



Title	Terahertz Integrated Circuits Based on Photonic-crystal Waveguide Platform
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Abstract of Thesis

Name (YU XIONGBIN)	
Title	Terahertz Integrated Circuits Based on Photonic-crystal Waveguide Platform (フォトニック結晶導波路プラットホームを用いたテラヘルツ集積回路)
<p>The terahertz (THz) frequency range (0.1–10 THz) has attracted considerable attention due to its large spectral bandwidth and small wavelength, in comparison to microwaves. However, THz systems are still large and complex owing to the lack of efficient integrated circuits. THz integrated circuits based on metallic transmission lines exhibit degraded performance mainly due to the propagation loss. Recently, a silicon (Si) photonic-crystal waveguide has been proved to offer two orders of magnitude less loss than the metallic lines. Owing to the factors including a lack of efficient interfaces or mode converters and narrow 3-dB operation bandwidth, it is challenging to employ the photonic crystal waveguide for developing THz integrated circuits. This dissertation focuses on the design of THz integrated circuits based on the photonic-crystal waveguide platform. A resonant tunneling diode (RTD) fabricated on an indium phosphide (InP) substrate is one of the most promising candidate THz active devices for compact sources and detectors.</p> <p>The thesis addresses RTD receiver, transmitter, self-injection locked oscillator and mixer integrated with photonic-crystal waveguides as well as THz communication demonstrations in the 0.3-THz band. Firstly, the mechanism achieving high coupling efficiency between the photonic-crystal waveguide and metallic hollow waveguide through a tapered Si interface is clarified by an impedance matching method. The interface employed to connect the photonic-crystal waveguide with expanded polytetrafluoroethylene THz fibers and free-space applications is then described. A tapered-slot mode converter with the photonic-crystal waveguide is proposed in order to efficiently integrate active devices with the waveguide. The mode converter is metallic and is fabricated on an InP substrate. The RTD receiver is successfully integrated with the photonic-crystal waveguide using the developed mode converter. A high coupling efficiency (~90%) and large 3-dB bandwidth (~50 GHz) are achieved. In communication experiments, 32-Gbit/s error-free (bit error rate $< 10^{-11}$) transmission and the wireless transmission of uncompressed 4K high-definition video are achieved. Moreover, the RTD transmitter is successfully designed and fabricated. The RTD transmitter has a record-setting oscillation power of ~50 μW. A THz fiber transmission link is demonstrated using the developed RTD transmitter and receiver. Error-free 10-Gbit/s and uncompressed 4K high-definition video transmissions are also successfully demonstrated using a 1-m-long THz fiber. A self-injection locked RTD oscillator is developed by coupling it to a high-Q photonic-crystal cavity. The oscillation frequency is successfully locked to the resonant frequency of the cavity. The linewidth is reduced from 8 MHz to 8 kHz. Then, a three-terminal RTD mixer integrated with a photonic-crystal waveguide is developed to increase the sensitivity of an RTD receiver. Coherent detection is successfully demonstrated with an increase in the sensitivity of >30 dB compared to direct detection. A binary phase-shift keyed THz communication experiment is performed to indicate the performance of the self-injection locked RTD oscillator. As a result, using the self-injection locked RTD oscillator can suppress phase fluctuation of constellation, and increase the opening factor of the eye diagram by ~1 dB compared with that of a free-running RTD oscillator. Finally, dispersion engineering of the photonic-crystal waveguide is performed. An isosceles triangular lattice photonic-crystal waveguide is described, which exhibits low loss with low dispersion. The simulated and measured bandwidth under the condition of low loss (<0.01 dB/mm) is approximately 10%, which is twice as wide as that of a conventional photonic-crystal waveguide. Hence, error-free 36-Gbit/s transmission using the 3-cm-long isosceles triangular lattice photonic-crystal waveguide is achieved. These results indicate the photonic-crystal waveguides can potentially serve as an efficient platform for developing THz integrated circuits.</p>	

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

マイクロ波と光波の中間に位置する、周波数100GHz～10THzの電磁波は、テラヘルツ波と呼ばれ、21世紀に残された最後の周波数帯のフロンティアとして、通信、センシング、計測等のシステム応用に向けた研究開発が活発になっている。このような応用の実用化ならびに産業化のためには、システムの小型集積化が不可欠である。テラヘルツシステムの集積化を妨げている要因のひとつに、発振器や検出器といった機能素子を接続するための配線あるいは伝送線の損失の問題があった。また、集積システムのI/Oインターフェースについても、低損失・広帯域な技術が必要とされていた。

本論文は、テラヘルツ波帯で最も低損失な伝送線として知られているSiフォトニック結晶導波路に着目し、該導波路をプラットフォームとして、発振器、検出器等の能動素子、ならびにフィルタ、共振器等の受動素子を実装することにより所望のシステムを実現する方法を提案し、いくつかの集積システムに適用することでその有用性を実証したものである。

具体的には、能動素子として共鳴トンネルダイオード(Resonant Tunneling Diode: RTD)を選択し、RTDとフォトニック結晶導波路とを効率的に結合するためのモード変換器の開発により、プラットフォーム上でRTD発振器、RTD検出器、RTDミキサを実現し、300GHz帯の高速無線通信システムに適用した。また、RTD発振器とフォトニック結晶による共振器とを集積化することにより、発振周波数の安定化に成功している。その他、プラットフォームと金属導波管や誘電体ケーブル(テラヘルツケーブル)とを接続するためのインターフェースの開発や、Siフォトニック結晶導波路自身の低分散化のための新構造の提案を行い、いずれも実験によってその実用性を示している。

以上、Siフォトニック結晶からなる伝送線をプラットフォームとする、新しいテラヘルツ集積システムの概念を提唱し、実際に、小規模の集積システムを開発して、無線伝送や有線伝送に適用に成功したことは、工学的に極めて大きなインパクトを与えるものであることから、本論文は、博士(工学)の学位論文として価値のあるものと認める。