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Technical note

Piezo-controlled intracavity wavelength selector for the far-infrared p-Ge laser

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Abstract

An electrically-controlled tunable intracavity frequency selector is demonstrated for the far-infrared p-Ge laser. The tunable laser mirror was driven by a piezo-element inside a liquid helium bath. This design allows very small controllable displacements of the tunable mirror that were impossible in previous mechanical systems. High-resolution spectroscopy of the laser output reveals the nature of mode-hop tuning characteristic for the tuning-element construction used. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

A tunable far-infrared laser is of interest for molecular spectroscopy, especially in the underexplored fingerprint region of low-frequency vibration and high-frequency rotation. Such a system may find practical use in emissions monitoring and detection of explosives, illicit drugs, or chemical warfare agents. A possible fundamental science application is laser spectroscopy of functionally important isomerization transitions of biological molecules. Far-infrared p-Ge lasers would be particularly well suited for intracavity laser absorption spectroscopy of semiconductors and semiconductor heterostructures at cryogenic temperatures, because p-Ge lasers themselves require cryogenic cooling. At present, p-Ge lasers appear to have more promise for tunable far-infrared laser applications than alternatives such as gas lasers, which lack wide continuous tunability, or free-electron lasers, which are impractical because of size and cost.

The p-Ge laser operates in the range 50–140 cm^{-1} (70–200 μm or 1.5–4.2 THz) [1]. Previous wavelength selection and tuning was performed using a manually adjustable intracavity selector element [2,3]. It has been shown that with such selectors the active cavity finesse can exceed unity [4]. For practical spectroscopic applications, an electrically activated selector is desired to obtain precise and repeatable control and to eliminate cumbersome manual linkages, which thermally load the cooling system and introduce mechanical

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hysteresis. A piezo-activated tuning element is demonstrated here.

2. Experiment

A schematic of the laser is shown in Fig. 1. The active crystal was cut from monocrystalline Ge doped with Ga to a concentration $N_A = 7 \times 10^{13}$ cm^{-3} and was 28.0 mm long with cross-sectional area 4.5×7.2 mm^2. The ends of the crystal were polished and made parallel to each other within 30″ accuracy and within 100 nm flatness. An electric field was generated in the crystal by applying voltage using a thyratron pulser to Al contacts, which were evaporated on opposite lateral sides of the crystal. The magnetic field was supplied by a superconducting solenoid. A 7.85 mm long Si spacer isolated the tuning element from the high-voltage contacts. The output mirror was of smaller diameter (4 mm) than the laser crystal to allow output of radiation.

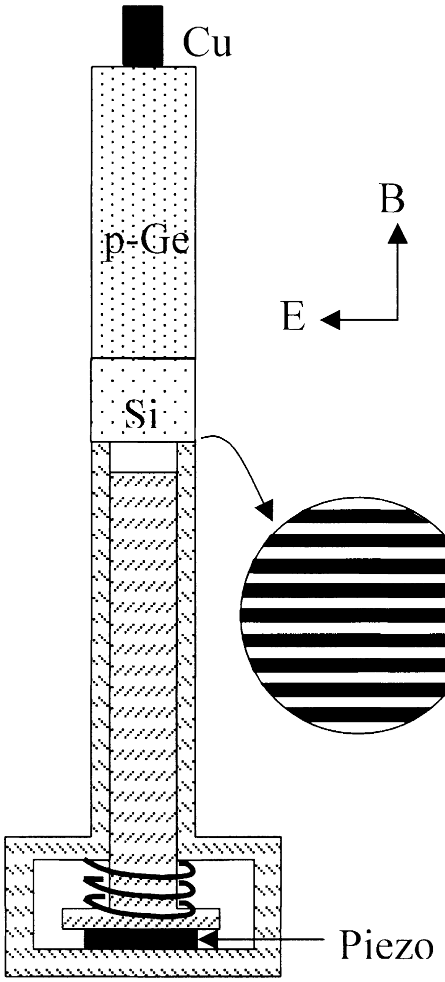

Fig. 1. Schematic of p-Ge laser with piezo-controlled tuning element.

The lamellar grating type [2,3] tuning element consisted of 0.5 mm wide Al stripes with period 1 mm evaporated onto the Si spacer on the side facing a movable plane mirror. The mirror was formed by the polished end of a brass piston, which was constrained to slide in a brass tube such that the mirror remains parallel with the active p-Ge crystal end face within 30″. The end face of the outer tube was polished simultaneously with the piston and has the same quality specifications.

A bronze spring held the piston firmly against the piezo-electric element, which consists of a stack of six ceramic disks and was 4 mm long. The piezo-element was roughly calibrated at room temperature by monitoring He–Ne laser light reflected by a mirror whose orientation was changed by the piezo. A shift of 7.5 ± 2.5 μm per 700 V was found. The piezo-element was electrically isolated from the piston assembly by wrapping it with Teflon tape. The initial gap between Al stripes and movable mirror was adjusted to approximately 140 μm when the piezo-element was unbiased. The system was inserted into a superconducting solenoid of 14.5 cm length and immersed in liquid helium.

The radiation was directed via brass light pipes from the laser to a Bomem DA8 Fourier spectrometer equipped with an event-locking [5] accessory (Zaubertek) for low duty sources. The detector was a Si-composite bolometer (Infrared Labs) with a 370 cm^{-1} low pass filter. The scan length sufficed for a resolution of 0.041 cm^{-1}. Interferograms were transformed at higher resolution (zero filling) to produce smooth profiles for the unresolved laser lines.

3. Results

Spectra are presented in Fig. 2. The voltage applied to the piezo-element is indicated above

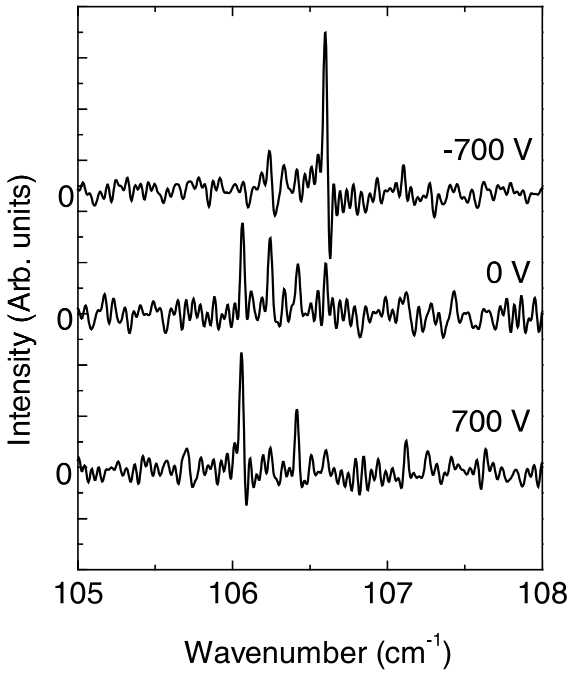

Fig. 2. Emission spectra of p-Ge laser with different bias applied to piezo-element. An electric field of magnitude 1.39 kV/cm was applied in 0.3 μs pulses at a 4 Hz repetition rate. The applied magnetic field was 0.88 T.

each trace. The envelope of the observed laser lines has about 0.6 cm^{-1} width, giving an active cavity finesse of 0.06 (axial mode interval divided by cavity resonance bandwidth [6]). The envelope shifts up about 0.3 cm^{-1} when -700 V is applied to the piezo. The spectrum shifts down by about the same amount when the bias polarity is reversed. The smooth ringing flanking unresolved laser lines (especially the strong ones) is an artifact of Fourier-transform spectroscopy with boxcar apodization, which was selected as the analysis option to obtain the highest resolution for the given scan length.

4. Discussion

It has been shown previously that p-Ge lasers with intracavity frequency selection can generate single-longitudinal modes, giving an active cavity finesse better than unity [4]. From the results of this paper we conclude that single-mode generation appears only at certain positions of the selector, when the selector resonance matches the highest power laser modes, as for example the Fig. 2 trace with bias of -700 V. Data presented here show that the spectrum fails to remain single mode while the selector is smoothly tuned by very small amounts. Instead the laser output tends to hop between those regularly-spaced longitudinal laser modes that suffer low loss at the Si–Ge interface [7]. Axial modes of the combined Si–Ge cavity that have low amplitude at the interface are favored [7]. When the selector is positioned between those low-loss resonances, the laser tends to produce multiple peaks (Fig. 2, bias = 0 V). A thin layer of Si oil at the Si/Ge interface reduced but did not eliminate this effect.

The observed peak spacing of 0.179 ± 0.001 cm^{-1} (Fig. 2) is almost exactly five times the calculated 0.0366 cm^{-1} axial mode spacing of the full Si and Ge cavity. Analysis [7] shows that for this cavity the Si–Ge interface loss should cause every fifth axial mode to be strong. A complete analysis of the peak structure will be presented in an upcoming paper on intracavity interface effects.

The tuning-element gap is set for the third order Fabry–Perot resonance, such that the gap is $3/2$ the selected wavelength. The measured spectrum with an unbiased piezo-element shows radiation centered at about 106.4 cm^{-1}. This implies a 141 μm gap i.e. close to the nominal 140 μm set during the cavity assembly. The estimated mirror displacement implied by the Fig. 2 shifts was 0.4 μm per 700 V, which is more than 10 times less than the room temperature calibration. At 4 K, piezoelectric displacement is known to be as little as 20% of the 300 K value. The Teflon wrapping of the piezo-element becomes less flexible at low temperatures, which may also reduce the displacement. The piezo-stack is under pressure, reducing mechanical hysteresis and instability present during the 300 K calibration. These considerations can account for a mirror displacement smaller than anticipated by more than an order of magnitude.

Analyzing the results of this paper and Ref. [4], we can conclude that the laser design investigated here allows single-line step tunability with ~5 GHz steps (0.179 cm^{-1}), defined by the Si spacer used.

To obtain smoother tunability of the p-Ge laser with this kind of selector, intrinsic intracavity interface effects need to be reduced or eliminated. This may be done by the reduction of the Si/Ge interface loss, possibly by index matching fluid or direct bonding, or by eliminating the Si spacer altogether. In that case $\sim$1 GHz step tunability, defined by longitudinal mode spacing for the $\sim$3 cm laser crystal might be expected. Further reduction of the tunability steps requires increasing the laser cavity length or making this length variable. To reduce uncertainty, a piezo-element that is well calibrated for low temperatures should be used. In addition, a piezo-element consisting of a single piece of ceramic would reduce hysteresis and instability.

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References

[1] E. Gornik, A.A. Andronov (Eds.), Opt. Quant. Electron. (special issue) 23 (1991).

[2] S. Komiyama, H. Morita, I. Hosako, Jpn. J. Appl. Phys., Part 1 32 (1993) 4987.

[3] A.V. Murav'ev, I.M. Nefedov, S.G. Pavlov, V.N. Shastin, Quant. Electron. 23 (1993) 119.

[4] A.V. Muravjov, S.H. Withers, H. Weidner, R.C. Strijbos, S.G. Pavlov, V.N. Shastin, R.E. Peale, Appl. Phys. Lett. 76 (2000) 1996.

[5] H. Weidner, R.E. Peale, Appl. Spectrosc. 51 (1997) 1106.

[6] A.E. Siegman, Lasers, University Science Books, Mill Valley, California, 1986, pp. 435–436.

[7] S.H. Withers, A.V. Muravjov, R.C. Strijbos, C.J. Fredricksen, R.E. Peale, in: M.M. Fejer, H. Injeyan, U. Keller (Eds.), Advanced Solid State Lasers, TOPS, vol. 26, Optical Society of America, Washington DC, 1999, p. 491.