electron beam in the cavity it is known as an “axis-encircling electron

Fig. 1. Schematic drawing of the LOG device.

beam." A beam electron gyrates around the center axis of the cavity [12], while in a conventional gyrotron, a beam electron rotates around a gyration center located on a concentric cylinder of the cavity. When we use an axis-encircling electron beam and the TE_{nm1} cavity mode, the interaction between the electron beam and the high-frequency electromagnetic wave takes place at the n th harmonic. Therefore, we can expect good mode selection, because mode competition with lower harmonics does not occur. This is an important advantage, because mode competition is the most severe problem in conventional high harmonic gyrotrons.

In the LOGs developed in the past, the axis-encircling electron beam is generated by the nonadiabatic effect of the cusp field [13] or the electron cyclotron resonance acceleration of electrons in along the axis of the gyrotron [14]. In both cases, the resulting electron beams have large values of ripple, that is, the displacement of guiding center from the center axis of a resonant cavity is large. This effect reduces the operation efficiency and increases the starting current for high harmonic operation.

Instead of such methods, we are using a novel system of electron gun and magnetic field that gradually changes direction to generate an axis-encircling electron beam with small ripple. As a result, we have successfully achieved third and fourth harmonic operation using rather small beam current [15].

III. EXPERIMENTAL APPARATUS AND PROCEDURES

Fig. 1 shows a schematic drawing of the LOG with the permanent magnet.

Fig. 2. Structure of the permanent magnet. The magnetization of each element is shown by an arrow. Dimensions are in millimeters.

Fig. 3. Profile of the magnetic field intensity along the center axis.

A. Magnet System

The permanent magnet consists of many elements of NdFeB as shown in more detail in Fig. 2. The structure is carefully designed to generate an appropriate profile of magnetic field on the center axis of the magnet system. Each NdFeB layer is divided into 12 elements in the azimuthal direction. An arrow indicates the direction of magnetization of each layer. The resulting field profile along the center axis is shown in Fig. 3. The measured maximum field intensity is 1.0729 T and the uniformity in the region indicated by "A," the cavity region, is better than 2%. The magnet system has an additional coil in the electron gun region to control the profile of magnetic field there. The coil consists of ten layers, each of ten turns. The coil current can be fixed at values between -13 A and $+13$ A. The additional field intensity near the cathode is 7×10^{-4} T/A.

B. Gyrotron Tube

Fig. 4 shows the structure of the LOG tube. Electrons are emitted from a circular area on the cathode surface made of LaB₆ and accelerated by the potential difference between the cathode and the body of the gyrotron. Electrons feel gradually increasing magnetic field and get vertical energy. Finally, an axis-encircling electron beam is formed and injected into the cavity. This may of producing the axis-encircling beam is quite

Fig. 4. Schematic drawing of the gyrotron tube.

Fig. 5. Profile of cavity I.

different from other LOGs [13], [14]. The whole tube is demountable, so, we can change every component including the cavity, window, and electron gun.

For n th harmonic operation, the cavity should be designed so that the resonant frequency of the TE_{n11} cavity mode is equal to n times the electron cyclotron frequency. Fig. 5 shows the detailed dimensions of the cavity, cavity I, which was optimized for fourth harmonic operation. In this cavity, TE_{411} cavity mode is excited near the field intensity of 1 T.

An additional coil is installed in the cavity region to control the field intensity there. The coil consists of 7 layers and a total of 74 windings. This coil is pulsed. The pulse width is 18 ms and repetition rate is 1 Hz. The coil current can be changed from -20 A to $+20$ A and the additional field intensity at the cavity is 6.98×10^{-3} T/A.

The inside of the tube is pumped out by an ion pump and a turbo molecular pump. The pressure is kept at 10^{-7} torr. The electromagnetic wave generated in a cavity is transmitted along a circular and is emitted from a boron nitride vacuum window.

C. Experimental Procedure and Conditions

The gyrotron operation is in pulsed. The typical pulse width is 1 ms and the used repetition frequency in abstract is 1 Hz. The maximum acceleration voltage and beam current are 40 kV and 1.5 A, respectively.

A pyroelectric detector is used to monitor the gyrotron output. In order to observe an emission pattern, an array of pyroelectric detectors is mechanically swept over an area about one meter above the output window.

The absolute value of output power is measured calorimetrically by a water load, in which a comparison is made with heating by a 1 W electric heater. Frequency measurement

Fig. 6. Computed efficiencies as a function of magnetic field intensity B.

is by a cylindrical cavity frequency meter or a Fabry–Perot interferometer.

IV. EXPERIMENTAL RESULTS

We have already completed the preliminary tests of two cavities. Cavity 1 was optimized for fourth harmonic operation using the TE_{411} mode, while cavity 2 was optimized for third harmonic using the TE_{311} mode. The test results are as follows.

A. Cavity 1 for Fourth Harmonic Operation

As described in the previous section, in the TE_{411} cavity made cavity 1 was designed for the fourth harmonic operation.

In Fig. 6, computed efficiency as a function of magnetic field intensity at the cavity is presented. [15] The parameter g is the pitch factor of the beam electrons. From these results, it is expected that the fourth harmonic operation will be optimized near 1.08 T. The efficiency should be less than 1%.

In Fig. 7, a set of typical experimental results are shown. It is seen that the operation is stable throughout the pulse. The pulse length is about 1 ms and repetition rate is 1 Hz. The acceleration voltage is 40 kV and the beam current is around 1.2 A. The output power was 0.47 kW. The corresponding efficiency is about 0.98%. The frequency measured by a frequency meter was 112.696 GHz.

The output power is plotted in Fig. 8 as a function of acceleration voltage V and in Fig. 9 as a function of the magnetic field intensity B . The parameter is the current I_{gc} in one of the coil layers installed at the electron gun. When I_{gc} is changed, the pitch factor of the beam electron g changes. This results in a change of efficiency. In the both figures, the corresponding electron cyclotron frequency f_c is indicated above the graphs. Both results are similar to the computer simulation results shown in Fig. 6.

Fig. 10 shows an emission pattern measured 1030 mm above the output window. A kind of standing wave structure in the azimuthal direction is seen. This means a counterrotating TE_{411}^-

Fig. 7. Observed patterns on an oscilloscope for fourth harmonic operation using the TE_{411} cavity mode. Output power (P), acceleration voltage (V), and beam current (I) are shown.

Fig. 8. Output power P as functions of cyclotron frequency f_c (acceleration voltage Vb is varied.).

mode coexists with a rotating mode TE_{411}^+ . From the observed emission pattern, the fractions of the counterrotating and rotating modes were estimated to be 5% and 95%. The appearance of the counterrotating mode was not expected and we are studying why the mode is present.

Third harmonic operation in the TE_{311} mode has also been achieved by cavity 1 at a slightly higher field intensity. Fig. 11 shows the output power P as a function of magnetic field intensity B . There are several peaks of output power. The three peaks appearing from 1.15 to 1.2 T are third harmonic operation due to excitation of the TE_{311} , TE_{312} , and TE_{313} cavity modes. The measured frequency for the TE_{311} mode is 89.3 GHz. Frequencies for TE_{312} and TE_{313} are slightly higher. The two peaks appearing below 1.1 T correspond to the fourth harmonic operation due to excitation of the TE_{411} and TE_{412} modes.

The output power for the mode TE_{311} was 1.7 kW. The efficiency was 3.3%.

Fig. 9. Output power P as a function of the cyclotron frequency f_c (field intensity B is varied.).

Fig. 10. Emission pattern observed at 1030 mm above the output window for fourth harmonic operation of cavity I in the TE_{411} cavity mode.

Fig. 11. Output power as a function of magnetic field intensity.

Cavity I has also achieved the fifth harmonic operation with the excitation of the TE_{511} cavity mode. However, the output power is rather low, of the order of 10 W. The frequency in this case measured by a Fabry–Perot interferometer was 138 GHz. Fig. 12 shows one of measured Fabry–Perot interferometer patterns. The frequency was determined from the spacing between the peaks.

Fig. 12. A Fabry-Perot interferometer pattern for the fifth harmonic operation of cavity I in the TE_{511} cavity mode. $V_b = 40$ kV, $I_b = 1.2$ A, $B = 1.037$ T, $\lambda = 2.17$ mm, and $f = 138$ GHz.

Fig. 13. Output power as a function of cathode voltage for operation at third harmonic of the cyclotron frequency of cavity 2 in the TE_{311} cavity mode.

B. Cavity 2 for Third Harmonic Operation

Cavity 2 was designed for third harmonic operation in the TE_{311} cavity mode. The radius and length were 2.36 and 50 mm, respectively.

In Fig. 13, the output power P of third harmonic as a function of the acceleration voltage V_b is shown with the current in one of the electron gun coil layers I_{gc} as a parameter. When V_b is changed, the electron cyclotron frequency f_c changes as well. The range of f_c where the fourth harmonic operation occurs broadens as I_{gc} is increased. The maximum power is 2.5 kW and the corresponding efficiency is 6.25%. The increase of the pitch factor as I_{gc} is increased affects the efficiency and the output power. The measured frequency is 84.88 GHz.

Fig. 14 shows an emission pattern for this mode. A feature of pure TE_{311} mode appears in the emission pattern. It is a manifestation of good mode selection in LOG. This is one of important advantages of LOG for development of high harmonic gyrotron.

V. CONCLUSION

We have constructed a large orbital gyrotron (LOG) with a permanent magnet system. The electron gun and the profile of

Fig. 14. Emission pattern observed at 1030 mm above the output window for third harmonic operation of cavity 2 in the TE_{311} cavity mode.

the magnetic field were optimized for the generation of a high-quality axis-encircling electron beam with a small ripple and large pitch factor.

Experimental tests of two cavities were carried out successfully. Cavity 1 which was optimized for the fourth harmonic operation in the TE_{411} cavity mode, delivered output power of 0.47 kW, corresponding to an efficiency of 0.96% and a frequency of 112.7 GHz. We have cavity I also operated at the third harmonic with output power is 1.7 kW, corresponding to an efficiency of 3.3% and a frequency of 89.3 GHz. Cavity 2 which was optimized for the third harmonic operation in the TE_{311} cavity mode. Delivered output power of 2.5 kW, corresponding to an efficiency of 6.25% and a frequency of 84.88 GHz was typically in 40 kV. Operation was pulsed. The pulse width was 1 ms and repetition rate was 1 Hz. Acceleration voltage and beam current are 1.2 to 1.3 A.

Cavity 1 also operated at fifth harmonic in the TE_{511} cavity mode. With rather low output power, of the order of 10 W and a frequency of 138 GHz.

Operations at the third, the fourth, and the fifth harmonics were achieved under acceleration voltage of only 40 kV. At the present, the frequency is ranged in millimeter-wave length region. In the future, we plan to construct a LOG with a superconducting magnet system in order to increase the frequency beyond 1 THz.

REFERENCES

- [1] B. Piosczyk, O. Braz, G. Dammertz, C. T. Iatrou, S. Kern, M. Kuntze, G. Michel, A. Moebius, and M. Thumm, "Operation of a coaxial gyrotron with a dual RF-beam output," in *Dig. 22nd Int. Conf. Infrared and Millimeter Waves*, H. E. Freubd, Ed., Wintergreen, VA, July 1997, pp. 114–115.
- [2] T. Idehara, S. Mitsudo, S. Sabchevski, M. Glyavin, and I. Ogawa, "Gyrotron FU Series—current status of development and applications," *Vacuum*, vol. 62, p. 123, 2001.
- [3] T. Idehara, T. Tatsukawa, I. Ogawa, H. Tanabe, T. Mori, S. Wada, and T. Kanemaki, "Development of a second cyclotron harmonic gyrotron operating at 0.8 mm wavelength," *Appl. Phys. Lett.*, vol. 56, p. 1743, 1990.
- [4] T. Idehara, T. Tatsukawa, S. Matsumoto, K. Kunieda, K. Hemmi, and T. Kanemaki, "Development of high frequency, cyclotron harmonic gyrotron oscillator," *Phys. Lett. A*, vol. 132, p. 344, 1988.

- [5] T. Idehara, T. Tatsukawa, I. Ogawa, H. Tanabe, T. Mori, S. Wada, G. F. Brand, and M. H. Brennan, "Development of a second cyclotron harmonic gyrotron operating at submillimeter wavelengths," *Phys. Fluids*, vol. B4, p. 267, 1992.
- [6] T. Idehara, I. Ogawa, S. Mitsudo, M. Pereyaslavets, N. Nishida, and K. Yoshida, "Development of frequency tunable, medium power gyrotrons (Gyrotron FU Series) as submillimeter wave radiation sources," *IEEE Trans. Plasma Sci.*, vol. 27, p. 340, 1999.
- [7] T. Kikunaga, H. Asano, Y. Yasojima, F. Sato, and T. Tsukamoto, "A 28 GHz gyrotron with a permanent magnet system," *Int. J. Electron.*, vol. 79, p. 655, 1995.
- [8] M. Glyavin, S. Sabchevski, T. Idehara, I. Ogawa, S. Mitsudo, K. Ohashi, and H. Kobayashi, "Numerical analysis of weakly relativistic large orbit gyrotron with permanent magnet system," *Int. J. Infrared Millim. Waves*, vol. 21, p. 1211, 2000.
- [9] T. Idehara, T. Tatsukawa, I. Ogawa, S. Wada, K. Yoshizue, F. Inoue, and G. F. Brand, "Single mode operation of a submillimeter wave gyrotron at the third harmonic resonance," *Phys. Fluids*, vol. B4, p. 769, 1992.
- [10] S. Sabchevski, T. Idehara, I. Ogawa, M. Glyavin, and K. Ohashi, "Simulation of a high harmonic gyrotron with axis-encircling electron beam and permanent magnet," *Int. J. Infrared Millim. Waves*, vol. 23, p. 675, 2002.
- [11] S. Sabchevski, T. Idehara, I. Ogawa, M. Glyavin, S. Mitsudo, K. Ohashi, and K. Kobayashi, "Computer simulation of axis-encircling beams generated by an electron gun with a permanent magnet system," *Int. J. Infrared Millimeter Waves*, vol. 21, p. 1191, 2000.
- [12] S. Sabchevski, T. Idehara, M. Glyavin, S. Mitsudo, I. Ogawa, K. Ohashi, and K. Kobayashi, "Design of a large orbit gyrotron with a permanent magnet system," *Vacuum*, vol. 62, p. 133, 2001.
- [13] K. Yokoo, M. Iguchi, N. Sato, and I. Ishihara, "Wide-band frequency tunable single mode gyrotron," in *Digest of 23rd Int. Conf. on Infrared and Millimeter Waves*, T. J. Parker and S. R. P. Smith, Eds. Colchester, U.K., Sept. 1998, pp. 317–318.
- [14] D. B. McDermott, N. C. Luhmann, A. Kupiszewski, and H. R. Jory, "Small-signal theory of a large-orbit electron-cyclotron harmonic maser," *Phys. Fluids*, vol. 26, p. 1936, 1983.
- [15] V. Zapevalov, T. Idehara, S. Sabchevski, K. Ohashi, V. Manuilov, M. Glyavin, S. Kornishin, A. Kufitin, V. Lygin, O. Malygin, M. Moiseev, A. Pavel'ev, V. Tzalolikhin, N. Zavolsky, H. Kobayashi, T. Yokoyama, I. Ogawa, S. Mitsudo, T. Kanemaki, Y. Iwata, and H. Hoshizuki, "Design of a large orbit gyrotron with a permanent magnet system," *Int. J. Infrared Millim. Waves*, vol. 24, p. 253, 2003.

Toshitaka Idehara was born in Ibaraki, Japan, on April 15, 1940. He received the B.S. degree in mathematics and the M.S. and D.S. degrees in physics from Kyoto University, Kyoto, Japan, in 1963, 1965, and 1968, respectively.

After graduating from Kyoto University, he joined Fukui University, Fukui, Japan, and was a Lecturer from 1968 to 1970 and an Associate Professor from 1970 to 1990. During this term, he worked in fundamental plasma physics. After 1979, his interest was directed toward the development of high-frequency gyrotrons. From 1990 to 1999, he was a Professor in the Applied Physics Department, Fukui University, and from 1992 to 1999, he was the Head of the Laboratory for Application of Superconducting Magnet, Fukui University. Since 1999, he has been a Professor and the Director of the Research Center for Development of Far-Infrared Region, Fukui University. His current research interests include development of frequency tunable, submillimeter wave gyrotrons, and their applications to plasma diagnostics and material physics.

Isamu Ogawa was born in Hamada, Japan, on August 15, 1955. He received the B.S. and M.S. degrees in physics from Ehime University, Matsuyama, Japan, in 1979 and 1981, respectively, and the D.S. degree in physics from Nagoya University, Nagoya, Japan, in 1987.

After graduating from Nagoya University, he joined Fukui University, Fukui, Japan. From 1989 to 1991, he was a Research Associate. Since 1991, he has been an Associate Professor in the Cryogenic Laboratory, Fukui University. His interest is directed to the system converting the output of a high-frequency gyrotron into a Gaussian beam and its application to the plasma scattering measurement.

Seitaro Mitsudo was born in Okayama, Japan, on April 17, 1965. He received the B.S., M.S., and D.S. degrees in physics from Okayama University, Okayama, Japan, in 1989, 1991, and 1994, respectively.

After graduating from Okayama University, he joined the Institute for Materials Research, Tohoku University, Sendai, Japan. From 1994 to 1998, he was a Research Associate. During this term, he worked in high-field magnetism. From 1998 to 1999, he was with the Applied Physics Department, Fukui University, Fukui, Japan, as an Associate Professor. Since 1999, he has been an Associate Professor with the Research Center for Development of Far-Infrared Region, Fukui University. His current research interests include development of frequency tunable, submillimeter wave gyrotrons, and their application for submillimeter wave ESR.

Yousuke Iwata was born in Aichi, Japan, on January 8, 1979. He received the B.S. and M.S. degrees in engineering from Fukui University, Fukui, Japan, in 2001 and 2003, respectively.

After graduating from Fukui University, he joined Mitsubishi Electric Company, Hyogo-ken, Japan, as a Researcher. His research interests include the development of submillimeter-wave gyrotrons.

Satoru Watanabe was born in Aichi, Japan, on July 28, 1980. He received the B.S. degree in engineering from Fukui University, Fukui, Japan, in 2003, where he is working toward the M.S. degree in engineering.

His research interests include the development of submillimeter-wave gyrotrons.

Yutaka Itakura was born in Iwami, Japan, on November 23, 1980. He received the B.S. degree in engineering from Fukui University, Fukui, Japan, in 2003, where he is working toward the MS. degree in engineering.

His research interests include the development of submillimeter-wave gyrotrons.

Ken Ohashi received the B.S., M.S., and Ph.D. degrees from Tohoku University, Sendai, Japan, in 1976, 1978, and 1991, respectively.

He joined the Magnetic Materials Research Center, Shin-Etsu Chemical Company, Ltd., Fukui, Japan, in 1978. From 1999 to 2001, he was a Visiting Professor at Fukui University, Fukui, Japan. He has been engaged in research on magnetic materials, magnetic circuit applications, and magnetic field analysis.

Mikhail Yu. Glyavin was born in Nizhny Novgorod (former Gorky), Russia, on February 14, 1965. He received the degree in microwave electronics and the Ph.D. degree in physics from the Gorky Polytechnical Institute, Gorky, U.S.S.R., in 1988 and 2000, respectively.

Since 1988, he has been working at the Institute of Applied Physics of the Academy of Sciences of the U.S.S.R. (from 1991—Russian Academy of Sciences), where he is engaged in the development of high-power gyrotrons for nuclear fusion. His dissertation was focused on studies of gyrotrons and more specifically on methods for increasing the efficiency. From 1999 to 2002, he was a Visiting Researcher at the FIR FU Center, Fukui, Japan. His research interests are in the field of the theoretical and experimental investigations of various gyro-device, including gyrotrons and their application to materials processing.

Hideki Kobayashi was born in Japan in 1967. He received the B.E. and M.E. degrees from Kanazawa University, Kanazawa, Japan, in 1990 and 1992, respectively.

In 1992, he joined Shin-Etsu Chemical Company, Ltd., and works at the Magnetic Materials Research Center, Fukui, Japan. He has been engaged in research on magnetic circuit application and magnetic field analysis.

Andrey N. Kuftin was born in Kstovo, Gorky region, Russia, on August 1, 1963. He received the degree in radiophysics from the Lobachevsky State University, Gorky, U.S.S.R., in 1985.

Since 1985, he has been with the Institute of Applied Physics of the Academy of Sciences of the U.S.S.R. (from 1991—Russian Academy of Sciences), where he is engaged in the development of high-power gyrotrons for nuclear fusion plasma heating and technological gyrotrons for material processing.

Tomonori Yokoyama was born in Japan in 1975. He received the B.S. and M.S. degrees from Hokkaido University, Sapporo, Japan, in 1997 and 1999, respectively.

He joined Shin-Etsu Chemical Company, Ltd., and works at the Magnetic Materials Research Center, Fukui, Japan. He has been engaged in research on magnetic circuit applications and magnetic field analysis.

Oleg V. Malygin was born in Gorky, Russia, on October 2, 1935. He received the degree in radiophysics from the Lobachevsky State University, Gorky, U.S.S.R., in 1958.

From 1958 to 1965, he was a Member of the Technical Staff at the Gorky Radio Physical Research Institute. He joined the Gorky Research Institute "Salyut" in 1965 and the Institute of Applied Physics, Russian Academy of Sciences, in 1977. From 1965 to 1986, he was Head of the Short-Wavelength Devices Laboratory. Since 1986, he has been a Senior Researcher and is currently engaged in the development of high-power gyrotrons for nuclear fusion plasma heating and technological gyrotrons for material processing, especially in technical investigations.

Vladimir E. Zapevalov was born in Bor, Russia, on November 30, 1949. He received the degree in radiophysics and the Ph.D. degree in physics from the Lobachevsky State University, Gorky, U.S.S.R., in 1972 and 1985, respectively. His dissertation concerned study of mode interaction processes in powerful gyrotrons.

Since 1972, he has been with the Lobachevsky State University, and since 1985, he has been with the Institute of Applied Physics of Russian Academy of Sciences of the U.S.S.R. (from 1991—Russian

Academy of Sciences), where he is engaged in gyrotron development. In particular, his interest is concentrated on the theoretical and experimental investigation of the problem of mode interaction and mode competition in gyrotrons and also on the study of gyrotron helical electron beam properties. In 1995, he became Head of the Gyrotron Laboratory, Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, where the current research projects are the development of high-power gyrotrons for nuclear fusion plasma heating and material processing.

Svilen P. Sabchevski was born in Popovo, Bulgaria, on August 20, 1958. He received the M.Sc. degree in electronic engineering from Saint Petersburg State Electrotechnical University, Saint Petersburg, Russia, in 1984, and the Ph.D. degree in physics from the Bulgarian Academy of Sciences, Sofia, Bulgaria, in 1991.

After his graduation, he joined the Institute of Electronics, Bulgarian Academy of Sciences, where he is an Associate Professor in the Electron Beam Technologies Laboratory. From 1999 to 2000, he was an Associate Professor and in 2002–2003 a Visiting Professor in the Research Center for Development of Far-Infrared Region, Fukui University, Fukui, Japan. His current research interests are in the fields of physics and applications of intense electron beam, computer-aided design of electron-optical systems, and vacuum electron devices. In recent years, he has been involved in several research projects for development of millimeter- and submillimeter-wave gyrotrons.