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Design, fabrication and characterization of a Schottky diode on an AlGaAs/GaAs HEMT structure for on-chip RF power detection

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ABSTRACT

A Schottky diode was designed and fabricated on an *n*-AlGaAs/GaAs high electron mobility transistor (HEMT) structure for RF power detection. The processing steps used in the fabrication were the conventional steps used in standard GaAs processing. Current–voltage measurements showed that the devices had rectifying properties with a barrier height of 0.5289–0.5468 eV. The fabricated Schottky diodes detected RF signals well and their cut-off frequencies up to 20 GHz were estimated in direct injection experiments. To achieve a high cut-off frequency, a smaller Schottky contact area is required. The feasibility of direct integration with the planar dipole antenna via a coplanar waveguide transmission line without insertion of matching circuits was discussed. A higher cut-off frequency can also be achieved by reducing the length of the coplanar waveguide transmission line. These preliminary results represent a breakthrough as regards direct on-chip integration technology, towards the realization of a ubiquitous network society.

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1. Introduction

The explosive growth of internet and wireless technologies starting in the late 21st century has opened up prospects towards an advanced ubiquitous network society; nanoelectronic devices are the most promising candidates for yielding such technologies. Therefore, nanoelectronic systems are increasingly vulnerable to malfunction due to incident electromagnetic (EM) radiation, particularly since many integrated circuits operate at lower and lower voltages. Damaging RF radiation can be produced intentionally, such as by high power microwave generators [1], or accidentally, such as by ambient sources like lightning. Then, it becomes a great interest to know how, and at what level, microwaves penetrate equipment shielding and reach the vulnerable chips. This motivated our group to work on on-chip RF detectors, both for measuring power at the chip level and for developing strategies to mitigate its effects. Knowing the RF power levels in various chips and locations within chips is likely to be more useful than the "digital" information that a given external RF power level made the circuits fail.

III–V materials are the most promising materials for high frequency device use because of the high electron mobility and other unique features such as the formation of two-dimensional electron gas (2DEG) layer [2,3]. The result of this is that the devices can be switched more quickly because there are lesser effects of collisions. Recently, the concept of the intelligent quantum (IQ) chip introduced by Hasegawa et al. [4] applied this compound semiconductor material as a base material for on-chip integration. Ideally, the chip power detectors would have a wide dynamic range, and be fabricated on this compound semiconductor. Schottky diodes are known as fast rectifying devices and can be used as RF detectors [5]. In special molecular beam epitaxy (MBE) grown geometries, RF detection up to 100 GHz has been reported [6]. However, in foundry fabricated Si-based diodes, detection of only up to 600 MHz has been reported [7]. Recently, a CMOS fabricated Schottky diode detecting RF signals up to 10 GHz in direct injection experiments and in the range of 9.5–19.5 GHz in microwave irradiation experiments has also been reported [8]. However, to our knowledge there has been no report on the design and fabrication of an *n*-AlGaAs/GaAs HEMT Schottky diode for RF power detector use. Recently our group have developed, besides RF power detectors, some other new functional devices such as THz wave detectors and plasma wave THz amplifiers utilizing the same AlGaAs/GaAs HEMT structure [9–11].

In this paper, the design and fabrication of a Schottky diode on an *n*-AlGaAs/GaAs high electron mobility transistor (HEMT) structure for RF power detection was reported. We also discussed the feasibility of direct integration with a planar dipole antenna via a coplanar waveguide transmission line without insertion of a matching circuit for real practical application. These preliminary results represent a breakthrough for direct on-chip integration technology, towards the realization of a ubiquitous network society.

2. Design and fabrication of the Schottky diode

We have chosen to fabricate a Schottky diode on the AlGaAs/GaAs HEMT structure because of the higher electron mobility that can be provided by the 2DEG layer. In addition, among novel modern structures, AlGaAs/GaAs heterostructures have emerged as the most popular material for confining electrons. As a semiconductor material for Schottky diode use, GaAs has been considered a most promising material because of its stability, capability of making a good Schottky contact and well-developed fabrication process technology. This material structure is also suitable for the development of the so-called IQ chip which has been considered as the most promising chip structure for future ubiquitous network society use [4]. The sample is an AlGaAs/GaAs modulation-doped heterostructure grown by molecular beam epitaxy. The interface of the *n*-doped AlGaAs layer and undoped GaAs layer defines a 2DEG system where electron motion perpendicular to the layer is frozen out, thus producing highly mobile electrons. The thickness of the main layers, from bottom to top, are as follows: 625 μm semi-insulated high dielectric constant GaAs substrate; 500 nm GaAs buffer layer; 10 nm AlGaAs buffer layer; 20 nm undoped GaAs layer; 10 nm AlGaAs spacer layer; *n*-doped AlGaAs (Si δ doping) barrier layer; 10 nm GaAs undoped cap layer. The devices were designed and fabricated using photolithography and a standard lift-off technique. The carrier mobility and the