[Invited] Building blocks and concepts for THz remote sensing and communications

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***Abstract*—We present technological building blocks and concepts under study which could ease the build-up of future THz remote sensing and communication systems. Critical issues regarding such systems mainly rely on the availability of sensitive and compact detectors together with powerful, large bandwidth and versatile sources.**

I. INTRODUCTION

ONE of the most interesting solutions for real time remote detection and identification of weapons and explosive in public places is the use of THz radiation. THz waves excite characteristic resonances of the material that allow discriminating among chemicals, and even among biological agents. Although prototype THz imagers already exist, until now the use of THz radiation for security purposes has been limited on one hand by the very low power delivered by the existing sources and on the other hand by the limited sensitivity of detectors operating at room temperature. THz quantum cascade lasers (QCL) can provide emitted powers up to tenths of mW, but requiring low temperature cryo-cooling. On the detection side cryogenically cooled detectors (in direct or coherent detection modes) could provide the necessary sensitivity but weight and complexity prevent large scale implementation on the field. In addition, security applications demands large stand-off distances (typ. 50 to 100m) and therefore could benefit from active systems which can i) illuminate the object or scene and therefore enhance the signal level, ii) allow coherent/heterodyne detection. In order to pave the route towards the implementation of THz remote sensing systems novel building blocks and concepts are studied that will be detailed in this presentation. In a similar way and almost with the same kind of requirements in terms of emitted power and detection sensitivity, high data bit rate THz communication systems could benefit from these building blocks. Such systems are already envisaged for 5G applications and large events as the future Tokyo Olympic Games [1]. Today, up to 100 Gbps has now been reached by several techniques (optics or electronics based) in the 300 GHz band [2].

Critical issues regarding such systems (remote sensing and communications) mainly rely on the availability of sensitive and compact detectors together with powerful and versatile sources (tunable for sensing, associated with a wide bandwidth for communications).

II. RESULTS

The high quality of THz carriers is also of utmost importance to enable these key applications. Considering THz generation from optical down-conversion, dual frequency lasers (DFL) appear as good candidates for the generation of extremely pure and highly tunable THz signals, through mixing in UTC photodiodes or photoconductive materials [3].

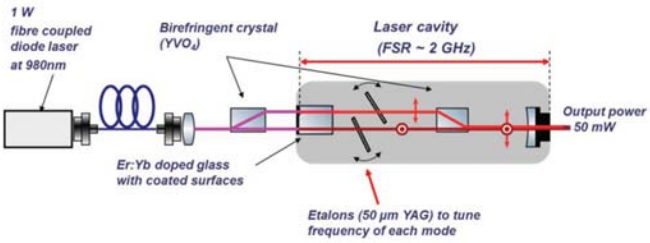

Fig. 1. Example of a solid state diode pumped dual frequency laser. The gain medium is a piece of Yb:Er co-doped glass, inserted within a cavity of 60 mm typical length. It delivers 10 mW output power on each optical frequency whose offset can be tuned, thanks to YAG etalons, over a typical 2 THz bandwidth. The "solid-state laser" approach provides both narrow linewidth, and low phase-noise on each optical component. The "single cavity" structure warrants a reduced phase noise of the beat-note, even without control loop.

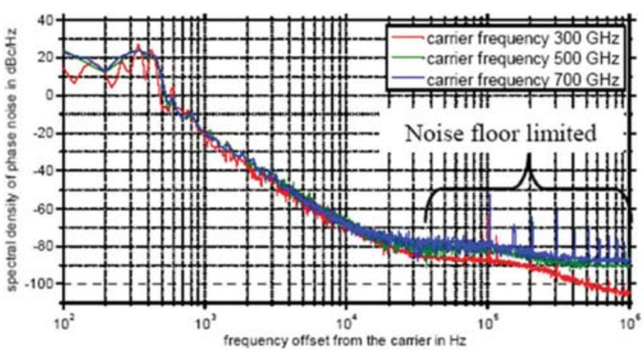

Fig. 2. Examples of the spectral density of the phase noise of the beat-note obtained when mixing the two frequencies from a DFL on a UTC photodiode (from IEMN). Note that the noise characteristics obtained without any control loop are almost the same when the frequency of beat-note is tuned from 300 to 700 GHz.

Such signals can be used, at low power level, as local oscillators (L.O) for coherent THz detection. When amplified through a traveling wave THz tube, including a carbon nanotube based cold cathode [4], or when used for injection and locking of THz QCLs, they can also provide the illumination source for THz remote sensing. Such lasers, mixers, tubes and injection locking schemes will be detailed.

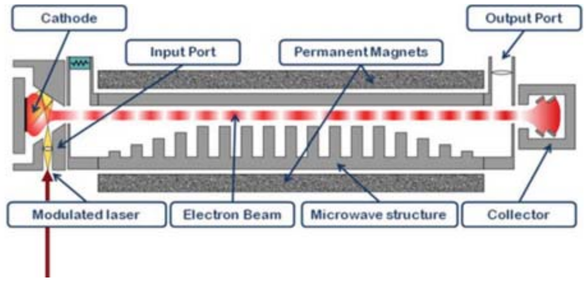

Fig. 3. Operating principle of an optically excited THz travelling wave tube. The cathode is made of an ensemble of carbon nanotubes (CNTs), optically excited through a plasmonic structure which align and concentrate optical field at the apex of CNTs. Field emission of CNTs (i.e electrons bunches) is modulated by a modulated or dual frequency laser beam through Fowler-Nordheim like effect.

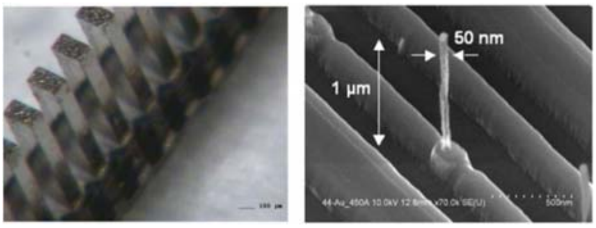

Fig. 4. Example of a THz slow wave structure realized using LIGA technique (20 to 200 µm typ. period with an aspect ratio > 1:10) (left). Example of a CNT grown on a "diffractive" structure. It provides an alignment of the polarization of the modulated optical beam (i.e of the corresponding electric field) onto the main dimension of the CNTs (right).

Potential use of plasma waves [5, 6] will be also presented which can be exploited for the realization of an efficient mixer operating at sub-millimeter wavelengths, either in semiconductor compounds or in graphene (Fig. 5). Once again it can be implemented in a coherent detection/injection scheme together with a solid state dual frequency laser.

Another type of mixer under study is based on the use of high Tc superconductive materials. When combined, for instance, with a L.O delivered by a THz QCL laser, such a high speed hot electron bolometer can provide a coherent detector to be used for both remote sensing and communications.

As potential perspectives, we will also introduce some new concepts under preliminary study such as i) injection of THz QCLs with a near infrared dual-frequency laser, ii) a travelling wave THz source based on structured graphene (exploiting in phase synchrotron emissions from a periodically corrugated graphene layer) (Fig. 6) and iii) THz emission based on spin-to-charge conversion as Inverse Spin-Hall effect, giving also rise to unconventional anomalous Hall effects in transition-metal based metallic spintronic multilayers [7] (Fig. 7).

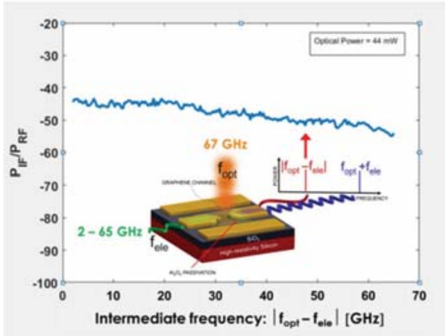

Fig. 5. Optoelectronic mixing within a h-BN/graphene/h-BN composite layer inserted in a coplanar waveguide. The waveguide is fed with a microwave signal at frequency f_{ele} (in the range 2-65 GHz) while the graphene layer is illuminated with a laser beam modulated at frequency f_{opt} (65 GHz). A signal at intermediate frequency $|f_{ele} - f_{opt}|$ is obtained, tuned through the range 2-65 GHz, with a ~-40 dB efficiency (ratio P_{IF}/P_{RF} on the vertical axis, still to be improved). Operation at higher frequencies is envisaged.

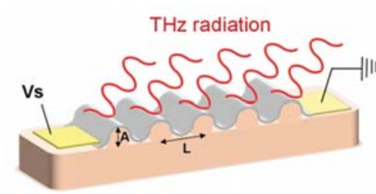

Fig. 6. Proposed original concept of a travelling wave THz source based on structured graphene. In phase synchrotron emissions from the periodically corrugated graphene layer is expected. Typical corrugations with A~ 10-50 nm and L~100-500 nm would result in an equivalent magnetic field of 100 T.

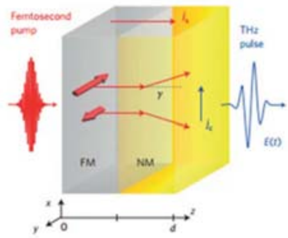

Fig. 7. Proposed original concept of THz emission based on spinorbitronics and spin-Hall effects in metallic multilayers. A fs laser pulse excites hot spin-polarized carriers at the interface between a ferromagnetic metal (FM) and a non-magnetic metal (NM). Spin relaxation generates ultrafast spin-currents and time-dependent charge oscillations.

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