Submitted to OSA Topical Meeting Optical Terahertz Science and Technology, March 14-16, 2005, Orlando FL.

Compact tunable p-Ge laser

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Abstract: Innovations in intracavity wavelength selection in the range 1.5 to 4.2 THz and compact control electronics enable a commercial application for a far-infrared p-Ge laser.

OCIS Codes: (140.3070) Infrared and far-infrared lasers; (140.5960) Semiconductor lasers.

1. Introduction

The far-infrared p-Ge laser has been extensively studied since its invention 20 years ago [1]. Despite high peak power (~1 W), broad tuning range (1.5 – 4.2 THz), high spectral density [2], and possibility of picosecond pulse generation [3], the p-Ge laser has found only limited application in academic research[4,5] and no commercial application until now. This can be attributed in part to the special requirements for control, excitation, and cryogenic cooling, for which no specifically-tailored commercial instrumentation has been available. Moreover, wavelength selection has been unpredictable and unreliable, such that a spectrometer has always been required to determine the emitted wavelength. Use of p-Ge lasers has been restricted to a few dedicated laboratories having sufficient resources and expertise to assemble the large variety of general purpose and home-made apparatus required. An independent *ab initio* development of p-Ge laser capability has happened only once in the United States [6]. The various implementations in labs worldwide differ widely and are usually bulky.

During 12-16 October 2004 under commercial contract, Zaubertek delivered and operated a tunable p-Ge laser to the Max Planck Institute for Extraterrestrial Physics (MPE) in Garching, Germany. The purpose was to determine the spectral line shape function and to search for spectral ghosts in the Photodetector Array Camera and Spectrometer (PACS) of the European Space Agency's Herschel Space Observatory. The purpose of this paper is to describe the innovations that made that job possible.

2. Electronics

Significant electronics developments included a high-power pulser based on insulated-gate bipolar transistors (IGBT), a high voltage (HV) power supply tailored to the requirements of the pulser and laser, a superconducting magnet supply, and laser control unit. All four units are compact and lightweight, which allowed them to be checked as personal luggage in two standard suitcases for the trip to Germany. Fig. 1 shows the system setup and operating there.

The HV supply provides 80 W of average power, which is more than adequate for the typical requirements of the p-Ge laser, which emits ~1 μs far-IR pulses at repetition rates of ~30 Hz. A relay drains the storage capacitors housed in the pulser when the HV supply is switched off. A front panel display gives the charging voltage. A two-prong HV connector on the unit back panel interfaces with the HV coaxial input of the pulser via a special cable. The HV supply is housed together with the magnet current supply in a case with dimensions 46 cm x 33 cm x 16 cm for a combined mass of 8.5 kG.

The superconducting-magnet current supply provides up to 40 A of regulated current with an adjustable voltage limit of 1-3 V. In the unlikely case of a magnet quench, this limit prevents thermal damage to the solenoid or excessive boil-off of liquid helium. Both HV and magnet current supplies operate off the same internal power supply, which can accept either 110 or 220 VAC.

The IGBT pulser is a stiff voltage source designed for low impedance resistive loads (3-10 ohm). Each of the two IGBTs in the dual package can switch up to 1200 V x 400 A with a rise and fall time of ~100 ns.

One IGBT is used to apply power to the laser crystal in a ~1 μs flat-topped pulse from 3 μF of capacitance charged by the HV supply. The second IGBT discharges the transmission line. These IGBTs are triggered by the "pulse" and "clamp" signals, respectively, from the laser control unit. The pulser has x100 voltage- and 0.1V/A current-probe outputs on the front panel for monitoring the high-power pulse on an oscilloscope. A relay disconnects the HV input if excessive voltage is applied to prevent damage to the IGBT. The mass of the pulser unit is 3.5 kg and its dimensions are 34 cm x 22 cm x 14 cm. The pulser is powered by 85-264 VAC 50/60 Hz.

The laser control unit puts out "pulse" and "clamp" signals with duration and repetition rate controlled by a front panel keypad with LCD display. The clamp turn-on is delayed 3 ns with respect to the pulse turn-off to ensure that the excitation and discharge IGBTs are never on simultaneously. These pulses are selectable 5 or 8 V into 50 ohm load or 5 V 75 ohm differential. A separate output provides an oscilloscope trigger, which precedes the "pulse" signal by 10 ns. The rise time of all signals is 5 ns. The mass of the unit is 2.5 kg in a 34 cm x 22 cm x 14 cm package, and it is powered by 85-264 VAC 50/60 Hz.

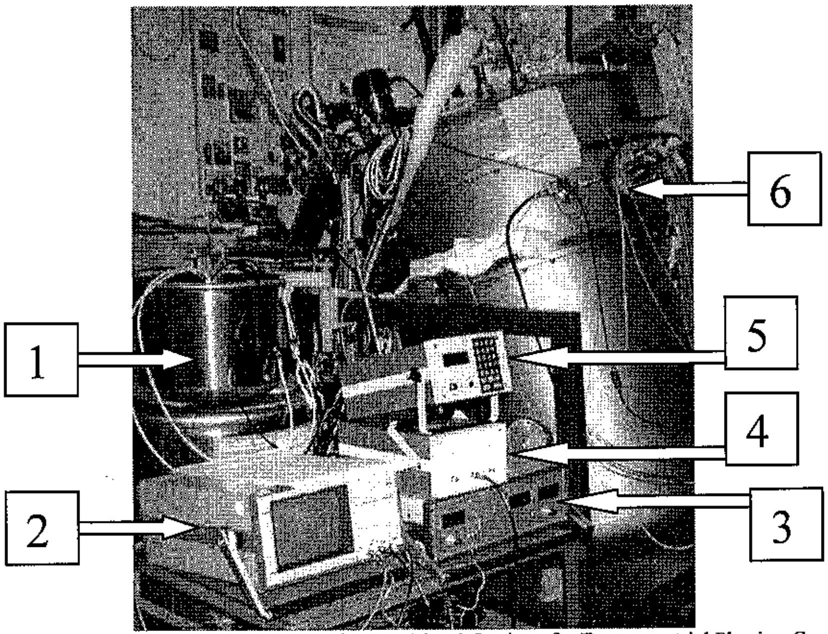

Fig. 1. The Zaubertek p-Ge laser in operation at the Max Planck Institute for Extraterrestrial Physics, Garching Germany. 1) Standard 60-liter liquid-helium storage dewar, which houses the superconducting magnet insert and laser. 2) Oscilloscope for monitoring laser intensity on a Ge:Ga photoconductor and the applied current/voltage pulse. 3) HV and magnet-current supplies; 4) IGBT pulser; 5) Laser control unit. 6) PACS cryostat.

3. Wavelength selection

A reliable and predictable means of intracavity wavelength selection was developed so that an independent spectrometer would not be necessary. This method was based on our previous work with thin Si etalons in the laser cavity[7] but with a passive spacer having gold stripes deposited on one surface added to enhance the selection[8]. A schematic of the construction and some laser spectra collected with a Fourier spectrometer are presented in Fig. 2. The emission lines with this selection method are composed of a few longitudinal modes giving an overall linewidth of ~0.1 cm^{-1}.

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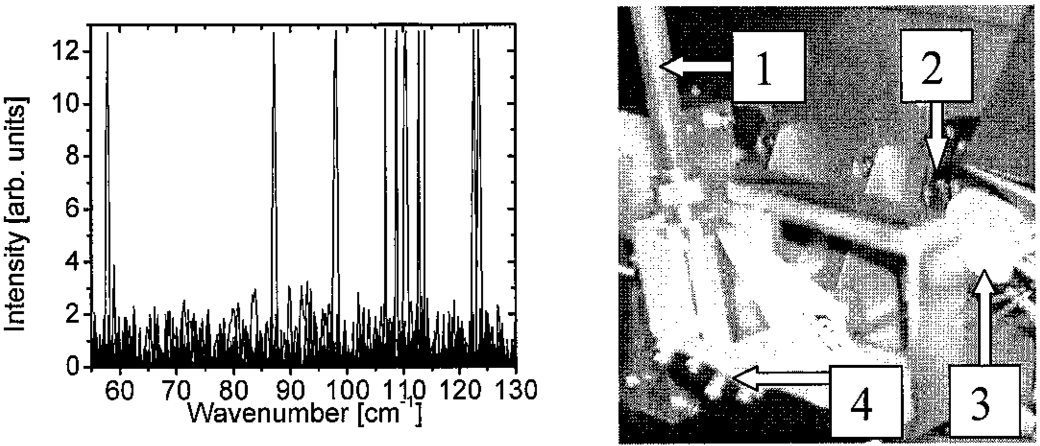

Fig. 2. (left) Emission spectra of the p-Ge laser with wavelength selecting elements. (right) Beam transfer optics: 1) light pipe; 2) PACS window; 3) TPX lens, 4) 90-deg light pipe mirror.

4. Special equipment

Three pieces of apparatus were constructed to facilitate the PACS job. First, a superconducting magnet insert was made to allow adjustable height of the magnet and crystal in a standard 60 liter liquid-helium storage dewar. The insert featured a built-in Ge:Ga photoconductor for monitoring laser signal while providing laser output through a vertically oriented brass light pipe. An advantage of such an insert over a dedicated cryostat is that no vacuum system, transfer of cryogens, precooling, or special training are required. Insertion is done slowly over a period of ~10 minutes resulting in just ~1 liter of liquid-helium blow-off.

Additional sections of light pipe and three 90-deg mirrors were used to lead the THz beam to the PACS entrance window with minimal attenuation in air. One end of the entire light guide is open to the liquid helium bath, which cryopumps the water vapor and purges the tube with He gas. The other end was sealed with a polyethylene window. Two-fold attenuation for the far-IR beam was measured after passage through this additional section of light pipe and turns.

The divergence of the beam at the light-pipe output was measured to be ~20 deg. A TPX lens with 10 cm focal length was cut on a lathe and hand polished to spherical shape in order to collect and focus the beam. With this lens a ~15-fold increase in collected signal was achieved, as measured with a bolometer.

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