論文 / 著書情報
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題目(和文)	高度情報通信ネットワーク基盤の実現に向けた半導体モノリシックマイクロ波集積回路に関する研究
Title(English)	Research on semiconductor monolithic microwave integrated circuits for the advanced information and communication network infrastructure
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種別(和文)	論文要旨
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

There has been a need to address social issues via systems that combine communication and sensing in virtual space and reality. In addition, in an age when everything is connected to the network, cyber-attacks are a great threat, and highly reliable and secure communication technologies are becoming even more important. These requirements call for systems that combine ever more advanced wireless communication technologies with fully virtualized base station and new quantum communication technologies as advanced information and communication network infrastructures. Various RF circuits are used in these systems and are keys to achieving system performance. Monolithic microwave integrated circuits (MMICs), where active microwave elements such as field-effect transistors (FETs) and diodes are integrated with passive elements on a single semiconductor chip, can allow for the optimization of RF circuits to meet the miniaturization and performance requirements in these advanced infrastructures. It is crucial to optimize the circuit constants of MMICs and improve the performance trade-off relationship by proposing new circuit configurations and device structures and combining different types of circuits. In this thesis, research is conducted on semiconductor MMICs as a viable route to high-speed, high-capacity, low-power consumption, low-cost, and high-reliability communications.

Key RF devices that would lay the foundation of advanced wireless communication systems combined with emerging quantum communication technologies include high-power and high-efficiency amplifiers and switches, low-cost transmit/receive (T/R) modules, and silicon-based quantum communication and computing chips. GaN devices are key components that account for a large portion of wireless communication systems' power consumption and cost. Electron spin qubits based on silicon quantum dots (QDs) with long coherence time and the advantage of miniaturization are great candidates for quantum networks and computation. Improving the performance of these devices is important, and we have researched as follows.

First, an ultra-wideband bandpass distributed GaN-MMIC power amplifier is designed and measured to realize fast and high-capacity communications. Non-uniform distributed amplifiers (NDPAs) are used as broadband high-power-amplifiers (HPAs), but there has been a trade-off relation between output power and bandwidth. Here, we have improved the trade-off relation by proposing a bandpass NDPA. We designed and evaluated a single-ended bandpass NDPA and a 2-way combined NDPA. Measurement results of the NDPAs show that the developed amplifiers achieve the highest output power and power density among the reported MMIC HPA with relative bandwidth of over 100%.

Second, the design and measurement of a GaN-MMIC high-efficiency power amplifier using the individual source via (ISV) structure is conducted to achieve low power consumption. In conventional FETs, the source fingers are each bundled and connected to the via holes through transmission lines. In this configuration, the parasitic resistance and inductance between the source fingers and the via holes degrades the amplifiers' gain and efficiency. Therefore, an ISV structure with small via holes in all source fingers was applied to improve the performance of GaN amplifiers. We also optimized an output matching circuit by considering the relationship between load impedance and circuit loss. Measurement results of the developed X-band GaN-MMIC amplifier demonstrate the highest performance in terms of the combinations of output power and power added efficiency (PAE) compared to existing state-of-the-art X-band MMIC HPAs.

Third, power amplifiers and a switch incorporating partial MMIC and GaN-on-Si technologies are developed. GaN-on-SiC HPAs have high performance, but tend to be expensive because of the high cost of SiC substrates. Therefore, we developed a GaN-on-Si-MMIC using a cost-effective silicon substrate. We also proposed a partial MMIC configuration that combines a GaN-based MMIC and low-cost, low-loss GaAs matching circuits. These MMIC configurations were combined into a chipset for low-cost T/R modules: a GaN-on-Si-MMIC DA, a GaN-on-SiC MMIC HPA with a GaAs MMIC input and output matching circuits, a high-gain GaN-on-Si HPA with a GaAs output matching circuit and a GaN-on-Si high-power switch. The T/R module configuration using these components achieves a comparable performance to conventional modules at about half the cost.

Finally, research on silicon QD devices for realizing quantum computers and networks is conducted. Design of compact and wideband on-chip matching circuits of QD charge sensor based on RF reflectometry towards fast readout of qubit state is implemented. The matching circuit of a charge sensor has so far been comprised of a shunt capacitor and a series inductor on the printed circuit board using chip components. To reduce the size and broaden the bandwidth of the matching circuit, we

extracted the equivalent circuit parameters on the silicon QD chip. We also formulated circuit constants of three matching circuits, the shunt capacitor-series inductor, shunt inductor-series capacitor and shunt inductor-series inductor. We compared them in terms of sensitivity and frequency bandwidth. The newly proposed shunt inductor-series inductor type was shown to have the widest bandwidth. The design with this configuration provides the bandwidth required for high-speed readout while using smaller inductance than conventional circuit configurations, demonstrating the feasibility of on-chip compact matching circuits.

The proposal of new MMIC configurations and analysis in these researches have achieved great performance among the other reported results. We believe that these results will contribute to the realization of the advanced information and communication network infrastructure.