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Carbon fiber electron injector for free-electron maser experiments

M. Korol, E. Jerby *, S. Eckhouse, M. Bensal, A. Shahadi

Faculty of Engineering, Tel-Aviv University, Ramat Aviv, Tel-Aviv 69978, Israel

1. Introduction

The electron emission ability of carbon fibers was studied early in the 1970s [1,2]. Electron emission from single carbon fiber was obtained in a wide range of residual gas pressures. A long operation time of the fiber and good emittance stability are reported [1]. A current of 1 mA at a voltage of 3.5 kV was obtained. No breakdown was observed after 100 h of continuous operation [2]. The estimated current density from a single fiber is 10^5 A/cm^2. The electron emission tends to be noisy in high pressures, above 5×10^{-7} Torr. The noise level can be reduced by heating the fiber, or by an appropriate resistor connected in series to the cathode.

Carbon-fiber emitters have been studied with commercial carbon yarns and with specially prepared fibers [3–7] in a wide range of cathode voltage, from 250 V to 1 MV [3]. Electron currents were observed both in pulse [3] and in a continuous operation. A preliminary heating of the fibers up to 2900°C for a few hours leads to a better current stability [5]. A better current stability is received also by increasing the average current and the cathode operating time [6].

A carbon fiber emitter made of a bundle of ~300 fibers is described in Ref. [4]. A current of 0.1 mA was measured at a voltage of 1–2.5 kV and a pressure of 10^{-6} Torr, for ~10 h of continuous operation.

Compared to other cathode types, the carbon-fiber emitter has the advantages of simplicity and low-voltage operation. Unlike the thermionic cathode, the carbon-fiber emitter does not require heating. Comparing it with the common carbon bulk field-emission cathode, it has the advantage of low-voltage operation, and it does not require special preparation and activation process.

Preliminary results of a carbon-fiber electron-gun experiment are described in this paper. The gun emits a

* Corresponding author. Tel. +972 3 6 408 048, fax +972 3 6 423 508, e-mail jerby@tauniom.tau.ac.il.

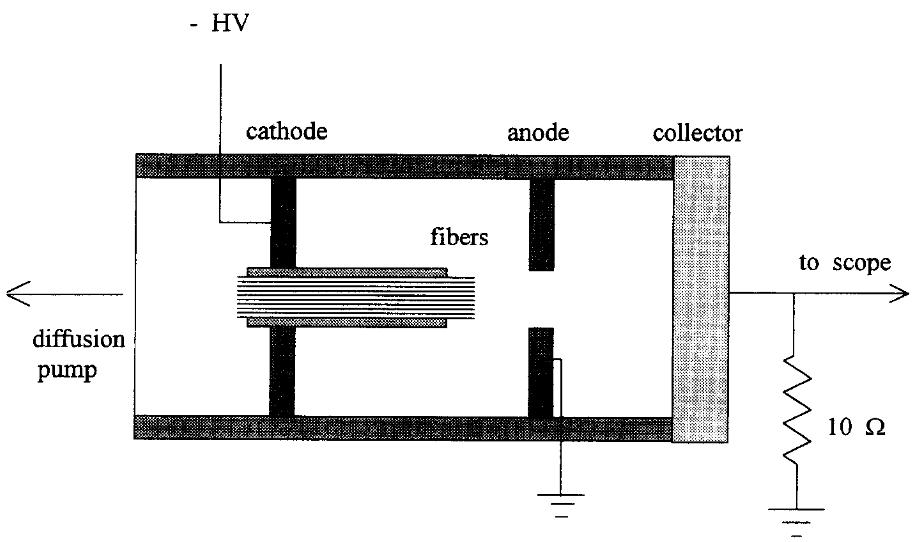

Fig. 1. Principal scheme of the carbon fiber gun.

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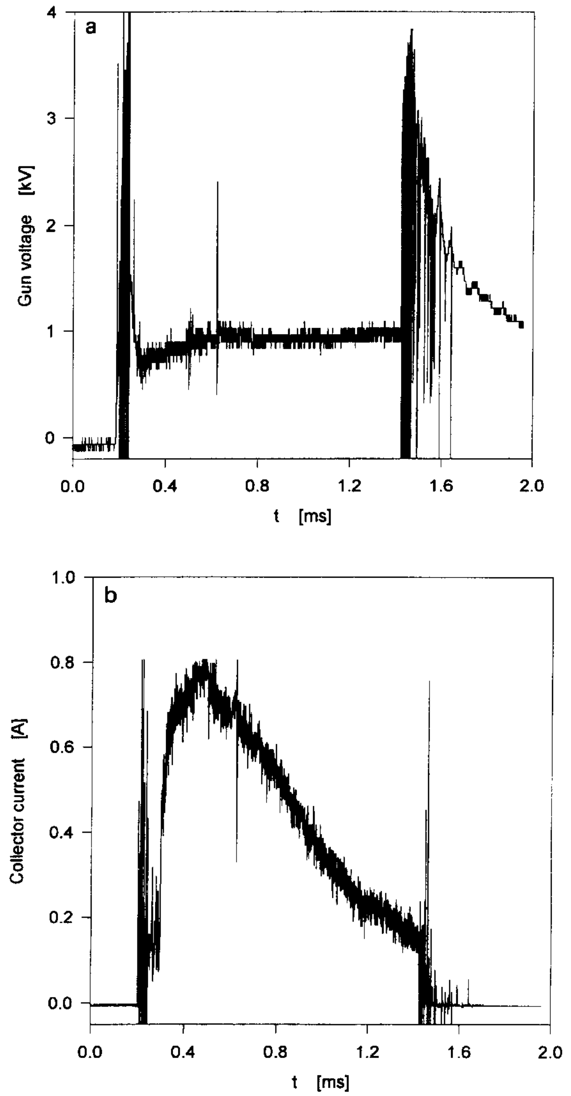

Fig. 2. Typical experimental results of the carbon fiber injector. (a) The carbon fiber gun voltage. (b) The electron beam current measured in the collector.

current of ~ 1 A at ~ 1 kV from a 5 mm diameter bundle of < 10 μm fibers. Possible applications of the carbon fiber gun in table-top cyclotron resonance maser and free-electron maser experiments are discussed.

2. Experiment

A scheme of the carbon fiber gun experiment is shown in the Fig. 1. The carbon-fiber electrode is placed inside the glass cylinder. Two tungsten electrodes, hermetically melted into the glass, are connected to the brass disks which form the cathode and the anode. The diameter of the hole at the center of the anode disk is 3 mm. A bundle of over thousand carbon fibers is placed in a copper pipe (5 mm inner diameter). The pipe is mechanically pressed at the end in order to tighten the fiber bundle and to provide a proper electrical contact. The fibers are carefully cut in the cathode emitting surface (without any etching process). The distance between the emitting surface and the anode is 10 mm.

The anode is connected to ground potential. A negative 1–3 kV pulse (1 ms pulsewidth) is applied to the cathode. The blank vacuum flange which seals the glass tube acts also as an electron current collector. It is connected to ground by a 10 Ω resistor to measure the effective electron beam current. The other side of the glass cylinder is pumped by a diffusion pump.

The cathode voltage and the collector current signals are acquired by a Tektronix TDS 540 digital oscilloscope. Typical results are shown in Figs. 2a and 2b, respectively. The voltage trace in Fig. 2a shows high-voltage noise for short durations at the beginning and the end of the pulse. In between, a stable 1 kV voltage is observed for ~ 1 ms. The current trace in Fig. 2b shows spikes at the pulse edges in accordance with the voltage noise durations. The current pulse reaches 0.8 A.

Further experiments are being conducted to study the electron emission characteristics from the carbon fiber cathode. The results presented in this paper motivate us to install carbon fiber guns in our nonrelativistic maser experiments at Tel-Aviv University. In particular, carbon fiber cathodes are designed to replace the existing thermionic cathodes in our traveling-wave FEM, the periodic and the non-dispersive waveguide cyclotron maser experiments, and in our recent masing TEM-mode FEM experiment [8].

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