iBROW project newsletter #1

September 2015

Welcome to the first iBROW project newsletter!

iBROW is a research project supported by the European Commission through Horizon 2020 under Grant Agreement 645369.

iBROW is a collaborative research project supported by the European Commission through Horizon 2020. The project will address the growing requirement for high bit rate short range wireless communication. It is expected that by the end of 2015 data traffic from wireless devices will exceed that from wired devices. Most of this traffic is video, with the fraction of high resolution video steadily increasing. Forecasts suggest that wireless data rates of multiple tens of Gbps will be required with a few years and this demand cannot be met with current technology.

The iBROW consortium believes that resonant tunnelling diode (RTD) transceiver technology could provide the solution. This low cost simple wireless transceiver architecture can achieve 10 Gbps by exploiting the mm-wave and THz frequency spectrum, and up to 100 Gbps is feasible in the longer term.

iBROW will run for three years and these bi-annual newsletters will report on the project progress, as well as news of other events and activities. More information is available on the project website (www.ibrow-project.eu) or by getting in touch by email (see below).

The iBROW team ready for action at the kick-off meeting (Glasgow; Jan-2015).

This first newsletter contains: an overview of RTD technology, news of record-breaking RTDs from University of Glasgow, THz standards work from TU Braunschweig and a preview of the ALT 2015 conference (07-11 Sep-2015; Faro, Portugal).

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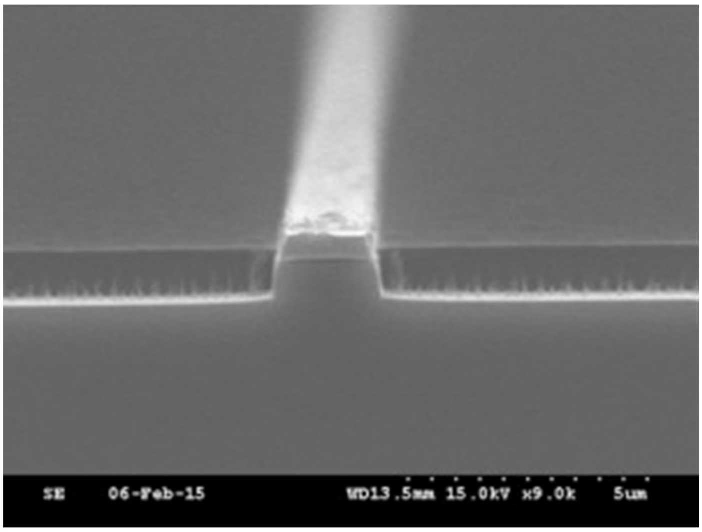
RTD technology for electronic THz sources

The terahertz (THz) frequency range (0.1 to 3 THz) is a growing research area because of its inherent advantages, e.g. wider bandwidth, improved spatial resolution compared with RF electronics, and new sensing opportunities including medical diagnostics, inspection of sealed packages and the detection of concealed weapons, chemicals and biological agents. However, there is a distinct lack of compact, robust, efficient and all solid-state sources offering powers >1 mW that operate at room temperature in this frequency range.

The iBROW project is developing such sources based on resonant tunnelling diode (RTD) device technology, primarily for the 90-300 GHz frequency range, to enable extremely high bitrate short range wireless connectivity. The approach uses oscillators employing up to four RTD devices both in synchronised and non-synchronised configurations, and crucially, using optimally sized (large) devices with stable DC operation.



RTD fabrication using BCB (benzo-cyclobutene) passivation/ planarisation.

RTDs are the fastest purely electronic, solid-state devices. RTD oscillators have achieved record fundamental oscillations at 712 GHz (~25 years ago!) and recently 1.55 THz, but with very low output power (a few microwatts). These oscillation frequencies are currently beyond the highest frequency transistor oscillators built to date. Detection experiments have demonstrated that the negative resistance responsible for these oscillations may persist to frequencies as high as 2.5 THz, indicating the potential of RTDs as a technology platform for THz electronics. However, to date they have not been used as local oscillators (LOs) in millimetre (mm)-wave or THz heterodyne systems or other practical systems because of their low output power.

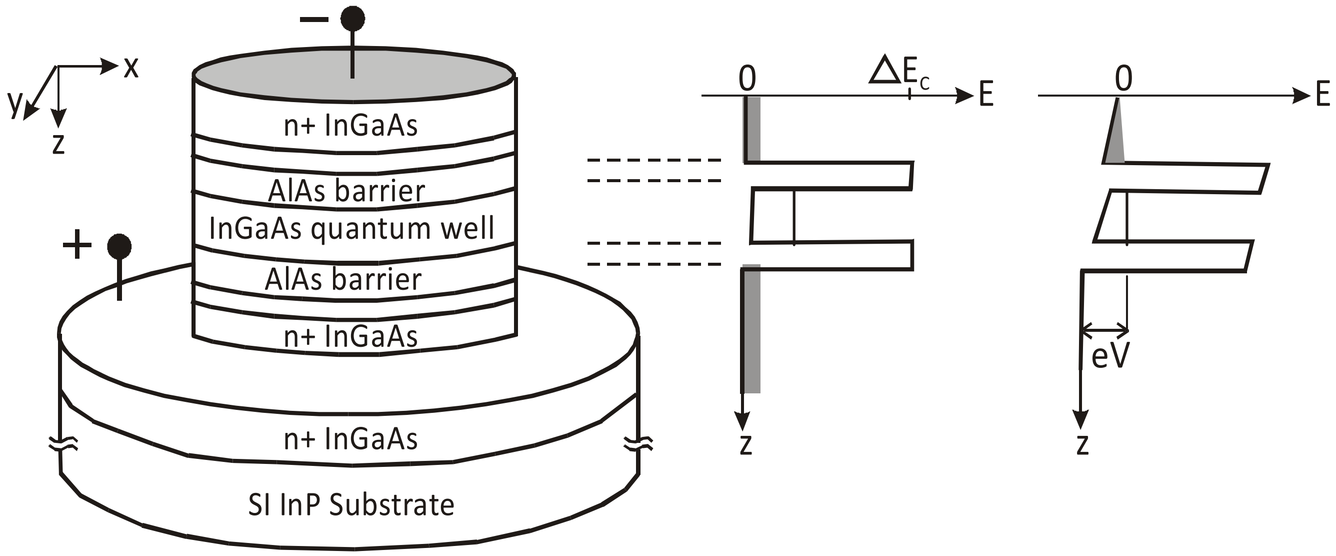
Competing technologies

For mm-waves, *Gunn-diode based LOs* are widely used, as they can deliver <2 mW output powers in the 200-300 GHz range. At THz frequencies, *far infra-red lasers* (which require cryogenic cooling), *backward-wave oscillators* (BWOs) or *Gunn oscillator-varactor* multiplier combinations are used. Typical power levels are in the 0.3-1 mW range at around 500 GHz. In comparison, the RTD offers greater DC-to-RF efficiency and does not suffer from linewidth multiplication. Compared with *impact ionisation transit-time* (IMPATT) diodes (which offer higher power at fundamental oscillation frequencies <400 GHz), the RTD has much lower intrinsic noise and thus provides a narrower oscillator linewidth in a given resonator. *Conventional transistor oscillators* (including Si-based devices) are increasingly reported in this frequency range, but require very fine sub-micron (or even sub-100 nm) features and amplifier stages to achieve modest output power levels (10s of µW). The RTD oscillator would be competitive for this >100 GHz frequency range because of its low power requirements, simple technology (photolithography usable up to 300 GHz), and the potential for portable compact sources of a few cm^3. Recently RTD-based multi-Gbps wireless transmission was demonstrated at ~500 GHz, although the range was only a few centimetres due to the low output power.

→ *This limitation of low output power is one of the main technology challenges being targeted in the iBROW project.*

Overview of the RTD device

An RTD consists of a vertical stack of nanometric epitaxial layers of semiconductor alloys forming a double barrier quantum well (DBQW), as illustrated below for a device realised in the InP-based material system which is being used in the iBROW project. The electrical carrier transport across the DBQW is mainly through the resonant tunnelling quantum effect.



InP-based DBQW RTD structure with energy band profiles at zero and at the first resonance.

RTDs exhibit two distinct features when compared with other semiconductor devices:

- *Negative differential resistance* This characteristic effectively corresponds to electric gain. This follows since the DBQW acts like a Fabry-Pérot interferometer for the charge carriers' wave-functions. This gives rise to an N-shaped current versus voltage (I-V) characteristic. The corresponding negative differential resistance (NDR) portion of the I-V characteristic gives rise to electric gain.
- *Extremely high frequency operation* This feature arises from the very thin (a few nanometres) resonant tunnelling structure along the direction of carrier transport. This makes RTDs the fastest pure solid-state electronic device operating at room temperature, with working frequencies in excess of 1.5 THz.

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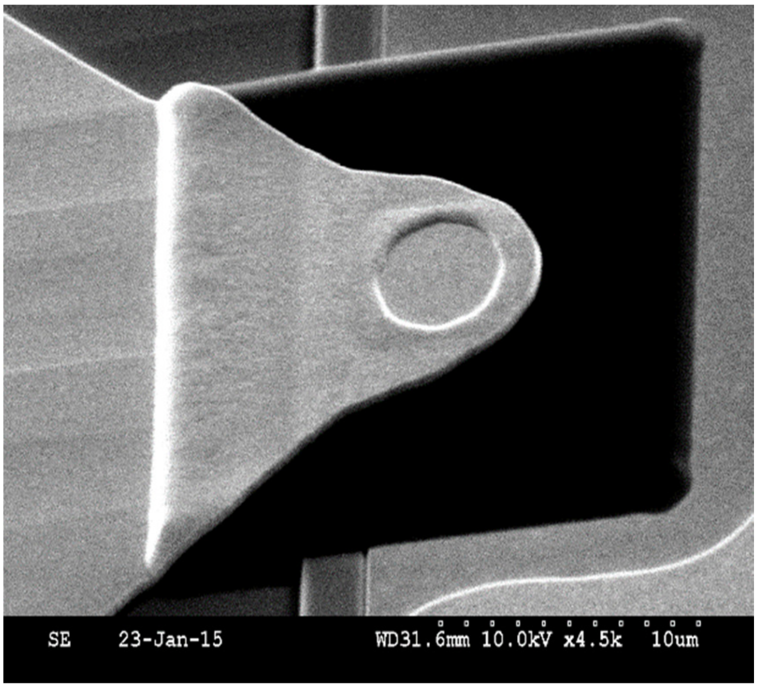
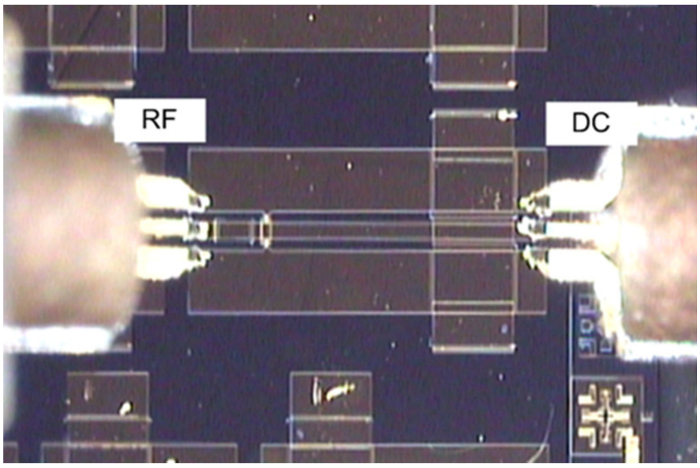


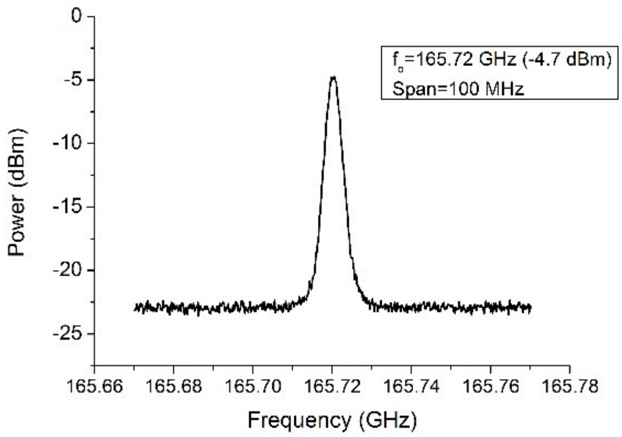
Scanning electron microscope (SEM) micrograph of a fabricated RTD device.

These unique features make it possible for RTDs to operate as amplifiers and oscillators, significantly reducing the number of elements required for a given function, and providing an interesting solution for high-speed communications.

110-170 GHz RTD oscillators with record output power performance

Integrated circuit free running oscillators employing two RTD devices in a single circuit in co-planar waveguide technology were recently realised at the University of Glasgow in the iBROW project. They demonstrated record output powers in the D-band frequency range: a 125 GHz, 156 GHz and 166 GHz oscillator employing large-size, 15 or 25 μm² RTD devices, produced 0.68 mW (-1.7 dBm), 0.47 mW (-3.3 dBm) and 0.34 mW (-4.7 dBm) output powers, respectively. The photograph below (left) shows an RTD IC oscillator during measurement, and (right) the measured spectrum of a 166 GHz oscillator. Simulation results show that with improved circuit design as well as circuit realisation, output powers reaching up to the industry desired levels of 5 mW in this band will be achievable in the near future. Future research is focussed on this and on realising oscillators with integrated antennas and oscillation frequencies beyond 200 GHz.





Left: Photograph of the fabricated oscillator that employs two RTD devices during measurement setup with probes landed on the chip. Right: Measured spectrum of the 166 GHz RTD oscillator

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iBROW project presentation at IEEE 802.15 (IG THz)

During the IEEE 802 Plenary in July 2015 at Waikoloa (Hawaii, USA) a presentation on the iBROW project was given to the IEEE 802.15 IG THz. The THz Interest Group (IG THz) was formed in 2008 and its focus is THz communications and related network applications operating in the THz frequency bands between 275 GHz and 3 THz. Such THz communications applications include; component to component, board to board, machine to machine, human to machine and human to human, (indoor and outdoor) wireless communications.

THz communication applications cover multiple categories with varying requirements. THz wireless systems could support transmission distances ranging from the very short (up to a few centimetres) to relatively long distances of several kilometres.

As a spin-off from the IG THz, the task group 3d (TG3d) was established in March 2014, which works on an amendment of 802.15.3 targeting 100 Gbps for switched point-to-point links at a carrier frequency of 300 GHz. Applications of interest include wireless data centres, wireless back-hauling/front-hauling, point-to-point close-proximity communication including kiosk downloading and intra-device communication. The group is currently working on the supporting documents describing the applications, technical requirements, evaluation criteria and channel models, which will be relevant for the call for proposals, which is currently scheduled to be issued in November 2015.

The technology developed in iBROW targets slightly different applications from those covered by TG3d. However, iBROW is very relevant for the IG THz and may form the basis for spinning off another task group towards the end of the project. The project presentation from July 2015 was well received and it was agreed that iBROW will contribute regularly to the IG THz.

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International Conference on Advanced Laser Technologies (ALT15): 07-11 Sep-2015

UAlg UNIVERSIDADE DO ALGARVE

Advanced Laser Technologies ALT15
7-11 September 2015, Faro, Portugal

The 2015 International Conference on Advanced Laser Technologies (ALT15; www.altconference.org/alt15) will be held at the University of Algarve (Faro, Portugal). The event is focused on fundamental and engineering aspects of laser technologies along with their applications in various research topics such as laser-matter interaction, surface and bulk materials engineering, ultra-fast phenomena, technological laser systems and diagnostics, bio-photonics, photo-acoustics, communications and THz technologies.

The ALT conference series was established in 1992 by the Nobel Prize Laureate Alexander Prokhorov, member of the Russian Academy of Sciences and Director of the General Physics Institute, and since then it has been a unique opportunity for presenting original research on fundamental and engineering aspects of laser technologies along with their applications in various areas (materials processing, laser medicine, photonic devices, systems for process control, etc.). Extended version of the conference abstract will be published as a special issue of Optical and Quantum Electronics (indexed by SCI and Inspec). ALT15 has already attracted more than 200 researchers. Among them are several iBROW consortium members and two invited papers will present the recent progress made in the project. *[Times subject to change.]*

(1) Optical Communication; Session OC-1 FRI 11-Sep-2015; 09:00-09:20 OC-I-1 (Invited)

"Performance assessment of fiber-wireless systems based on 1.55 µm directly modulated VCSELs," H. M. Salgado (INESC TEC, Portugal)

(2) THz Sources & Applications; Session TH-1 MON 07-Sep-2015; 11:20–11:40 TH-I-2 (Invited)

"Resonant tunneling diode terahertz sources," E. Wasige, J. Wang, A. Khalid, A. Kelly, D. Cumming, (University of Glasgow) & J. Figueiredo (CEOT, University of the Algarve).

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