Optically driven Field Emission Array for THz amplifiers

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Abstract: We present the first steps for the validation of a field emission array (FEA) adapted to the modulation of electron beams at THz frequencies. This specific cathode relies on the coupling of an infrared dual-frequency laser ($\Delta f \sim 1$ THz) with a field emitter array composed of Multi-Wall Carbon Nanotubes. Thanks to the pre-modulation of the electronic beam, increased powers are expected for the Traveling Wave Tube (TWT) configuration. To maximize the coupling efficiency, a 1D metallic grating is used to localized and magnify the incident energy laser beam around each field emitter. Numerical optimization as well as the experimental validation of the grating performances are presented.

Keywords: field emission, carbon nanotube, surface wave, grating, terahertz

Introduction

The Terahertz part of the spectrum (0.3 – 10 THz) presents a great interest in many fields such as space, security, medical and biology. For example, it provides new ways to detect weapons in crowded areas or to investigate the presence of drugs and explosives [1]. Up to now different ways have been proposed to address these issues (quantum cascade lasers, vacuum electronic devices, photomixing) but output powers are still limited to few mW. Indeed, compact sources are difficult to realize in this spectral range due to excessive losses both in optical and electronic systems.

Our approach proposes to increase powers delivered in the THz region using a TWT amplifier configuration. For such electronic devices, previous studies have demonstrated the interest of pre-modulating the electronic beam before releasing the energy of electrons to the amplified wave [2]. In particular, even small modulation depths have shown to induce highly efficient beam/wave interaction. Pattern of the European Project Ophther, we expect to take advantage of this feature to reach output powers on the order of 100 mW.

To obtain modulations of electronic beams at THz frequencies, the field emission mechanism occurring on cold cathodes can be coupled to a dual-frequency laser [3, 4]. In this case, a mixing component is generated in the emitted current thanks to the non-linearity of the tunneling current in the emission process. In particular, this effect requires the laser polarization to be aligned with the emitter axis (antenna coupling [5]). Up to now, this specific

polarization alignment has lead to consider only the side illumination of single emitters.

Nevertheless, to achieve the optical driving of integrated FEAs, vertical illumination is more practical. Therefore, to make the incident polarization compatible with this layout, we propose to integrate the FEAs on a specific 1D metallic grating design. This periodically corrugated structure is engineered to acts as a photonic band gap medium for surface plasmons (SP) [6]. More precisely, it allows to couple incident light to a surface resonance which localizes the incident radiation around each emitter location with the right polarization. The design and the optimization of this object constitute the first steps toward the generation of pre-modulated electronic beams at THz frequencies. In the following, we give an overview of the grating working principles, its numerical optimization and its experimental validation.

The grating design

Figure 1. Sketch of the considered periodic structure

A surface plasmon is a surface wave that corresponds to a resonant coupling between collective oscillations of metal electrons and an electromagnetic wave bound on both side of a dielectric-metal interface. In the infrared range, its dispersion relation on a flat metallic surface lies just below the light line. This characteristic imposes to find a moment matching route to couple it with the wavevectors of our normally incident laser beam. According to the diffraction law, this coupling is provided with a grating component equal to λ , the wavelength of the incoming radiation. After SPs are excited on the cathode, we localize them around particular areas in order to maximize the coupling with field emitters. In order to produce this confinement, we consider a second periodic component with a $\lambda/2$ period. This component allows to open a photonic band gap in the vicinity of the electromagnetic states that have been projected by diffraction. Then, the localization of energy on the grating surface can be produced by introducing a defect on this last component. For practical

realization, our final periodic structure associates these two harmonic components in a binary profile which minimizes the higher harmonics ($\lambda/3$, $\lambda/4$, ...). After the investigation of the efficiency of several defects, we obtain the geometry presented on figure 1.

The numerical optimization

A numerical optimization has been performed using our 2D dispersive Finite Difference in Time Domain code. This procedure aims to reduce radiative losses of SPs propagation on the metallic grating. In particular, we investigate losses induced by the finite size of the grating and by the corrugation depth. The computation corresponding to the spatial distribution of the localized mode is given on Figure 2. Interestingly, the field at the center is enhanced by a factor of 10 to 20 on the emitter location. Besides, we stress that the full-width at half maximum of the mode is 15nm for a 1.55 μm telecom laser. This is fully compatible with the mixing in the THz range which only requires detuning of few nms at this wavelength.

Figure 2. Structure of the simulated localized mode

The experimental validation

Two experiments are currently investigated to validate this concept respectively in the far field and in the near field regions:

- In order to validate energy localization, we develop an experimental setup to obtain the near field map of the electric field. This map is obtained by downscaling the electromagnetic problem to microwave frequency. Electric fields are then easier to probe by using a millimeter length antenna. In this configuration, a network analyzer was used to obtain the profile presented on figure 3 which experimentally confirms the expected mode shape.

- The simulated structure is also fabricated at telecom wavelength using an ion milling technique to pattern a gold thin film evaporated on a silicon substrate. A setup for normal incidence reflectometry is currently developed in the laboratory and is giving the first results.

Figure 3. Experimental map of the electric field at the surface of the grating

Conclusion

In conclusion, we are investigating the properties of a metallic surface grating to achieve the mixing of electronic beam up to THz frequencies. The design of the optimum structure and the numerical optimization are presented in addition to the experimental validation of the mode shape. Reflectometry measurements and perspectives for application of surface gratings in vacuum microelectronic will be discussed.

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