A Dual-Pass High Current Density Resonant Tunnelling Diode Terahertz Emitter

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***Abstract*— We report on a dual-pass high current density InGaAs/AlAs/InP resonant tunnelling diode (RTD) terahertz (THz) emitter. Our dual-pass technique reduces overall fabrication complexity, improves the reproducibility for creating low resistance ohmic contacts, and allows accurate control over the final device area. This has been made possible by measuring the RTD current-voltage (I-V) characteristic during the fabrication process and defining both contact electrodes at the start of the fabrication. We extract information about the RTD performance using this method and demonstrate fundamental room temperature emission at 0.35 THz.**

I. INTRODUCTION

RESEARCH into terahertz (THz) technology is receiving increasing interest as the region between 0.1-10 THz offers a wide variety of applications, including ultra-broadband wireless communications [1] and imaging [2]. The observation of negative differential conductance of resonant tunnelling devices (RTD) at terahertz frequencies was first reported by Sollner *et al.* in 1983 [3]. To date, the RTD is recognised as the fastest electronic device, with fundamental oscillation at 1.55 THz reported [4]. InGaAs/AlAs/InP is an excellent material system for high performance RTDs due to the high electron mobility of InGaAs, ability to create low resistance non-alloyed ohmic contacts, lattice matching to InP, and the large energy separation between the conduction band minima of InGaAs and AlAs. Low resistance ohmic contacts are required to minimise dc voltage drops and resistive-capacitive (RC) time constants [5]. A high operating current density also places significant emphasis on the final device area and the manufacturability of low resistance ohmic contacts, meaning that process variability are critical to the final device characteristics.

In this work, we report on a double-pass high current density InGaAs/AlAs/InP RTD THz emitter. Our structures are grown by metal-organic vapour phase epitaxy (MOVPE) and fabricated using standard i-line photolithography and wet etching. Novelty is introduced by flowing the emitter current through the full RTD structure by a large second contact electrode on the collector side. This reduces the number of process steps, enables low resistance contacts to be more easily manufactured, and allows accurate control over the final device area. We demonstrate how this fabrication technique can also be used to extract information about the RTD characteristics, such as RTD peak voltage and contact resistance. Finally, we demonstrate emission at 0.35 THz from the devices fabricated using our new method.

II. FABRICATION PROCESS

Fig. 1 shows the fabrication process flow of the RTD THz emitter. Both contact electrodes are fabricated in a single metal evaporation process at the start of the fabrication process. This not only ensures that the emitter and collector semiconductor-metal interfaces are identical and of low resistance, but the fabrication process is also simplified, and reproducibility is improved as damage to the surface from future processing is minimised. The fabrication process is based on wet etching to avoid plasma damage associated with dry etching. An air-bridge contact is fabricated by wet etching to produce a "tunnel" below the exposed Au stripe [6]. As the emitter and collector electrodes are fabricated *before* the RTD mesa area is defined, full control over the RTD mesa area is achieved by measuring the I-V characteristic of the RTD during this wet etch process. Accurate control over the final device area is important not only from a manufacturing perspective to minimise the device variability in volume manufacture, but also with regard to impedance matching the RTD to the antenna for maximum power extraction. This is followed by coupling the RTD to a slot antenna through metal-insulator-metal (MIM) interconnection technology, and placing the chip upon a hyper-hemispherical lens. A surface-mount stabilisation resistor is also attached to the device to inhibit parasitic oscillations over the bias supply lines.

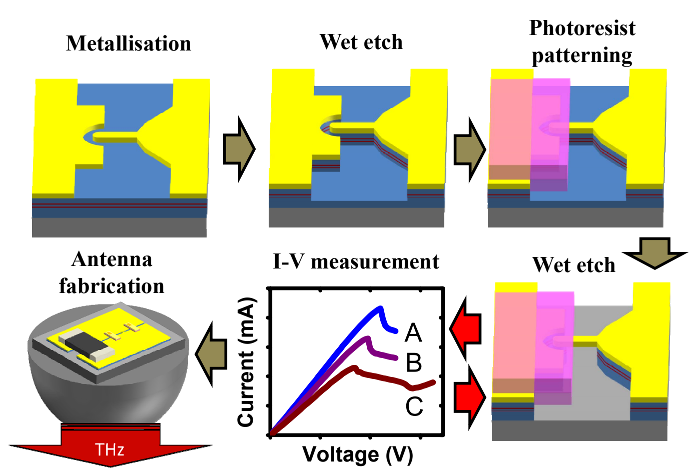

Fig.1. Fabrication process flow of a high current density RTD using standard i-line photolithography and wet etching.

III. RESULTS

Fig.2(a) shows the RTD I-V characteristic measured during the etch process. A reduction in peak current and peak voltage is observed with increasing etch time. The observed reduction in peak current is associated with a reduction in mesa size, as the total tunnelling current is proportional to the mesa area. A final device area of 3.3 μm^2 is achieved with an areal etch accuracy of < 1 %. The inset shows a scanning electron microscope (SEM) image of the fabricated device. The reducing peak voltage is associated with the voltage drop across parasitic resistance in the circuit.

Fig.2(b) shows the peak voltage and peak current as a function of etch time. Extrapolating the peak voltage as a function of mesa area provides information on the RTD characteristics. A peak voltage of ~225 mV is determined in the limit of zero peak current by extrapolating the quadratic fit to the peak voltage as a function of etch time. This voltage minimum consists of the voltage drops across the 3.3 μm^2 collector contact, and between the emitter and collector layers of the RTD at resonance. The voltage drops across the large emitter contact, the supply resistance, and air-bridge are excluded in this limit, as these resistive elements do not change in size during the etch process. A total resistance of 5 ohms is deduced for the aforementioned resistive elements, where 2 ohms is assigned to the emitter contact and 3 ohms to the supply. Using LTLM, a specific contact resistivity of 8 Ω.μm^2 is measured for the collector contact, and a peak forward voltage of 168 mV is deduced between the emitter and collector layers of the RTD at resonance.

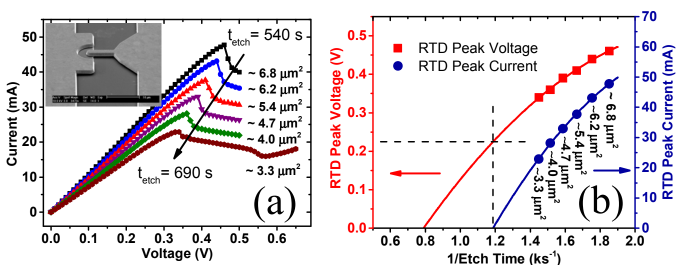

Fig.2 (a) I-V characteristics measured during the wet etch process. The device area shown in μm^2 represents the total RTD area and is calculated from the peak current density measured from a second sample fabricated using e-beam lithography. The inset shows a SEM image of the fabricated device (b) RTD peak voltage and peak current as a function of etch time. The black dotted lines guides the eye to the intercept point on the curve of the extrapolated quadratic fit to the RTD peak voltage for a zero peak current.

Fig. 3(a) shows a graph with the I-V characteristics of the same RTD THz emitter with and without bias stabilisation. The detected THz output power is also shown as a function of the supply voltage. As expected, no well-defined negative differential resistance region is observed for the stabilised RTD which includes a stabilisation resistor of 8.2 Ω. The shift in peak voltage between the stabilised and un-stabilised RTD is attributed to the finite resistance between the SMU and the RTD. Emission at 0.35 THz is measured from the RTD when biased in the negative differential resistance (NDR) region. A maximum output power of ~100 nW is measured at the bias of 0.54 V, the mid-point of the NDR region, to allow for maximum voltage and current excursions. The measured output power is an underestimate due to limited collection efficiency of our detection system. Fig. 3(b) shows the measured optical signal as a function of the Fabry-Perot displacement. The clear fundamental frequency Fabry-Perot oscillations confirm emission at 0.35 THz. There is no evidence of higher order oscillations.

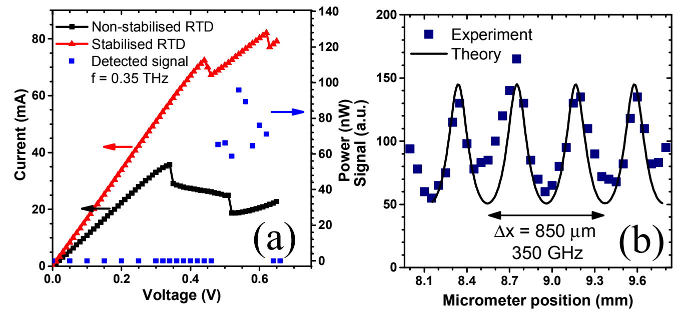

Fig. 3 (a) I-V characteristics of the same RTD measured with and without bias stabilization and output power as a function of the supply voltage (b) detected signal as a function of Fabry-Perot etalon displacement.

IV. SUMMARY

We reported an InGaAs/AlAs/InP resonant tunnelling diode terahertz emitter using a new dual-pass technique. Using this technique we achieved a final device accuracy of < 1 % for a 3.3 μm^2 device, and fabricated reproducible low resistance ohmic contacts of 2 ohms for the emitter and the collector. The RTD devices were monolithically integrated with slot antennas on an InP substrate, and emission at 0.35 THz was demonstrated

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