Design and Characterisation of a 3.5-THz Fundamental Schottky Mixer

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Design and Characterisation of a 3.5-THz Fundamental Schottky Mixer

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***Abstract*—Mixers operating at ambient temperatures are essential for realisation of THz heterodyne receivers for long lifetime space missions. In this paper, we report the design, circuit and block fabrication, assembly and characterisation of a 3.5-THz fundamental Schottky diode mixer. Design of planar, integrated mixer circuit realised using a suspended stripline technology on a 2-μm GaAs substrate and video signal detection results are presented.**

***Index Terms*—Fundamental mixers, Heterodyne receivers, Schottky diodes, Terahertz electronics**

I. Introduction

High-resolution molecular spectroscopy at terahertz (THz) frequencies is a valuable tool for understanding the chemical composition of the Earth and other planetary atmospheres. In particular, the detection of gas species such as atomic oxygen (OI) at 4.7 THz [1] and hydroxyl radical at 3.5 THz in the least explored atmospheric regions can improve the climate and weather prediction models. With the recent unprecedented progress of quantum-cascade lasers (QCLs), the realisation of THz heterodyne spectrometers is now feasible. QCLs can provide a few mW of output power and operate in continuous-wave (CW) mode, thereby making it an ideal candidate as a local oscillator (LO) source for THz receivers [2]. Overall, there is a need for development of compact, reliable receivers up to 5 THz to enable high-resolution molecular spectroscopy.

To meet the scientific objectives and instrumentation requirements of future earth observation missions, frequency converters operating at ambient temperatures are preferable. Detectors based on Schottky diode technology are workhorses behind high-altitude balloons and space-borne missions such as ODIN, Microwave Instrument for Rosetta Orbiter (MIRO) and Jupiter icy moons explorer (JUICE) mission [3]. It offers a wide range of intermediate frequencies (IF), fast response time, and can work in ambient temperatures, thereby eliminating the need for cryocoolers [4].

Integrated and planar Schottky diode technology developed during the 90s opened up for more reliable and advanced terahertz mixers and multipliers compared to previous whisker-contacted devices [5]. In 1999, Siegel et al. demonstrated membrane-based technology that allows for low electrical parasitics and operation at terahertz frequencies [6]. Based on this monolithic membrane diode technology, the first planar 2.5 THz Schottky diode heterodyne receiver was developed for a NASA spaceflight mission using a CO_2-pumped methanol far-infrared laser. Based on this, we have developed a fabrication process for realised supra-THz integrated mixer circuits.

This paper reports the design, circuit and E-plane split block fabrication and assembly of the 3.5-THz planar, single-ended Schottky diode mixer in section II. Followed by the video detection experiment results in section III.

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II. Method

Fig. 1 shows the full 3D-EM model of the 3.5-THz fundamental mixer implemented in a finite element method (FEM) solver. The incoming radiation from the 3.5-THz QCL is coupled to the mixer by a diagonal horn integrated into a WM-64 rectangular waveguide (64 μm $\times$ 32 μm). The signal is coupled to the diode via an E-plane probe. To present the optimum RF/LO embedding impedance to the diode and to have maximum energy coupling, geometry optimisation and backshort tuning was carried out. To prevent RF signal leakage into the IF chain, a hammer-head filter was designed [7]. The rounded corners arising from the milling process is taken into consideration in the 3D-EM model design. To ensure only the fundamental quasi-TEM mode exists in the RF channel, the height and the width of both top and the bottom channels were optimised.

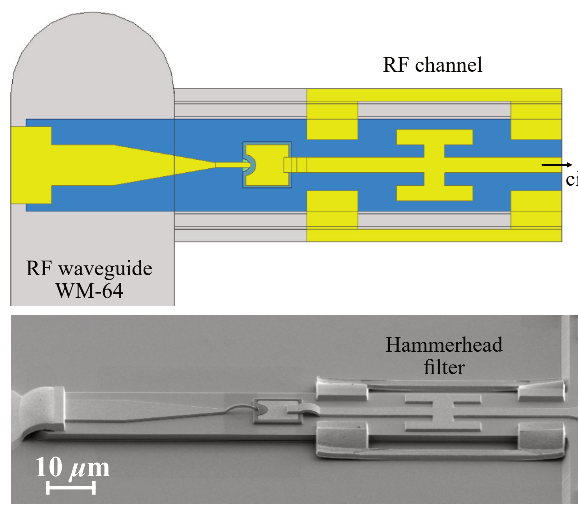

Fig. 1. 3.5-THz Schottky fundamental mixer. a) 3D-EM model of the fundamental mixer showing the rectangular waveguide WM-64 and the RF channel which houses the Schottky diode and the hammerhead filter. b) Scanned electron micrograph (SEM) of the integrated mixer circuit realised on a 2-μm GaAs substrate.

To realise THz components above 2 THz, minimising the circuit losses and parasitics is crucial. Hence, the 3.5-THz fundamental mixer circuit was realised using suspended stripline technology in a 2-μm thick GaAs membrane. An epi-layer doping concentration of about 6×10^{17} cm^{-3} was chosen to reduce parasitics and to operate below the cut-off frequency. It is followed by a highly doped buffer layer with a concentration of about 5×10^{18} cm^{-3}. E-beam lithography was used to define each pattern. The dc performance of the circuits were evaluated before the circuits were released and the diode series resistance (R_s) and ideality factor (η) were extracted. Three different Schottky contacts were fabricated (0.14 μm^2 $\pm$ 20%) to tackle problems that may arise due to fabrication tolerances.

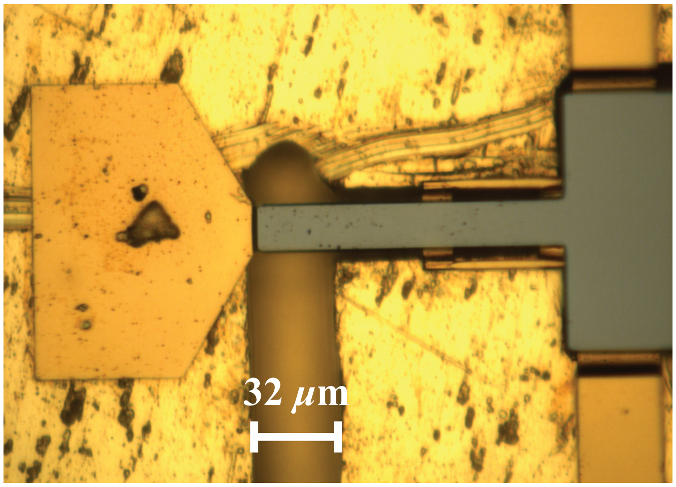

Fig. 2. Photograph of the integrated 3.5-THz Schottky diode mixer assembled in an E-plane Aluminum split block sputtered with 1-μm-thick gold. Note: The circuit is mounted upside down.

Fig. 2 shows the photograph of the fundamental mixer circuit assembled in an E-plane split-block machined using a high-precision Kern CNC machine at Chalmers University of Technology. The aluminum blocks were cleaned, etched and sputtered with 1-μm gold.

III. Results

Photograph of the experiment setup at the German Aerospace Center (DLR) is shown in Fig. 3.

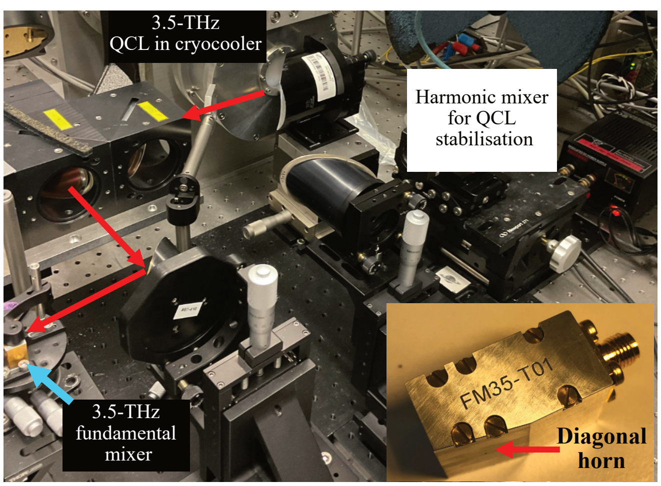

Fig. 3. Picture of measurement setup at the German Aerospace Center, Berlin. Inset: Fully assembled 3.5-THz fundamental mixer.

An off-axis parabolic mixer was used to focus the THz signal from the QCL. The signal was split using a beam splitter. Maximum power from the QCL was directed to the fundamental mixer via a Martin-Puplett diplexer which will be later utilised for noise temperature measurements. Whilst the other part of the signal will be sent to the Schottky harmonic mixer for QCL frequency stabilisation [8]. The total path length from the QCL to the fundamental mixer was about 70 cm and the QCL power at the mixer interface measured using a Thomas Keating power meter was about 5 mW.

For video detection, a mechanical chopper operating at 15 Hz was used for signal modulation and the video signal was observed using an oscilloscope and lock-in amplifier [9]. Fig. 4 shows the recorded video signal versus applied dc-voltage and the corresponding *I-V* response of the diode. The current safety limit was set to 1 mA. Noise temperature measurements and integration of harmonic mixer to this breadboard is currently under progress. We request for a full paper submission to the special issue in IEEE-TTST.

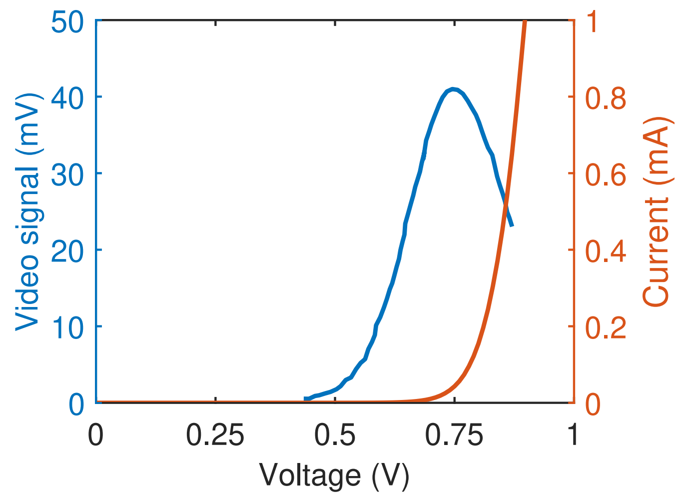

Fig. 4. Video detection. (Left axis) Video signal recorded using a lock-in amplifier and an oscilloscope. The peak signal was observed at 0.75 V. (Right axis) *I-V* response of the Schottky diode with 0.11 μm^2 contact area.

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