Flat-panel CRT with channel guides

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Abstract

Electron beam guides hold the promise of a flat-panel display based on CRT technology. We propose to integrate the periodic focusing electrodes of such beam guides on a glass channel plate for a robust and simple design. The feasibility of this idea is tested numerically and experimentally.

1. Introduction

Flat-panel CRT-type displays have been a research topic for many years, particularly since they allow for a re-use of the established and well-understood CRT technologies and materials [1-2]. Typically, an electron beam is injected parallel to the screen and then deflected by electromagnetic fields to the right position on the screen. However, these flat CRTs usually suffer from non-uniform spot shape and size and errors in the beam landing angle and position. Besides the electron-optical problems, any reasonably sized flat-panel CRT needs internal vacuum support, but this would interfere with the scanning electron beam.

These problems are solved in matrix-type displays like field-emission displays, where a separately modulated electron beam is used for each pixel. However, these displays require a very large number of cathodes (or a uniform planar cathode) and a large number of cathode drivers.

A compromise between both approaches can be found in so-called electron beam guide displays, where a matrix-type addressing in one direction (a row of electron sources) is combined with beam deflection in the other direction (columns of electron beam guides). As sketched in figure 1, the electron beam guides direct the electron beams parallel to the screen to the addressed line of pixels, and then deflect the beams out of the guide to the screen. Several beam guiding displays have been investigated by RCA laboratories in the 1970s and 1980s [3-5] and later applied by Futaba in a vacuum fluorescent display [6].

Although RCA laboratories demonstrated a working prototype of a black and white guided-beam display, the manufacturing requires an assembly of a large number of high-tolerance parts. For color displays the alignment problem is even more stringent, since either three very small beam guides or a beam guide with additional scanning electrodes are required to address the RGB sub pixels [5]. Besides the mechanical difficulties, the extraction of electron beams requires switching potentials of the order of 450 V, which implies a large dissipation and expensive drive circuitry.

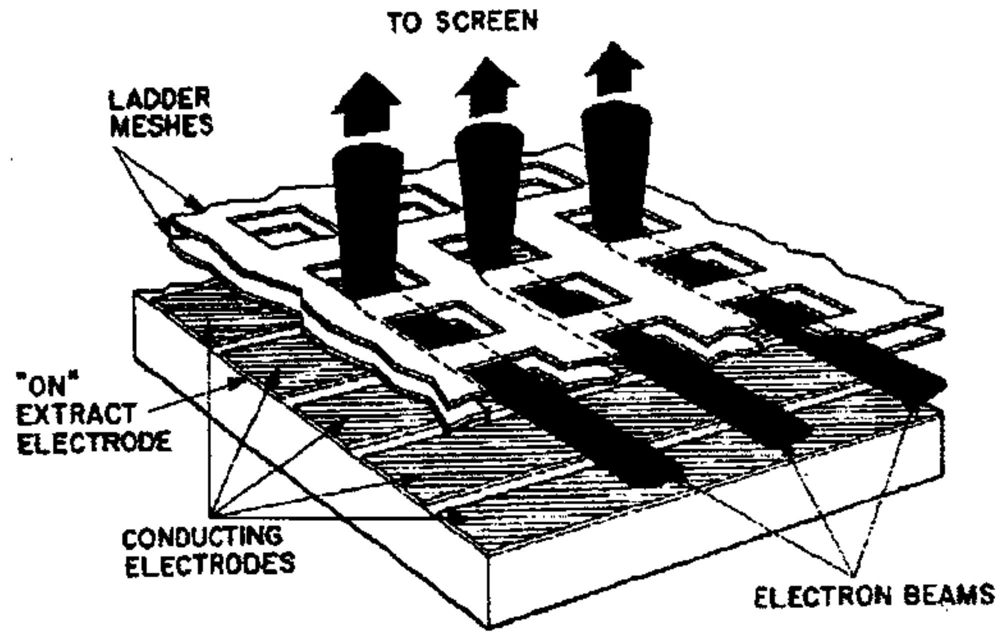

Figure 1. Sketch of an RCA beam guide. Figure taken from Ref. [1].

Here, we propose a new flat display principle based on a "channel guide". This is a periodic-focusing guide with improved stability and manufacturability as compared to the earlier guides. As sketched in figure 2, the basic idea is to use glass technology as has been developed for plasma display panels to integrate a periodic-focusing electrode structure onto a glass channel plate. The integration of electrodes on a channel plate gives the following advantages:

- a reduction of the number of elements to align,
- less variations between electrodes due to e.g. vibrations or alignment errors,
- a more symmetrical potential distribution perpendicular to the beam direction, which improves the stability of the guide,
- lower switching voltages (< 200 V) and more control over the extraction process, since the periodic-focusing electrodes inside the channel can also be used for extraction (similar to the Futaba concept [6]),
- possibility of color displays, since the pixel pitch is comparable to that of plasma displays, i.e. limited by the glass channel dimensions.

In section 2, we demonstrate the feasibility of an efficient channel guide display with color pixels of 0.6 by 0.7 mm (sub pixels of 0.2 by 0.7 mm) by means of numerical simulation. The experimental verification of the high transmission efficiency of a channel guide is discussed in section 3. We summarize our findings in section 4.

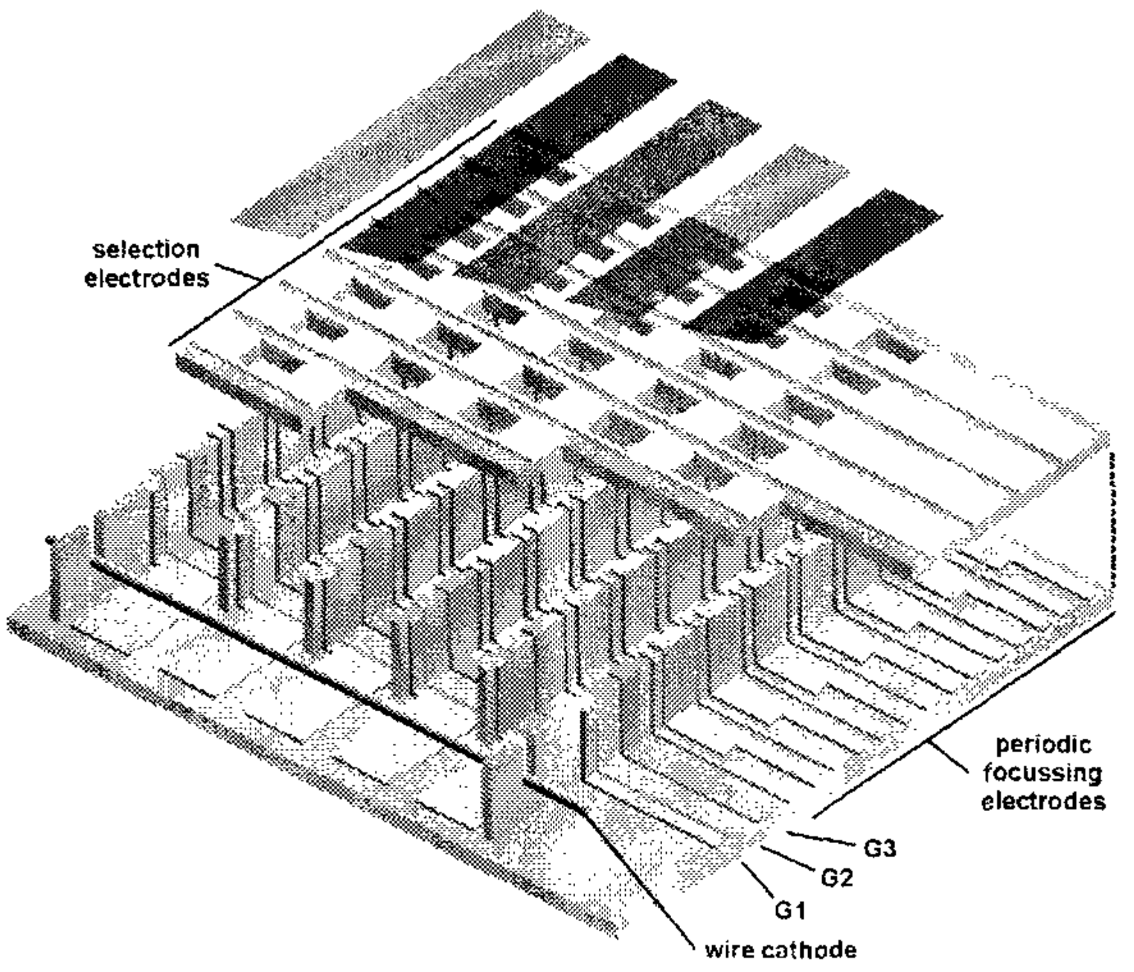

Figure 2. Basic lay-out of a. channel guide display: periodic focusing electrodes are deposited on a glass channel plate to form an electron beam guiding channel. By electrodes deposited on a second glass plate the electrons are extracted and consequently accelerated to a position on the phosphor screen.

2. Simulation of a color channel guide display

The channel guide is based on periodic-focusing ring-shaped electrodes with alternating high and low potentials [7]. The electrodes are deposited on glass plates with a periodicity of 0.7 mm along the channel direction. The channel width is 0.2 mm. To avoid breakdown a 3.5 mm spacing is kept between the channel plates at a low potential and the phosphor screen at 4 kV. Thus a total display thickness less than 1cm seems possible. The narrow electrodes (see figure 2) are deposited inside the channels of the bottom glass plate, as well as on the bottom side of the top glass plate, such that closed rings are formed. The broad electrodes on the bottom channel plate are insulated from the broad electrodes on the top glass plate containing the extraction holes. By giving the top and bottom part of the broad electrodes different potentials, the loss of symmetry due to the presence of extraction holes can be restored.

For the simulations we use a particle-in-cell method that takes into account the space-charge repulsion between the electrons, as described in Ref. [8]. For simplicity, we trace electrons as generated in a conventional triode section, where the size of the electron beam is first reduced by use of a diaphragm in front of the periodic structure (see figure 3). Of course, beam injection into multiple parallel channels of a real display requires a line source instead of a conventional triode.

The injection, transmission and subsequent extraction of an electron beam is shown in Figure 3. As periodic potentials, we use 150 V on the narrow electrodes, 41.5 V on the broad electrodes (bottom plate) and 25 V on the broad electrodes on the extraction plate to correct for the Durchgriff through the extraction hole and restore the symmetry in the channel.

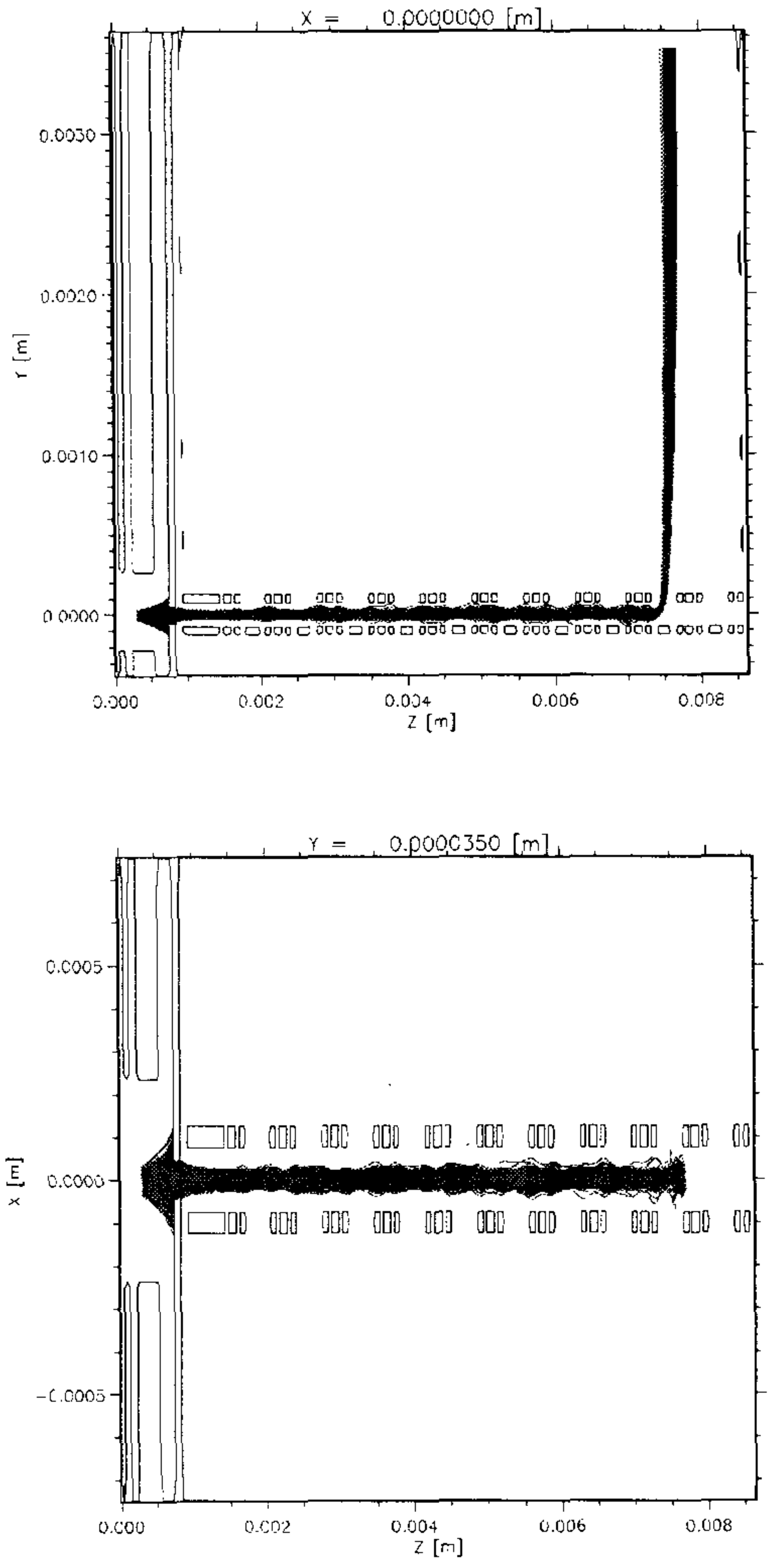

Figure 3. Horizontal and vertical projection showing the simulation result of an electron beam in a single channel in a channel guide display: an electron beam from a conventional triode is injected into a 10-period electrode structure and extracted at the 9th exit hole.

The beam is extracted by blocking the channel (switch the potential of the narrow electrode behind the addressed exit hole from 150 V to −10 V) and pushing the electrons away from the bottom of the channel (set lower part of broad electrode to −5 V). In fact, the zero-potential plane in the channel forms an electron mirror, the angle of which can be tuned by balancing the two blocking potentials [6]. The majority of the electrons are reflected by the mirror in the direction of the extraction hole and accelerated to the phosphor screen. A small amount of electrons is scattered back into the channel. We find a transmission to the screen of 99.5 %. In addition, the obtained spot on the phosphor screen has the same dimensions as the space used by a sub-pixel. So, the guiding channels are suited to construct a display without post-deflection or post-selection means.

The beam current in the configuration is 30 A. At the 4 kV screen potential and a typical phosphor efficiency of 10 lm/W, about 1 lm of light is generated per channel, which is more than sufficient for display applications. At higher values of the current, the repulsive space-charge force becomes stronger than the periodic focusing force and the electron beam hits the channel walls.

3. Channel prototype

We have tested the beam transmission properties on a single-channel guide, where, for ease of construction, all dimensions of the system have been scaled with a factor 5 (as compared to the display dimensions in section 2). The channel was constructed by sandblasting the bottom and top half of the channel in 1.5mm thick soda-lime glass plates. After deposition of the electrode structure, the glass plates were mounted together. This resulted a channel with a diameter of 750 m and a length of 80mm.

The channel electrodes were deposited using a cataphoretic (negative) photoresist and consisted of a Cr-Al-Cr stack, where the Cr and Al layers have a thickness of 50 nm and 1-2 m, respectively. The total guiding structure in the channel has 23 periods, where the high and low potential electrodes have a width of 500 m and 2500 m, respectively. The spacing between the electrodes is 250 m.

The numerical design of this test guide without extraction holes is shown in figure 4. The corresponding potential settings are given in table 1. We note that in this design the triode section, like the periodic structure, is integrated on glass at the entrance of the channel. Only the thermionic oxide cathode has to be mounted in front of the channel. The advantage of integrating the triode section on glass is that it gives a perfect alignment with the rest of the channel. Thus the generated electron beam is automatically positioned on the central axis of the channel. Furthermore, unlike in the previous simulations, no diaphragm was needed to restrict the beam.

Figure 5 shows photographs of the channel guide. The top photo shows the complete system: glass plates with a thermionic cathode mounted in front of the center channel, and connection foils to the periodic electrode structure. Several channels were constructed on the glass, but only the center channel was used. The bottom photo shows a close-up of the cathode region with a part of the periodic electrode structure. The red square emphasizes the integrated triode section.

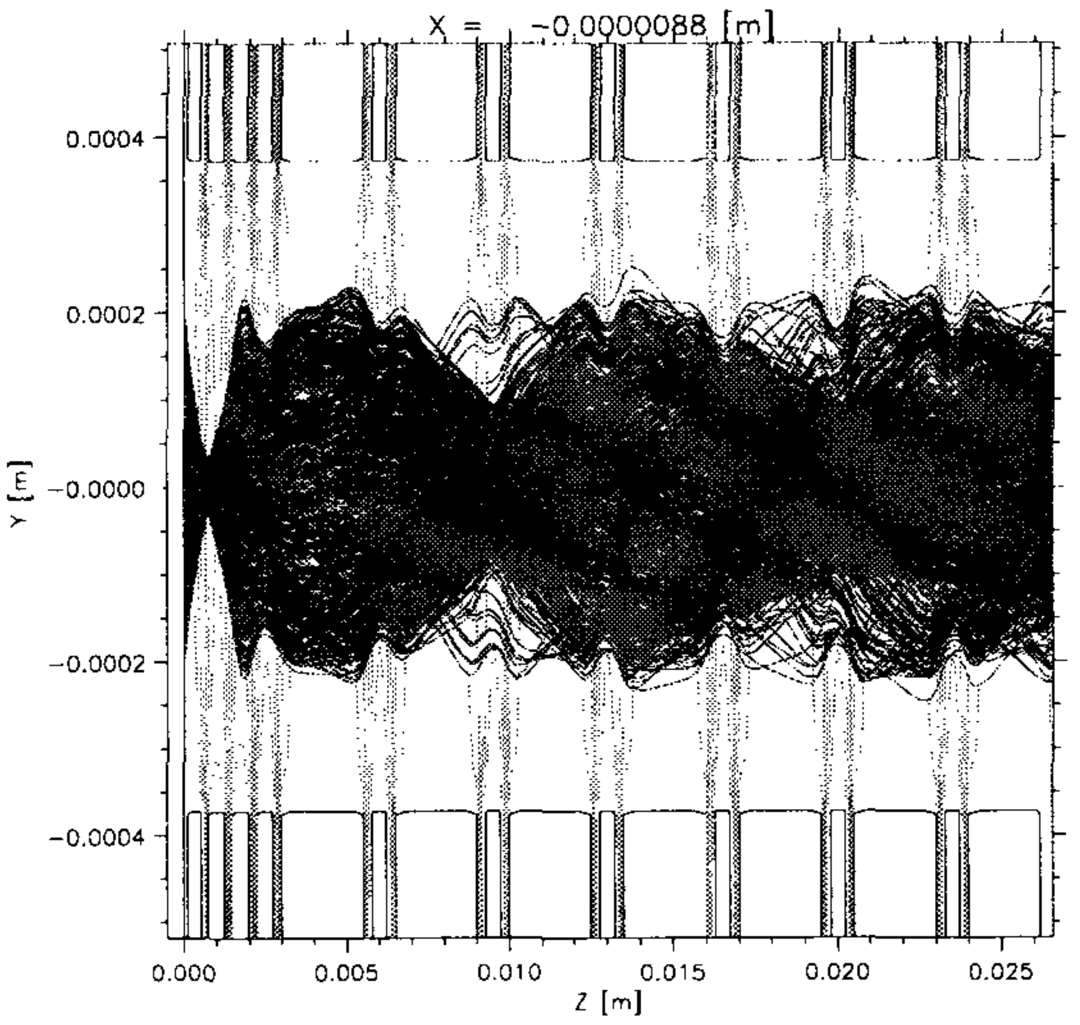

Figure 4: Detailed simulation of the experimental channel guide. The electrode contours are depicted in black, equipotential lines in green, and electron trajectories in red.

The performance of the experimental channel guide has been tested in a vacuum chamber. The transmission of the channel was determined by measuring the current flowing into the cathode and the current flowing from the anode. The anode was positioned at the end of the center channel and consisted of a glass plate covered with ITO and phosphor, which enabled us to see the spot created by the electron beam.

Electrode	Simulation	Experiment
Cathode filament	6.3 V	8.7 V
Cathode	0 V	0 V
G1	-10 V	-10 V
G2	250 V	230 V
G3	35 V	40 V
Narrow electrodes	200 V	200 V
Broad electrodes	50 V	65 V
Anode	-	250 V

Table 1. Potential settings of the test guide.

For the transmission experiments we started with the voltage settings as derived from simulations (see table 1). After fine tuning the different voltage settings a transmission of 99±1 % was achieved with the voltages given in the table. As observed, the voltage setting of the simulations and the experiments match quite well.

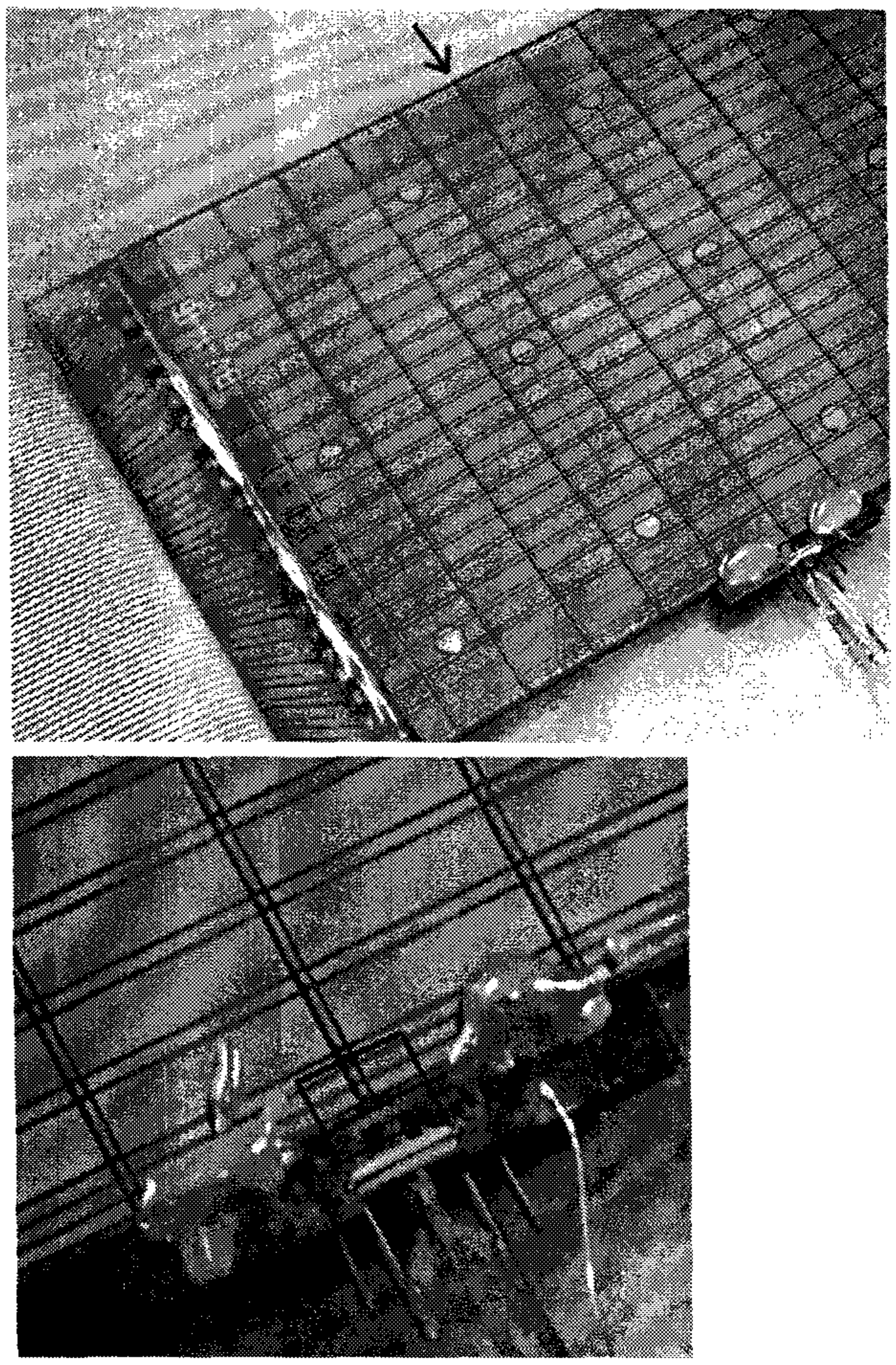

Figure 5. Two photos of the test guide. The red arrow in the top photo indicates the exit of the center channel; the red square in the bottom photo indicates the triode section, where the thermionic cathode is mounted at the entrance of the center channel.

The only significant difference between simulation and experiment is the cathode temperature. In the simulations a standard cathode operating temperature corresponding to a filament voltage of 6.3 V was used. This resulted in a electron beam with a current of 150 A. Because the cathode used in the experiments had been exposed to air after an initial activation, its performance was strongly degraded, even after reactivation. Therefore, a higher filament voltage of 8.7 V was used in the experiments. At these settings we were able to transmit an electron beam with a current of about 30 A through the channel with a transmission close to 100 %. For higher currents the G1 voltage had to be increased (less negative) or the filament voltage had to be increased. However, this leads to a more divergent beam at the entrance of the channel, which resulted in charging of the channel wall due to electrons hitting the glass between the electrodes. Due to this charging the stability of the guide dramatically decreased for beam currents above 30 A.

4. Conclusion

We propose to integrate the electrode structures of electron beam guide displays onto glass channel plates to improve the mechanical robustness of the system and simplify the manufacturing process. Numerical simulations demonstrate with regard to the electron optics that injection, transmission and extraction of electron beams are feasible for color displays with sub millimeter pixel sizes. The transmission efficiency is better than 99 % with switching voltages below 200 V. Experiments on a 23-period test channel agree well with numerical results.

5. Acknowledgement

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