文章编号: 1001 - 9014(2005)05 - 0321 - 03

MEASUREMENT OF THE FREQUENCY SPECTRUM OF A SUBMILLIMETER CW SOURCE BY HETERODYNE MIXING AND DIRECT DETECTION

SHEN Xiao-Fang, YAO Qi-Jun, LIN Zhen-Hui, SHI Sheng-Cai
(Purple Mountain Observatory, NAOC, CAS, Nanjing 210008, China)

Abstract: It is of particular interest to characterize the frequency spectrum of signal sources at submillimeter wavelengths. The heterodyne-mixing and direct-detection (Fourier transform spectrometer, FTS) methods were introduced to measure the frequency spectrum of a submillimeter CW source (phase-locked and tunahle from 460-520 GHz). A 500-GHz superconductor-insulator-superconductor (SIS) tunnel junction was employed as a mixer for the former method but a direct detector for the latter. The measurement results are compared.

Key words: frequency spectrum; submillimeter sources; heterodyne mixing; direct detection; FTS

CLC number: TN0 **Document code**: A

用外差混频和直接检波方法测量亚毫米波连续波源的频谱

申小芳, 姚骑均, 林镇辉, 史生才
(中国科学院紫金山天文台,江苏 南京 210008)

摘要:在亚毫米波频段,表征信号源的频谱特性是一项重要工作.用外差混频和直接检波(傅里叶变换频谱仪,FTS)两种方法测量一个亚毫米波连续波源(采用锁相技术且可在 460 ~ 520GHz 范围内调频)的频谱. 500 ~ GHz 频段超导 SIS 隧道结在外差混频方法里用作混频器,而在直接检波方法里作为直接检波器. 并对两种方法得到的结果进行了比较.

关 键 词:频谱;亚毫米波源;外差混频;直接检波;傅里叶变换频谱仪

Introduction

It is well known that the submillimeter region (i. e., THz) is rich in scientific and technological opportunities. But it remains to be fully explored owing to the technological difficulty. Developing a robust source technology, capable of operating in this region, is one of significant technological challenges. There are a multitude of approaches to the submillimeter source problem (e. g., fundamental solid-state oscillators, harmonic generation from lower frequency sources, and mixing from optical sources). It is of particular interest to characterize the spectral characteristics (e. g., spectral shape, frequency stability, and power stability) of submillimeter sources to make use of them in areas such as radio astronomy, atmospheric research, and laboratory spectroscopy.

A 500-GHz CW submillimeter source is investigated here. The submillimeter source indeed consists of a solid-state Gunn oscillator (phase locked and tunable from 77-87 GHz) and a six-time (x2x3) multiplier, giving a frequency coverage of 460-520 GHz (produced

Received: 2005 - 01 - 17, **revised date**: 2005 - 06 - 15 **收稿日期**: 2005 - 01 - 17, **修回日期**: 2005 - 06 - 15
Foundation item: The project supported by CAS (KJCX2-SW-T2) and National Natural Science Foundation of China (20030001)
Biography: SHEN Xiao-Fang (1979-), female, Nanjing, Doctor, research area is direct detection.

by Radiometer Physics GmbH, Germany). With a phase-lock-loop included, the Gunn oscillator should have sufficiently high frequency and power stabilities. In this paper, we focus on the characterization of the spectral shape of the 500-GHz CW source (after the multiplier).

There are two kinds of techniques adopted commonly to measure the frequency spectrum of high-frequency CW sources, i. e., heterodyne mixing and direct detection. The heterodyne-mixing method employs a mixer (with a local-oscillator signal) to down convert the output signal of the measured source into an IF signal that is able to be measured by conventional spectrum analyzers, while the direct-detection method measures it straightforwardly with the aid of a Fourier transform spectrometer equipped with a sensitive detector.

1 Spectrum measurement by direct detection

For the direct-detection method, as introduced before, an FTS system is necessary to measure the frequency spectrum of the 500-GHz CW source. Hence we constructed an FTS system with a conventional design [1~3]. As shown in Fig. 1, the key component of the FTS system is a Martin-Puplett interferometer (MPI), which is composed of two rooftop mirrors (one fixed and the other movable) and a wire grid (as a beam splitter) and is located in between the 500-GHz CW source and a signal detector. With a monochromatic signal of wavenumber σ_0 and intensity $B(\sigma_0)$ incident on the MPI, and when the movable rooftop mirror scans, the MPI produces an interferogram of an intensity given by $I(x) = B(\sigma_0)[1+\cos(2\pi\sigma_0 x)]$. Here x designates the optical-path difference between the two arms of the MPI. Obviously, the source distribution B (σ_0) can be recovered by the inverse Fourier transform, $B(\sigma_0) = \int_0^\infty I(x)\cos(2\pi\sigma_0 x)dx$.

To detect the output signal of the MPI, we adopted a superconducting SIS mixer[4] with a frequency response centered around 500 GHz. In fact, we measured the change of dc current of the SIS junction, biased at 1.5 mV (of a dark current of 13.7 μA), when a chopper (of a chopping frequency of 80 Hz) modulated two incident signals, i. e., the 500-GHz CW source and a room-temperature load. Such a sensitive detector can ensure small signals to be detected easily. The measured current change was then amplified and recorded by a lock-in-amplifier (LIA). The frequency spectrum of the CW source can be recovered by the inverse Fourier transform of an interferogram, i. e., the measured current change as a function of the optical-path difference of the MPI.

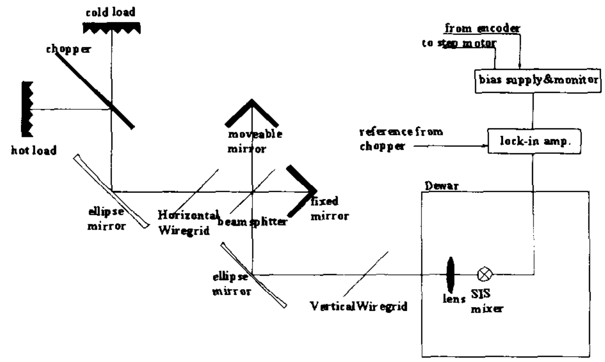

Fig. 1 Schematic view of an FTS system
图1 FTS系统示意图

The 500-GHz CW source was measured with this FTS system for 486 GHz. Notice that the MPI was scanned only once in a step-by-step movement of the mirror, with each step having a 3-second sampling time to average out the noise. A step motor was used to drive the moveable rooftop mirror whose position was recorded accurately by a linear encoder. The step distance and maximum travel length of the movable rooftop mirror were set at 75 μm and 75 mm, respectively, to have a 2-GHz frequency resolution and the highest measurable frequency of 1 THz (to cover possible output of harmonics other than 6). Fig. 2 exhibits the frequency spectrums of the 500-GHz CW source measured at 486 GHz. Obviously, it has a good signal-to-noise ratio and is rather pure without other harmonics existed. It should be pointed out that the scanning time must be increased considerably to observe a frequency spectrum of higher resolution (from GHz to MHz, for example).

2 Spectrum measurement by heterodyne mixing

With an additional CW source (as a local oscilla-

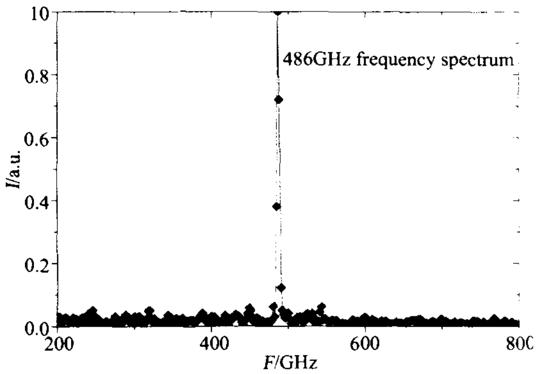

Fig. 2 Frequency spectrum of the 500-GHz CW source at 486 GHz measured by direct-detection
图 2 用直接检波方法测得的 500-GHz CW 源在 486GHz 的频谱

tor) being able to output a signal close to 500 GHz and sufficiently strong for mixer pumping, it is convenient to measure the frequency spectrum of the 500-GHz CW source by the heterodyne-mixing method. A BWO (backward-wave oscillator) of frequency coverage of 460-700 GHz and a power level of several mw was chosen. The 500-GHz superconducting SIS mixer was employed again, but as a mixer. The measured 500-GHz CW source was first downconverted into an IF (intermediate frequency) signal and then amplified by an IF chain, which consists of a cooled HEMT (high electron mobility transistor) low-noise amplifier, a room-temperature amplifier, and a band-pass filter (1.56 ±0.3 GHz). The IF signal was monitored by a spectrum analyzer (HP E4408B). The overall view of the measurement setup is shown in Fig. 3. For this measurement we set the measured CW source at 486 GHz (by its phase-locked function) as the BWO frequency was not precisely calibrated. Then we adjusted the cathode voltage (i.e., frequency) of the BWO to have an output IF signal fall into the coverage of the IF band-pass filter. By observing the movement direction of the IF spectrum, we found that the BWO indeed had a higher frequency. Fig. 4 demonstrates the frequency spectrum of the 500-GHz CW source at 486 GHz. Obviously, the corresponding frequency of the BWO is 487.546 GHz.

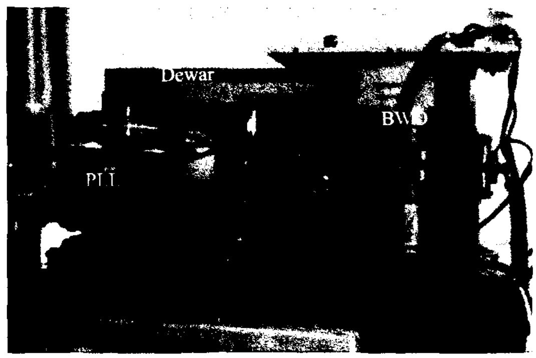

Fig. 3 Overall view of the measurement setup of heterodyne mixing
图 3 外差混频测量的系统图

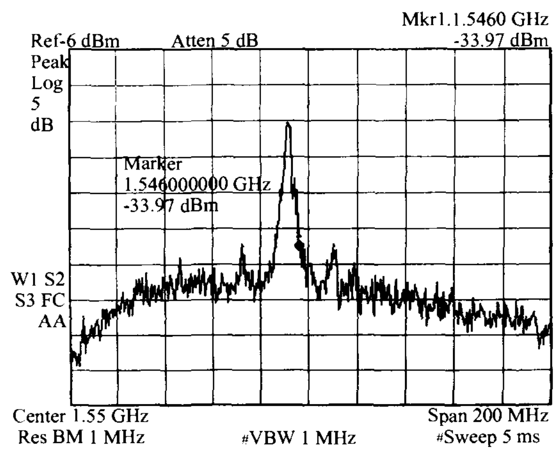

Fig. 4 Frequency spectrum of the 500-GHz CW source at 486 GHz by heterodyne mixing
图 4 外差混频法测得的 500-GHz CW 源在 486GHz 的中频频谱

3 Conclusion

We have successfully measured the frequency spectrum of a 500-GHz CW source using the heterodyne-mixing and direct-detection methods. The heterodyne-mixing method is fast and it has high resolution (several MHz), but needs an additional source (LO). Furthermore, the measurable frequency coverage is rather limited and the quality of the measured frequency spectrum depends strongly upon the frequency and power stabilities of the LO source. By contrast, the direct-detection method is rather straightforward. But its measurement time is much longer, especially for high-resolution measurement.

Acknowledgement:

X. F. is grateful to Dr. Kenichi Kikuchi of NASDA and Prof. Hiroshi Matsuo of NAOJ for many helpful discussions and suggestions. Thanks are due to Ms. Jin Huang of PMO for her assistance. (下转第 327 页)

应力缓冲层的 InAs 量子点样品中,由于 GaAs 层的加入增加了势垒的限制,因此有效地抑制了载流子的热激活和热转移所造成的非辐射复合跃迁. 这对提高量子点激光器的热稳定性具有非常重要的意义.

3 结论

我们利用 PL 谱和 AFM 测试方法研究了在2 nm $In_{0.2}Ga_{0.8}As$ 和 x ML GaAs 的复合应力缓冲层上淀积 InAs 量子点结构的发光特性和表面形貌的变化. 由于薄层 GaAs 的引入改变了晶格失配度,导致量子点密度显著增加. 同时,这也有助于提高量子点中 In 的组份,使量子点的高宽比增加,促进发光峰红移. 从 PL 积分强度随温度变化的对比可以得到,采用 $In_{0.2}Ga_{0.8}As$-GaAs 复合应力缓冲层的结构对于提高量子点激光器的热稳定性具有非常重要的意义.

REFERENCES

[1] QIU Zhi-Jun, GUI Yong-Sheng, CUI Li-Jie, *et al.* Magneto-transport of electron symmetric and antisymmetric states in highly doped InGaAs/InAlAs single quantum well [J]. *J. Infrared Millim. Waves* (仇志军, 桂永胜, 崔利杰, 等. 掺杂 InGaAs/ InAlAs 单量子阱中电子对称态和反对称态磁输运研究. **红外与毫米波学报**), 2004, **23**(5): 329—332.

[2] WANG Zhi-Ming, LU Zheng-Dong, FENG Song-Lin, *et al.* The study of growth interruption of self-assembled InAs/GaAs islands[J]. *J. Infrared Millim. Waves* (王志明, 吕震东, 封松林, 等. 自组织 InAs/GaAs 岛状结构生长停顿研究. **红外与毫米波学报**), 1997, **16**(5): 335—338.

[3] MENG Xian-Quan, XU Bo, JIN Peng, *et al.* Dependence of optical properties on the structure of multi-layer self-organized InAs quantum dots emitting near 1.3 μm [J]. *J. Crystal Growth*, 2002, **243**: 432—438.

[4] Chu L, Arzberger M, Bohom G, *et al.* Influence of growth conditions on the photoluminescence of self-assembled InAs/GaAs quantum dots [J]. *J. Appl. Phys.*, 1999, **85**(4): 2355—2362.

[5] Chung T, Walter W, Holonyak Jr N. Coupled strained-layer InGaAs quantum-well improvement of an InAs quantum dot AlGaAs-GaAs-InGaAs-InAs heterostructure laser [J]. *Appl. Phys. Lett.*, 2001, **79**(27): 4500—4502.

[6] LIU Hui-Yun, Hopkinson M, Tuning the structural and optical properties of 1.3 - μm InAs/GaAs quantum dots by a combined InAlAs and GaAs strained buffer layer [J]. *Appl. Phys. Lett.*, 2003, **82**(21): 3644—3646.

(上接第 323 页)

REFERENCES

[1] Sumner P Davis, Mark C Abrams. *Fourier Transform Spectrometry* [M]. San Diego: Academic Press, 2001. 10—11.

[2] Bell, Robert John. *Introductory Fourier Transform Spectroscopy* [M]. New York: Academic Press, 1972. 33—44.

[3] Kenichi Kikuchi, Yasunori Fujii, Junji Inatani. Simple FTS Measurement System for Submillimeter SIS mixer [J]. *Int. J. IR MM Waves*, 2002, **23**: 1019—1027.

[4] ZHANG Wen, SHAN Wen-Lei, SHI Sheng-Cai. Investigation of Embedding Impedance Characteristic for a 660-GHz Waveguide SIS Mixer[J]. *J. Infrared Millim. Waves* (张文, 单文磊, 史生才. 660-GHz 频段波导型 SIS 混频器嵌入阻抗的特性研究. **红外与毫米波学报**), 2002, **21**(6): 465—468.