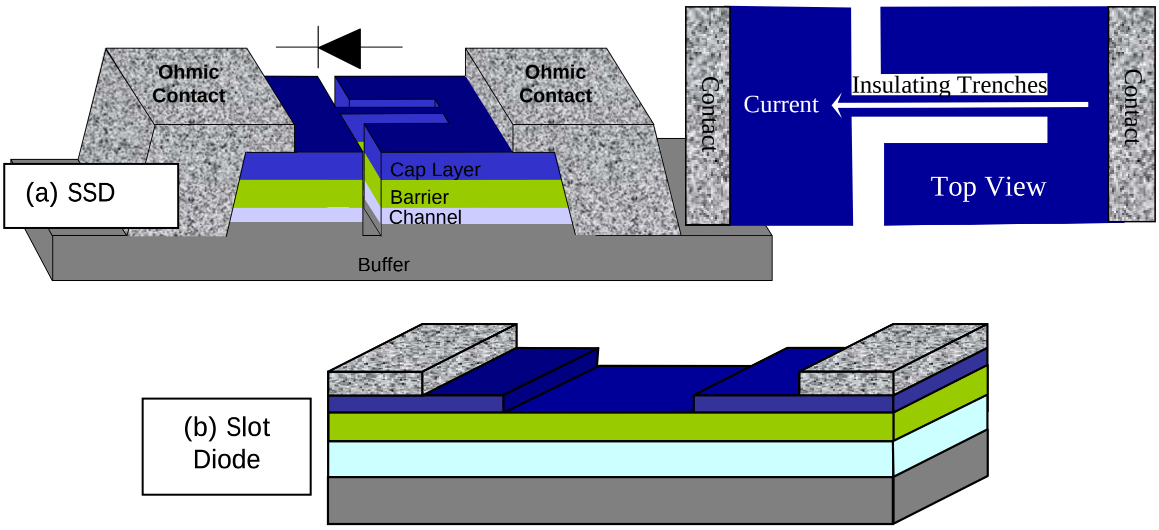
PUBLISHABLE SUMMARY

ROOTHz is a 3 year collaborative project funded within the 7th Framework Program (contract #243845) that started on January 1st, 2010. Four countries are represented in the consortium, Spain (coordination), UK, France and Sweden, with a well balanced effort and clear complementarities, as shown by the strong previous links between the research groups involved in this project.

ROOTHz addresses the bottleneck of Terahertz Science and Technology, where the fabrication of room temperature, continuous wave, compact, tunable and powerful T-ray sources (at low cost, if possible) is of primary interest. For this sake we propose to exploit THz Gunn oscillations in novel (narrow and wide bandgap) semiconductor nanodevices, which have been predicted by simulations but not experimentally confirmed yet. The fabrication of THz detectors with the same technology will complement this objective and make possible the demonstration of a simple THz detection/emission subsystem at the end of the project.

A typical approach to obtain THz sources, from the electronics side, is the use of frequency multipliers of fundamental oscillators such as RTDs, IMPATT and Gunn diodes. The oscillation frequency of classical Gunn diodes (based on the transfer of electrons to the upper valleys) can only be extended to a certain limit, around 300 GHz (associated with the scattering and energy relaxation frequencies). The novelty of our approach for overcoming this limit lies in combining two innovations:

- The material system, wide and narrow bandgap semiconductors: **GaN** where Gunn oscillations have never been observed and will be able to operate at high temperature and deliver a large amount of power; on the other side high-mobility **InGaAs** and **InAs** channels should improve the performances of THz detectors.
- The type of devices: In order to fabricate continuous wave (CW) THz emitters based on Gunn oscillations, instead of using "classical" vertical *n+nn+* junctions, we will investigate two new types of planar nanodevices: the **slot diode**, and the **self-switching diode (SSD)**.



Geometry of a typical (a) self switching diode and (b) a slot diode.

The simplicity of the technological process used for the fabrication of both types of nanodiodes is remarkable, since it only involves the etching of insulating trenches or recess lines on a semiconductor surface (a single step of high resolution lithography). Two main research lines will be followed:

- **Ultra-fast Gunn oscillations in slot diodes based on InGaAs:** In order to achieve oscillation frequencies in the THz range, the high field domain must be created in a very short time and move much faster than the saturation velocity of electrons in the channel. Monte Carlo simulations have shown that an InGaAs slot diode (two contact, recessed high mobility heterolayer) can work as a planar ultra-fast Gunn-like diode with oscillation frequencies exceeding 1 THz. Since this theoretical prediction has not yet been experimentally confirmed, one of the main goals of this project is to fabricate and characterise such a device.

- **Classical Gunn oscillations in SSDs based on GaN and InGaAs**: The special geometry of SSDs benefits the onset of Gunn oscillations since the electrical field is well focused at the cathode side of the channel and the electron concentration is increased by the side field effect, so that the classical criteria for Gunn oscillations is more easily reached. The main advantages of using GaN is that it will provide much higher power than traditional GaAs Gunn diodes at very high frequency (in excess of 300 GHz) due to its high saturation velocity, high breakdown field and the possibility of high temperature operation. The appearance of Gunn oscillations will also be examined in InGaAs (although the power will be much lower in this case) in order to verify the possibility of integrating THz emitters with detectors in the same dice.

The practical result of this project will be the fabrication of a CW, powerful, compact, room temperature source above 1 THz. No clear observation of continuous Gunn oscillations in GaN devices has been made; therefore, a first experimental evidence of such an effect could already be considered as a success of the project. The same can be stated for the ultra-fast Gunn oscillations. Both mechanisms have been predicted by Monte Carlo simulations but never experimentally observed. Another interesting novelty of this approach is the planar design of the devices, which allows not only for the enhancement of power emission and detection (by means of parallelization and the use of appropriate antennas) but also for introducing various devices with different characteristic frequencies that can provide better broadband performance and more flexibility of design.

The SSD provides an attractive rectifying non-linear *I-V* characteristic (without the use of any doping junction or barrier structure) and its threshold voltage can be tuned from almost zero to more than ten volts by adjusting the channel width and other geometric parameters. Additionally, since many SSDs can be placed in parallel without the need of interconnects (thus overcoming the high-impedance problems, typical in nanodevices, which may limit their extrinsic frequency performances) the sensitivity of the detectors can be enhanced by simply adding more devices in parallel. Moreover, the downscaling of SSDs is very simple, and by using high mobility semiconductors such as InGaAs the realization of devices working in the THz range as power detectors or frequency multipliers is foreseen. In this project we will investigate the use of novel Sb-based heterojunctions (mainly with InAs channels, but also InSb), with much higher mobility than InGaAs and allowing for ballistic transport even for longer devices, which can improve the cutoff frequency and the sensitivity of the detector response at THz frequencies. The operation of GaN SDDs as THz detectors will also be investigated for the possible integration with GaN emitters in the same dice, despite their expected poorer high frequency performance. Up to now, some experimental characterization of SSDs as THz detectors has already been made, but only at low temperature and in a limited frequency range using devices without an optimized design (and with no integrated antenna). In this project we aim to extract a complete spectrum of detection at room temperature, with quantitative and well calibrated data for the sensitivity in the 0.5-2 THz band.

During this first year of project progress we have been able to fabricate and characterize the first batch of devices, but no hint of THz emission has been obtained for the moment. On the other side, very promising results of THz detection has been obtained with arrays of InGaAs SSDs, even if they had no antenna.