iBROW – Innovative ultra-BROadband ubiquitous Wireless communications through terahertz transceivers

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1. Introduction

The demand for bandwidth in wireless short-range communications has doubled every 18 months since 1980 [1], and it is expected that wireless data-rates of multiple tens of Gbit/s will be required by the year 2020 [2]. Broadband internet with high bandwidth services and applications such as high definition multimedia, web-TV with multi-casting capabilities, real-time video and fast peer-to-peer applications are in continuous evolution and demanding ever higher data rates. In parallel, the increasing penetration of the population with mobile devices like tablets and smart phones, as well as the general trend to mobile broadband connectivity along with the "smartification" of our technical environment ("Internet of Everything") will contribute decisively to this trend.

To address the predicted future network usage requirements, the iBROW project aims at the development of energy-efficient and compact ultra-broadband short-range wireless communication transceiver technology. The envisaged usage and deployment scenarios such as ultra-broadband services for indoor- and campus- or stadium-like environments have in common that they address end users and may involve a high number of detached RF-frontend nodes in order to provide good coverage. Furthermore, high bitrate communicating wireless nodes operating in the range of up to 100 Gbit/s as targeted by iBROW involve extremely high signal processing effort in the front- or backhaul, driving costs and requiring high power consumption. This problem can be to certain extent addressed by radio-over-fibre (RoF) concepts in centralised radio access network-like architectures (CRAN) or distributed antenna systems (DAS). Both have in common that the bulk of signal processing tasks is shifted into a central node, which may run the high performance signal processing and hence can be more expensive and power consuming than the remote RF-frontend nodes which can be held relatively primitive and efficient needing only low power.

iBROW is pursuing its objective through the exploitation of Resonant Tunnelling Diode (RTD) based transceiver technology, and targets the development of (1) an all-electronic RTD suitable for integration into cost-effective wireless portable devices and (2) an optoelectronic RTD, consisting of the integration between a RTD and a photodetector and a laser diode, which will be suitable for integration into mm-wave/THz femtocell base stations connected to high-speed 40/100Gbps fibre-optic networks.

To achieve the targeted 100 Gbit/s wireless transmission speeds it is indispensable to rely on the exploitation of the mm-wave and THz frequency bands [3], above 60 GHz and up to 1 THz, since the frequency spectrum currently in use (in the 1-6 GHz range) is not expected to be suitable to accommodate the predicted future data-rate requirements, in spite of the significant and continuous progress that has been achieved in spectrum efficiency techniques, including spatial re-use methods such as beam-forming and MIMO. The proposed RTD technology can serve both source and detector functions.

This paper will describe several results already achieved on iBROW and preview upcoming work including a brief description of the target application scenario, and the modelling of the mm-wave/THz channels at the target operation frequencies of 90 and 300 GHz. In addition, a few results will be presented on the high performance RTD oscillators in the 75-200 GHz range as well as first results on the integration of InP RTD epitaxial wafers on a silicon host substrate through wafer bonding.

2. iBROW target application scenario

Figure 1 illustrates the iBROW target scenario, identifying both downlink (DL) and uplink (UL) communication directions as well as the key technology blocks being developed, namely (1) the all-electronic RTD suitable for integration into cost-effective wireless portable devices, and (2) the optoelectronic RTD, consisting of the monolithic integration between a RTD and a photodetector (an RTD-PD) and hybrid integration with a laser diode

(RTD-PD-LD), which will be suitable for integration into mm-wave/THz femtocell basestations connected to high-speed 40/100 Gbit/s fibre-optic networks.

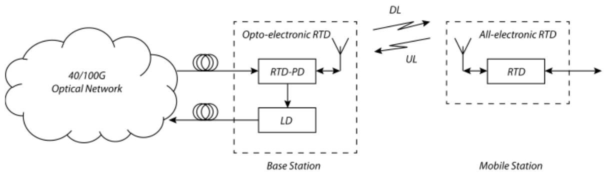

Figure 1 – Schematic representation of the iBROW target application scenario.

3. Channel modelling for THz indoor communications

A channel model is an essential component for the system and link level simulations. It is based on channel measurements with Vector Network Analyser (VNA) or channel sounder (CS) and describes the channel characteristics. Channel models are generally classified into deterministic and statistical models. The former requires a detailed description of application scenario, such as the ray launching channel model [4]. The latter generates a channel randomly based on the statistical channel characteristics. Both models depend on the choice of application scenario and the statistical channel model provides more sense of generality and requires less computational effort. Besides the static channel model, another important aspect of the indoor wireless channel is the human blockage problem of the propagation path since the human body can no longer be assumed transparent as at several GHz carrier frequencies. To model this phenomenon, a human blockage model was developed [5] as well as a realistic human movement model [6]. The generation and application of channel models are depicted in Fig. 2.

Within iBROW, three representative application scenarios are considered: a small office scenario, a meeting room and an auditorium. The single office scenario accounts for 1-2 users while the meeting room scenario has an increased numbers of users where in addition to the static situation, a dynamic component plays an additional role. For the third scenario, the number of users is higher and the concept of distributed antennas can be investigated. Fig. 3 shows a photo of the second scenario and the corresponding ray tracing model.

Preliminary channel measurements have been carried out in the small office scenario. The results are presented in [7]. Compared to the channel with conventional lower frequencies, the investigated channels suffer from a much higher free space path loss and the distributions of the angles of departure/arrival are more specular. Since the bandwidth is very broad, the symbol duration is usually shorter than the delay spread, which suggests serious inter-symbol interference.

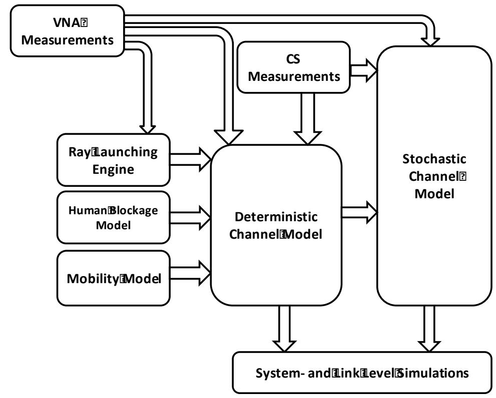

Figure 2 – Generation & application of channel models.

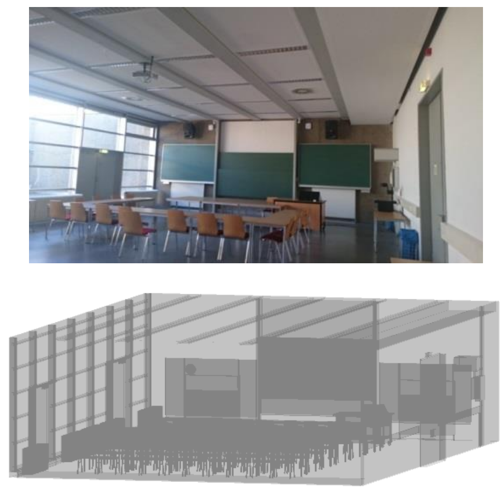

Fig. 3 – Meeting room scenario and ray launching model.

4. The RTD technology

An RTD device consists of a narrow band gap semiconductor material sandwiched between two thin wide band gap materials. These devices lend themselves to an efficient integration with optoelectronic components (photodetector and laser) since they are made from the same material system [10]. RTDs also require very low power consumption and unlike traditional transistor technologies, they possess an intrinsic gain (provided by its negative differential conductance region) which allows for a simple and energy efficient implementation, avoiding the employment of a number of complex transceiver building blocks, such as power or low noise amplifiers which can be rather inefficient [10]. RTD devices exhibit the highest oscillation frequency among traditional electronic devices. The published highest frequency of single device RTD oscillator is 1.55 THz with 0.4 μW output power [11].

iBROW targets the realisation of indium phosphide (InP) based RTDs on a silicon host substrate with devices and circuits realised using conventional integrated circuit technology in order to achieve a potentially very high-speed and low-cost solution. The RTD technology being developed at University of Glasgow aims to raise the power level up to several milliwatt (mW) for frequencies over 100 GHz. To date on iBROW, 76 GHz / 0.95 mW, 125 GHz / 0.34 mW, 156 GHz / 0.24 mW, 166 GHz / 0.17 mW RTD oscillators were have been realized [12][13].

The epitaxial heterostructure of RTDs fabricated in iBROW (Fig. 4a) are grown by molecular beam epitaxy (MBE) on a semi-insulating InP substrate by IQE Ltd. The devices are fabricated using optical lithography. A micrograph picture of the completed RTD device is shown in Fig. 4b. The maximum available power (P_{max}) of single RTD oscillator can be estimated from $(3/16)\Delta V\Delta I$, where ΔV is the peak-valley voltage difference, and ΔI is the peak-valley current difference. By optimizing the layer structure, it is possible to maximize the ΔV and ΔI to further increase the obtainable power [14].

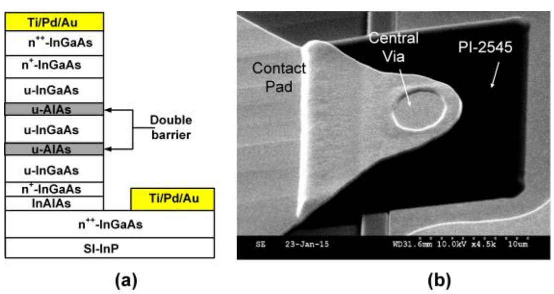

Fig. 4 (a) The epitaxial layer structure of a RTD device. (b) Micrograph of the fabricated 5×5 μm² RTD device.

Measurement results

The oscillators were characterized on-wafer by using an Agilent spectrum analyser with relevant external mixers. The results are, summarized in Table 1. RTD oscillators presented here demonstrated significantly high performance in terms of higher output power, especially in W-band frequency range. In these designs, no intent was made to match the impedance. Future designs will employ optimized epi-structures and integrated impedance matching networks, in particular integrated antenna loads designed to match the RTD impedances.

TABLE 1: SUMMARY OF RTD OSCILLATOR PERFORMANCE

Device size (μm^2)	CPW length (μm)	Freq. (GHz)	Power (dBm/mW)	DC Power (mW)
16	120	75	-0.2/0.95	422
25	30	125	-1.7/0.68	415
15	30	156	-6.3/0.24	374
15	20	166	-7.7/0.17	191

5. III-V on silicon technology

In order to introduce III-V materials in the low cost silicon platform manufacturing, the wafer bonding approach is of great interest due to the limitations of growing compound III-V hetero-epitaxial layers directly onto silicon. Direct wafer bonding refers to a process by which two mirror-polished wafers are put into contact and held together at room temperature by adhesive forces, without any additional materials. This technique has become a technology of choice for materials integration in various areas of microelectronics, microelectromechanical systems and optoelectronics [15]. In iBROW, characterizations of III-V epitaxial layers on InP wafers required for the RTD manufacturing show that surface defectivity is low enough to expect a correct bonding. Furthermore, a plasma surface activation before bonding was used to maximize the bonding strength after a low temperature annealing imposed by the difference of thermal expansion coefficient between InP and Si. Epitaxial layers on 50mm InP wafers were successfully bonded on oxidized 200 mm Si wafers. Acoustic characterization of the bonding interface shows a correct bonding yield which will allows us to develop post bonding RTD manufacturing step.

6. System considerations

In the emerging mass markets of fibre to the x (FTTx) and ubiquitous high bandwidth wireless access all the benefits of integration will be important, particularly low power and low cost. The technology must therefore be capable of addressing end-consumer markets, which means that it will face extremely high cost pressure and must support ease of deployment, i.e. our solutions need to be low cost, or at least must have the potential to become low cost when the technology matures during the coming years. In addition, back- or front-haul technologies for the wireless nodes need to support the above mentioned ease of deployment and must not involve high cabling effort. Especially in indoor environments, cabling can involve high effort and costs; under such conditions, unsuitable system architectures may become showstoppers. For instance, star-like network topologies would allow for highest data rates, but involve very high cabling effort (i.e. a fibre to each node). For this reason, advanced multiplexing techniques (TDM, WDM, T-WDM) and bus or daisy chain topologies are favourable. Last but not least, the system needs to be very energy efficient in order to avoid expensive and noisy active and noisy cooling solutions and to allow for low operation costs.

7. Conclusion

This paper described several aspects of the work being carried out on the European project iBROW towards realising a mm-wave/THz transceiver technology in RTD technology. Several achievements were highlighted and future directions pointed out. In the 300 GHz band iBROW is already well positioned to make impact both on Standardization of THz communications systems at IEEE 802 and spectrum regulation at the ITU-R level [16].

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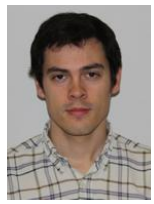
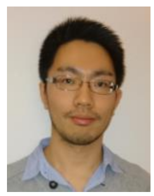
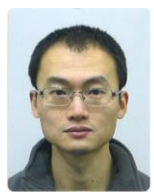


Luís Pessoa is a senior researcher at INESC TEC, mainly involved in the conception and management of R&D projects. His research interests include: coherent optical systems, fibre supported microwave systems, RF and microwave devices and antennas.



Bile Peng is a PhD candidate at Technische Universität Braunschweig. His research interests are THz channel measurement, modelling and estimation.



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Wolfgang Templ heads the department for radio transceiver research at Nokia Bell Labs where the investigation and design of new disruptive concepts for future communication systems based on new enabling device technologies is an important area of work.