HIGH CURRENT DENSITY (> 1 A/CM^2) CATHODES BASED ON CARBON NANOTUBES FOR VACUUM MICROWAVE AMPLIFIERS

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Most long range telecom systems utilize microwave transmission links. With requirements for higher bandwidth and more channels, these microwave links are increasingly using the 30 GHz and above frequency range. In order to satisfy the power and bandwidth requirements for long range communications, satellites are using (up to 100) travelling wave tubes (TWTs) delivering around 100W.
In a TWT, the amplification process is based on the interaction between a modulated electron beam and an electromagnetic wave. However, up to now, only thermionic cathodes emitting a continuous electron beam are used. The beam has to be post modulated and this increases the size/weight of the TWTs by a factor of around 2. Thus, TWTs are bulky and heavy, and take up a valuable budget in a satellite (particularly for the satellite launch).
The most effective way to reduce the size and weight of a TWT is via direct modulation of the electron beam at the cathode. For this purpose, a cathode-grid assembly can be used. Compared to thermionic cathodes, field emission cathodes operate at high fields and the very low cathode-grid transit time allows then to design high frequency devices. Spindt demonstrated that arrays of Mo tips with integrated and self aligned gate electrodes exhibit excellent field emission performances in a dedicated ultravacuum system (peak current per tip up to 100 µA for a 100-tip array, [1]). Microwave cathodes were successfully modulated in a 10 GHz klystrode (10 µA/tip, modulated current of 4 mA, [2]) and in a 6.8 GHz TWT (0,5 µA/tip, modulated current of 5 mA, [3]). However, no further developments seem to have been done, probably because Mo tips are relatively fragile and also because cathodes with integrated gate electrodes exhibit very high input capacitances (cathode-grid spacing ~ 1µm) which are limiting their high frequency performances.
Arrays of carbon nanotubes are extensively studied as cold cathodes for vacuum nanoelectronic applications because CNs are extremely robust, are able to emit large electron current densities (> 1 A/cm^2) and can be operated with large cathode-grid spacings (eg. 100 µm). In order to evaluate this new technology for microwave amplifiers, we have been studying CN devices which operate at 1.5 and 32 GHz.
5 µm height and 50 nm diameter (at tip apex) multiwall carbon nanotubes/nanofibers (CNs) were grown by plasma enhanced chemical vapour deposition (fig. 1). After growth, a rapid thermal anneal at 850°C was performed to improve both their crystalline quality and their electrical contact to the substrate. This allowed us to fabricate CNs each capable of 60-100 µA emission current in continuous mode (fig. 1 and [4]). A 1.5 GHz diode based on a 0.5 x 0.5 mm array of 2500 CNs delivered a peak current density of 12 A/cm^2 (12 µA/tip, modulated current of 30 mA, fig. 2 and [5]). First results on identical CN arrays integrated in a 32 GHz microwave triode will be presented (fig. 3).
This new type of cold cathode could lead to a breakthrough in vacuum amplifier technology and in particular for TWTs.
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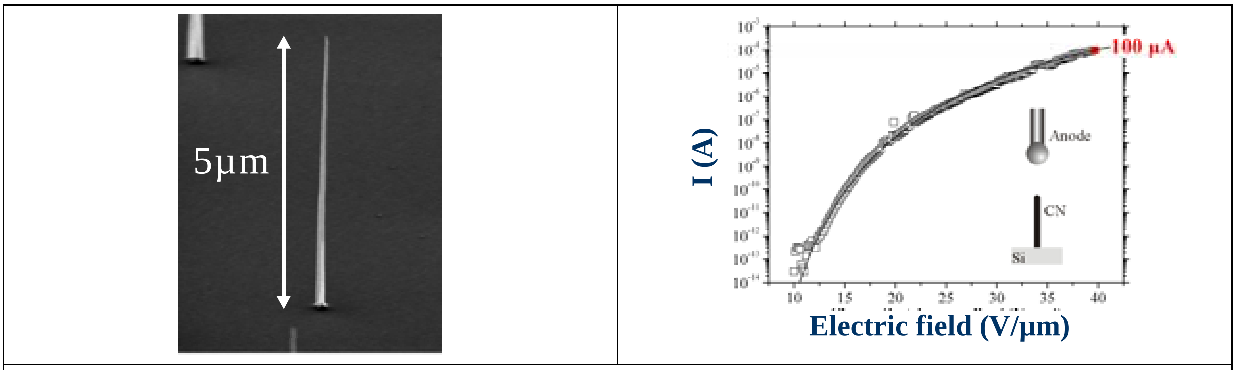

Fig. 1: SEM picture (left) and field emission properties (right) of a 5 µm height and 50 nm diameter CN. E. Minoux et al., Nano letters 5, 2135 (2005).

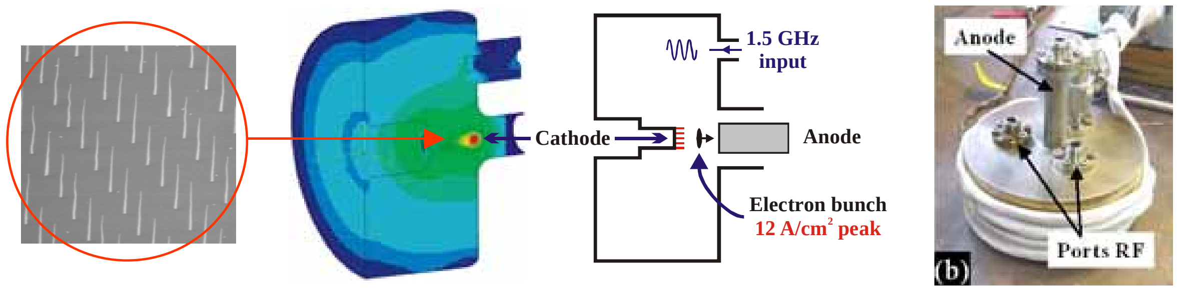

Fig. 2: Array of 2500 CNs (10 µm pitch) integrated in a 1.5 GHz diode.

The peak current density is 12 A/cm^2. K. Teo, E. Minoux et al., Nature 437, 968 (2005)

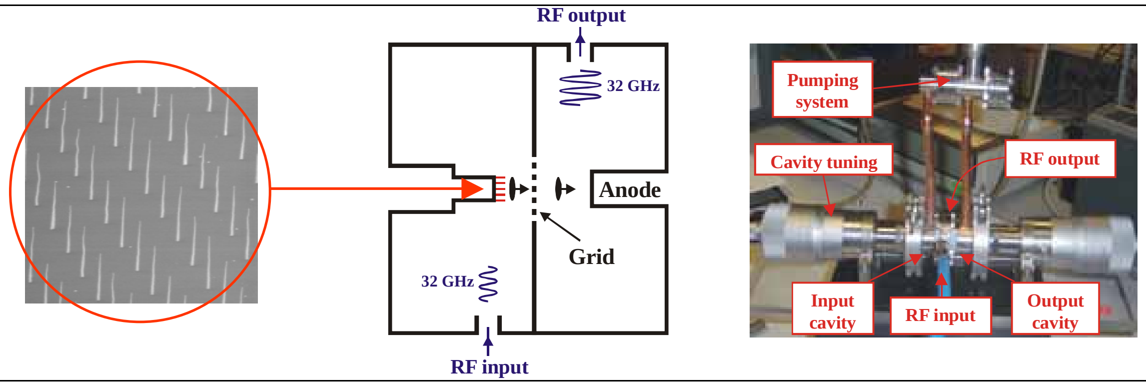

Fig. 3: Array of 2500 CNs (10 µm pitch) integrated in a 32 GHz microtriode.

First experiments will be presented