# iBROW project newsletter #3

*September 2016*

**Welcome to the third iBROW project newsletter!**

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

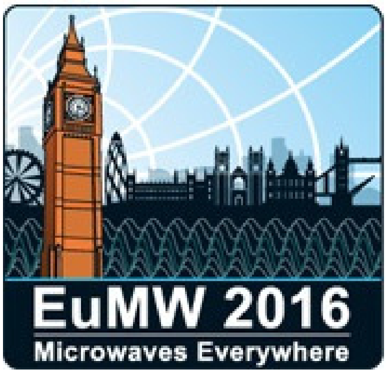
iBROW is a collaborative research project supported by the European Commission through Horizon 2020. The project will address the growing requirement for high bit rate short range wireless communication by exploiting the opportunities offered by resonant tunnelling diodes (RTDs). The project has already passed its mid-term point and the preparations for a demonstration of the technology are already underway. This newsletter contains:

- *iBROW presence at European Microwave Week in London early October 2016*
- *A discussion of the modelling of RTDs from University of Algarve*
- *Packaging considerations for high speed RTD and laser devices from Optocap*
- *An update on progress in reducing thread dislocation density (TDD) from IQE*
- *III-V on Si wafer bonding for RTD processing from CEA-LETI and III-V Lab*

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).

## iBROW at EuMW 2016

European Microwave Week (www.eumweek.com) is one of the industry's biggest annual events. This year the 19th EuMW will be held in London (03-07 Oct-2016), and includes an exhibition, three conferences, workshops, short courses and seminars.




iBROW will have a dedicated workshop (WF07) entitled "Compact and High Performance Millimetre-Wave and THz Sources & Systems" on FRI 07-Oct-2016. During the conferences there will be several other iBROW papers presented by University of Glasgow, covering various aspects of RTDs and related THz communications.

*There is also an iBROW booth (#075) with some 300 GHz devices on test, as well as some goodies to promote the project! Come along and meet the team!*

| | | |
|---|---|---|
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# Design and modelling of resonant tunnelling diodes

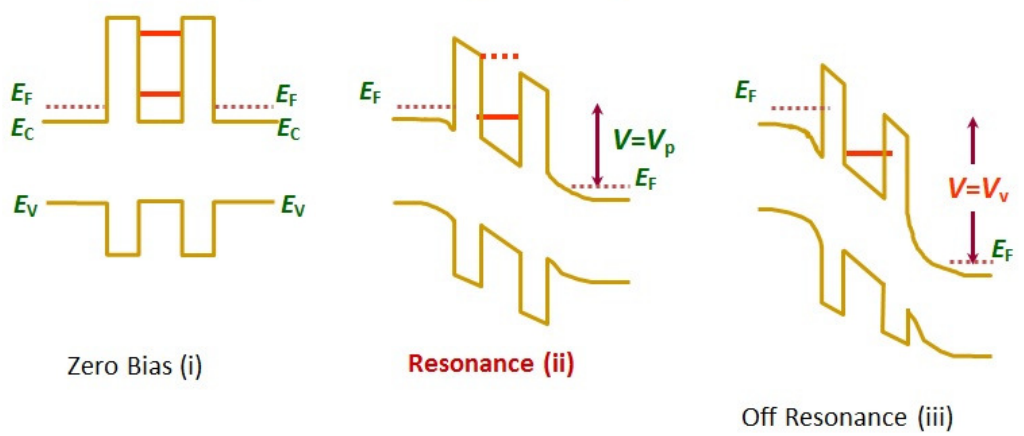
UAlg
UNIVERSIDADE DO ALGARVE

The iBROW project aims to develop cheap tiny transmitter chips based on RTDs capable of producing terahertz signals of several milliwatts at room temperature. The project will also demonstrate high speed high efficiency integrated semiconductor emitters and photodetectors employing an RTD structure with sufficient power/sensitivity for exploiting the full potential of the THz spectrum, and allowing for seamless fibre-wireless interfaces.

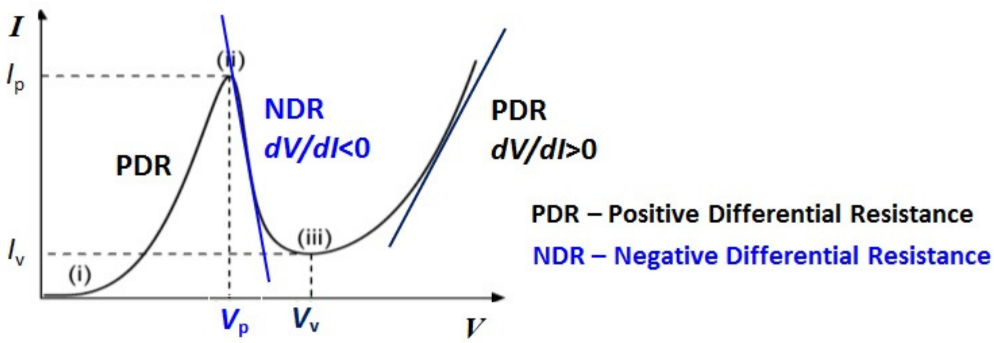
Due to their ultra-wide bandwidth negative conductance region (up to few THz) RTDs have long been considered strong candidates for the generation of THz radiation. When embedded into a resonator tank, oscillations at the resonator's fundamental frequency build up from noise due the RTD's negative conductance amplification effect, i.e. oscillations close to the resonator's fundamental frequency, instead being damped, are amplified by the device's negative conductance.

A basic semiconductor double barrier quantum well (DBQW) RTD consists of a semiconductor material with a certain band-gap (the quantum well) sandwiched between two thin layers of a higher band-gap material (the barriers). The DBQW is itself sandwiched between two doped layers of materials with band-gaps close to that of the well material, the emitter and collector, which form reservoirs for electrons.

DBQW-RTD band profiles under applied voltage



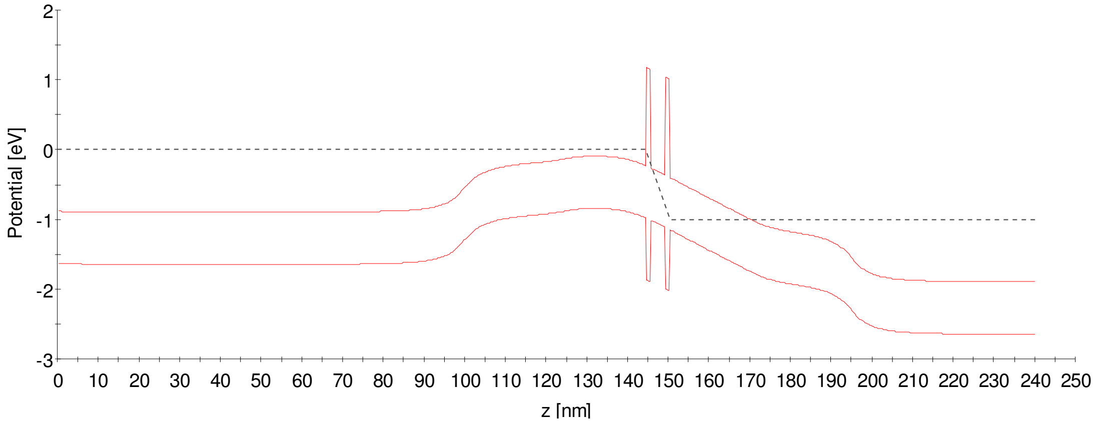

Current-Voltage (I-V) curve



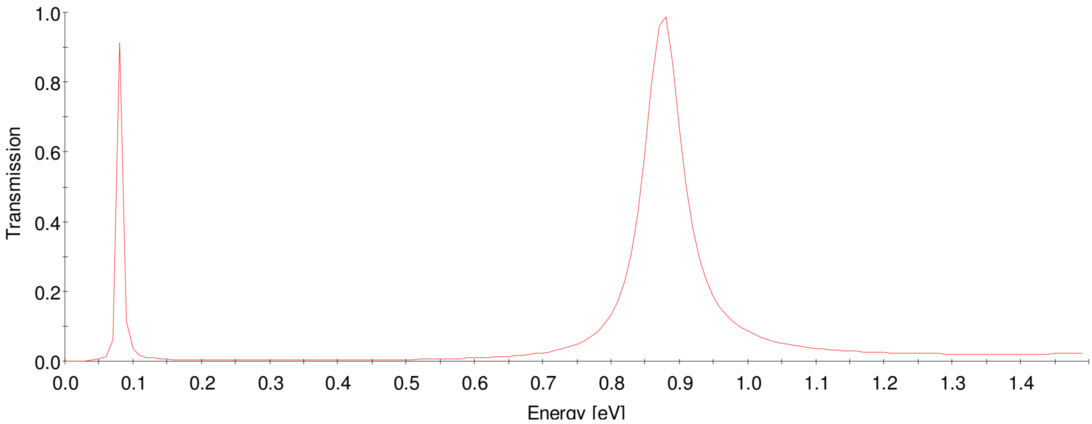

When a voltage is applied across the device, the DBQW acts as a filter for electrons trying to cross the structure, favouring the ones with energies close the quantum well energy levels. This filtering process gives rise to an N-shaped relationship between voltage and current instead of a straight line (as in a resistor) or an exponential curve (as in a rectifying diode): as the applied voltage is increased, at first the current rises (corresponding to a positive differential conductance) as the applied voltage pulls down the energy of the first quantum well level towards the Fermi energy level of emitter electrons. The rise of the applied voltage leads to an increasing number of electrons able to cross the structure through the first level of the well. Any additional increase of the applied voltage moves the first quantum well level toward the band-gap region, which leads to a sharp current drop and the device's differential conductance becomes negative. A further increase of the applied voltage gives rise to a gradual current increase, corresponding to the second positive differential conductance region.

The RTD, as a nano-electronic device, is an open quantum system in which electron transport is three dimensional, time dependent, time irreversible, dissipative, and many-body interactive, with both particle and energy exchanges with the device environment. The device system is therefore very different from a simple isolated quantum system, where a conservative Hamiltonian and the boundary conditions for the Schrödinger equation may be readily formulated. The iBROW device structure design and modelling requires considerable research on material and band-gap engineering properties, together with a thoroughly analytic investigation of the structures and the use of appropriate quantum mechanical modelling packages towards the production of device operating at the highest frequency and providing the power levels well above one milliwatt.

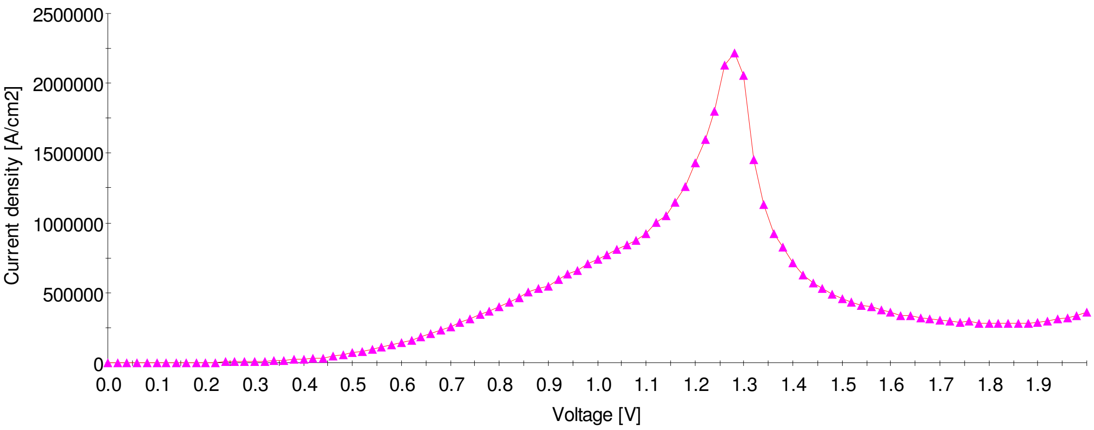
The structures under consideration are based on the InGaAs (well)/AlAs (barriers) DBQW grown on InGaAs (emitter & collector)/InP (substrate) with the incorporation of features (additional spacer layers etc.) that can lead to superior functionalities.




*Potential across the structure: emitter – DBQW - collector.*




*Charge carrier (electrons) transmission across the structure at 0.0 V.*




*I-V characteristic*

For more info contact José Figueiredo jlongras@ualg.pt

## Packaging for 300 GHz communications

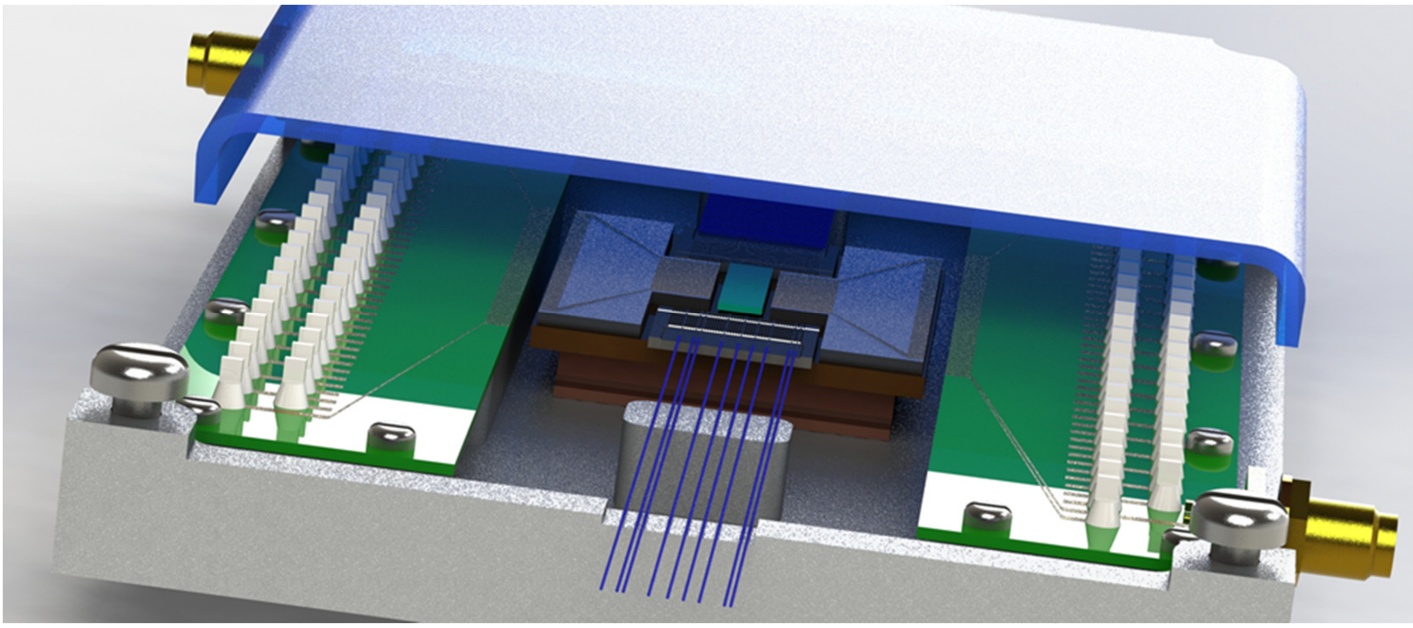
Optocap Ltd. provides contract package design and assembly services for microelectronic and optoelectronic devices. As part of iBROW, Optocap is focused on the delivery of high speed product designs for speeds of up to 300 GHz for use in the wireless communications data transfer market. This includes consideration of key design aspects including thermal management, optical design, high-speed (RF) integration, mechanical design, process development, supply chain evaluation and routes to high volume manufacture. For this project Optocap has developed two separate platforms: an open package engineering design, and a fully hermetic solution.

**Open package design**

The first design is based on an open package platform (using off-the-shelf components where possible) to give access for probing the components during testing and development. These components include, laser diodes, photodiodes, MZIs (Mach Zehnder Interferometers), couplers/ splitters and photonic integrated circuits. Using probes, electrical signals from a generic or custom PCB design can be supplied to the devices. Using single or ribbon cable optical fibres signals can be supplied or monitored.

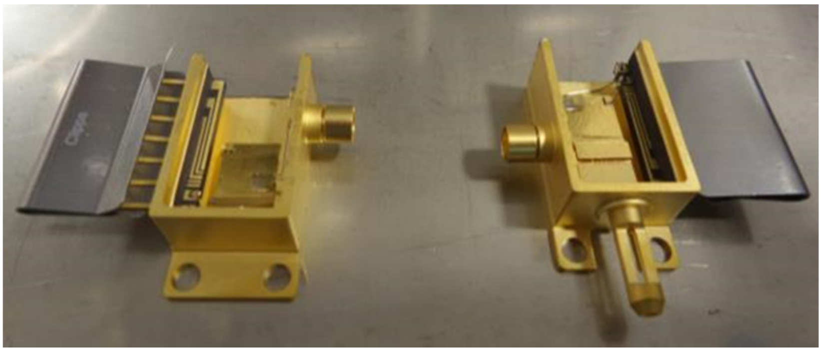
The platform allows for thermal management for different sizes of chip with various power requirements by using a range of TECs (thermoelectric coolers) from a few watts to many. This also allows devices to be characterised across a relatively wide temperature range. As the demand for more functionality onto a single photonic chip increases, so the demand for more inputs and outputs increases within a single platform. This open approach allows users to test the functionality of devices without going to the cost of a fully hermetic solution and prior to making adjustments to component performance, where required. The ability to integrate the device into a demo system reduces cost and time to market.

The unit can be (non-hermetically) sealed with a lid to provide a stable environment. However, it is well documented that a truly hermetic sealed package provides an improved environment for semiconductor and optical components which offers better device longevity.

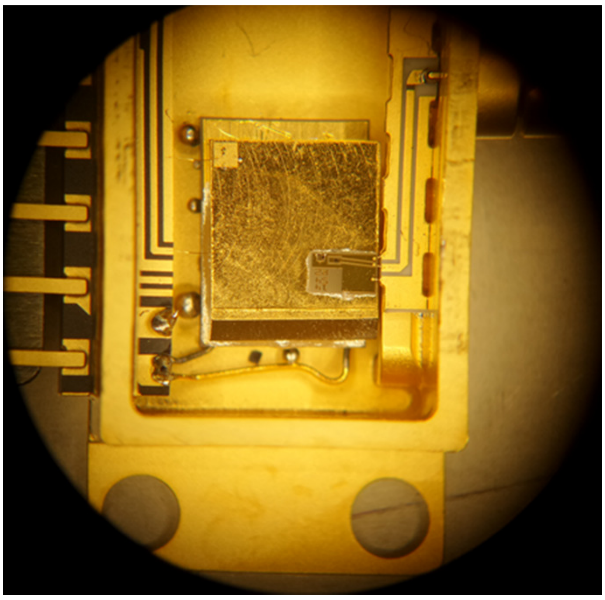


*Open package design for easy access to devices during test phase.*

### Hermetic package design



This involves Optocap working with INESC, UGLA and CST to develop a hermetic solution capable of delivering high data transmission rates with 300 GHz carrier signals. The combination of using RF simulation software for package design and the assembly of test vehicles allows a strong correlation between theory and practice. Components (laser diodes and high-speed carriers) supplied by our partners along with the Optocap catalogue of components has generated a 10 GHz packaged solution to demonstrate the correlation between the simulation and actual measured data.



*Optocap is developing a fully hermetic solution for improved reliability.*

These results will allow the partners to design an optimised package platform with suitable tracks and interfaces and to develop processes capable of integrating the iBROW devices including: RTD-PD, RTD-LD, oscillators and antennas as well as standard components, for example, thermistors and TECs.

Beyond this, Optocap is ensuring that the long term reliability, cost and quality of the product are not compromised and the design will fulfil all the requirements of international telecommunications standards.

For more info contact Ian Oxtoby
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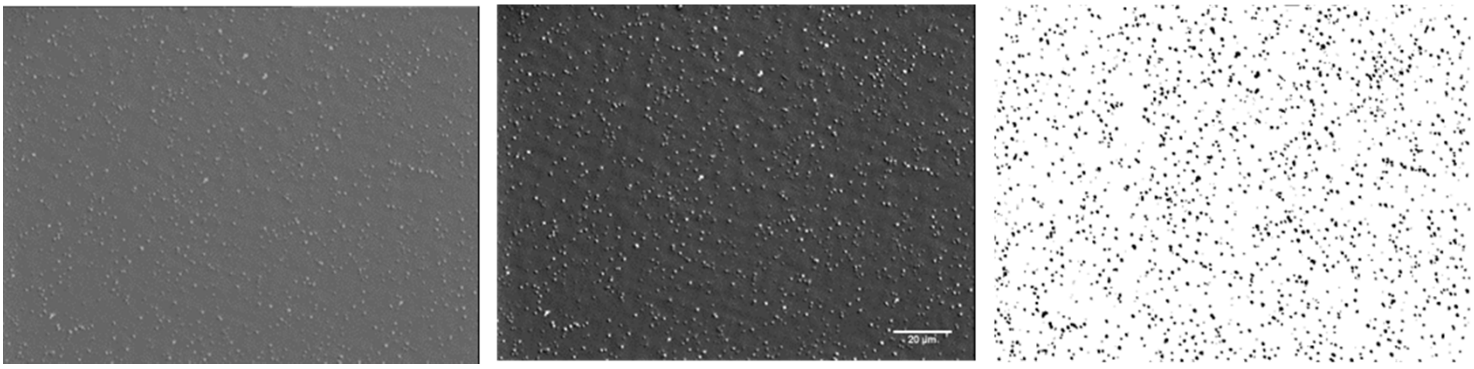
## Threading dislocation density measurement

Traditional evaluation of the threading dislocation density (TDD) in epitaxial layers has relied on cross-section tunnelling electron microscopy (TEM). This is a time consuming and costly exercise which, due to the limited area inspected and the effects of variation in sample thickness, can also be unreliable. This is particularly true as the defect density drops and the number of dislocations per image is small.

IQE's silicon epitaxy division (www.iqesilicon.com) has developed an in-house wet-etching metrology technique to quantify etch pit density (EPD). Following the etching of the surface of individual samples or wafers, a 200 µm × 200 µm image of a section of the sample is captured, enhanced and analysed to give a defect density.

In contrast to the standard method of cross-sectional TEM, this technique provides a fast, cost-effective alternative that offers improved accuracy for measurements of lower defect density. It is expected that this type of method will become essential to obtain accurate measurements for growth processes with TDD of less than $10^7$ cm$^{-2}$.



*Microscope images of 200 µm × 200 µm samples of the sample following the etching of the surface*
*→ Post etch* *→ Digitally Enhanced* *→ Contrast + EPD quantification*

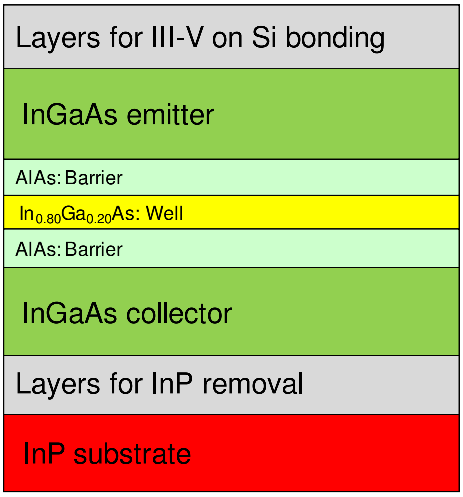
At the start of the development programme the original Ge-Si templates had a measured TDD of ~$5\times10^{8}$ $cm^{-2}$. To obtain the quality of the subsequent RTD epi layers for the planned devices, the target for the iBROW program was a TDD of <$5\times10^{7}$ $cm^{-2}$. Through careful experimentation and a series of process modifications, impressive improvements have been achieved. The latest processes show defect densities of <$1\times10^{7}$ $cm^{-2}$, i.e. an improvement of two orders of magnitude from the initial wafers!

For more info contact Stuart Edwards: SEdwards@iqep.com

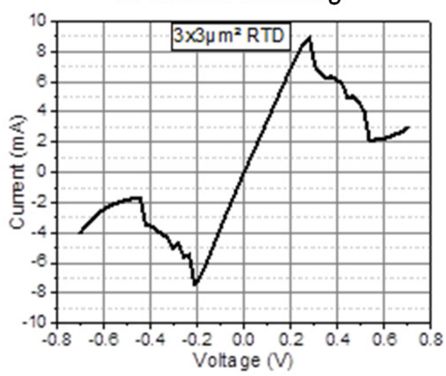
## III-V on Si bonding for RTD processing

A first batch of inverted RTD structures optimised for III-V on silicon bonding were grown by MOVPE at III-V Lab. The emitter top contact layer (after growth) becomes the bottom contact layer after wafer bonding and InP substrate removal. The active RTD zone comprises a double barrier quantum well (DBQW): an In-rich InGaAs quantum well sandwiched in AlAs barrier layers. The structure also includes specific layers on the top to facilitate the III-V on Si bonding.

50 mm InP wafers of such a structure were bonded on 200 mm Si wafers by CEA-LETI. The surface defect density was low enough to allow III-V on Si bonding with high yield as shown by the acoustic characterisation of the bonded wafer. More information on this process will be presented in the next newsletter. Following InP substrate removal and wafer dicing (75 mm) the RTD processing has been launched by III-V Lab. Promising results are expected! Standard RTDs (non-inverted structure) on InP have been previously processed for benchmarking. The devices demonstrate a peak current density around 100 kA/cm², a peak-to-valley current ratio (PVCR) >4 and a clear NDR region on forward mode as well as in reverse mode. This allows III-V Lab to validate the quality of the RTD zone grown by MOVPE.




*Inverted RTD structure for III-V on silicon bonding*




*I(V) characteristics of 9 µm² RTD on InP grown by MOVPE*

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