Shaped and multiple electron beams from a single thermionic cathode

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Low throughout remains the single biggest problem of electron-beam lithography. Using low electron dose and highly sensitive resists will result in variations arising from shot noise, while employing high beam currents leads to beam blur due to the coulombic interactions among electrons. Variable-shaped beam and parallel bream approaches have emerged as promising alternatives, with companies such as IBM and KLA-Tencor having devoted significant efforts. It is also notable that Schottky emission sources are typically preferred over cold field-emitters, as thermal sources are known to offer better stability during the writing time, albeit at the cost of beam spot size. The heat spread in a conventional cathode (which is typically a good thermal conductor) also makes it impossible to create a variable shaped emission spot or multiple closely packed emission spots on the same cathode surface. It is also desirable to excite/control the cathode optically, which would enable addressing the beams using lasers.

Here, we demonstrate shaped and multiple thermionic electron emission spots from a single cathode. The cathode consists of an array of vertically aligned carbon nanotubes (a carbon nanotube forest) with macroscopic dimensions, grown using chemical vapor deposition. Previously, we reported a "Heat Trap" effect, through which the heat generated at a laser-illuminated spot on this otherwise conductive material remains localized.[1] This allows the spot to locally heat to thermionic emission temperatures using laser powers as low as only a few milliwatts. Here, we show that this effect can be used to create emission areas that essentially follow the shape of the irradiating light beam or multiple beams. Figure 1 shows the experimental apparatus, where the electron-emitting surface of the nanotube forest sits at 45 degrees with respect to the phosphor screen capturing the emission pattern (on the left of the figure). The laser beams are perpendicular to the plane of the figure, and the incandescent glow of an illuminated hot spot can be seen (the 1064-nm infrared laser is invisible to the camera). Images of the electron beam on the phosphor screen can be seen on figure 2 for various conditions including a single circular electron beam, two adjacent circular electron beams produced using two laser beams, and a line-shaped electron beam produced using a line-shaped laser beam made with a cylindrical lens. In all cases, the shape/size of the electron beams shows good fidelity to those of the laser beams. The effect can also be combined with field-emission. Given that the shape of a laser beam can be controlled using devices such as programmable gratings, these cathodes could provide a basis for simple and compact shaped/multiple-beam systems, addressed using low-power lasers.

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[1] P. Yaghoobi, M. Vahdani Moghaddam, A. Nojeh, Solid State Comm. **151**, 1105 (2011)

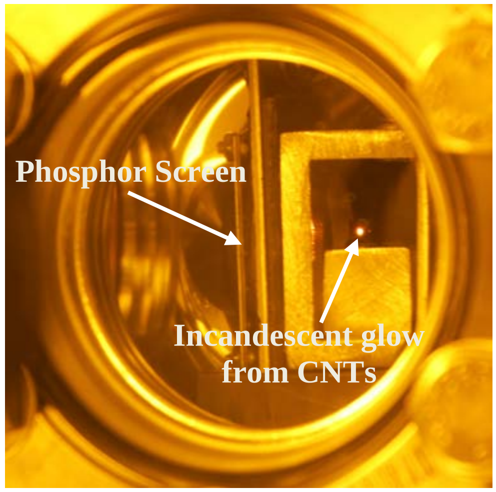

Figure 1: The experimental aparatus. The applied accelerating voltage is 2000 V and the laser beam (λ = 1064 nm) is focused on the side wall of the nanotube forest onto a spot of R ~ 250 μm in radius. The laser power (P) is 20 mW.

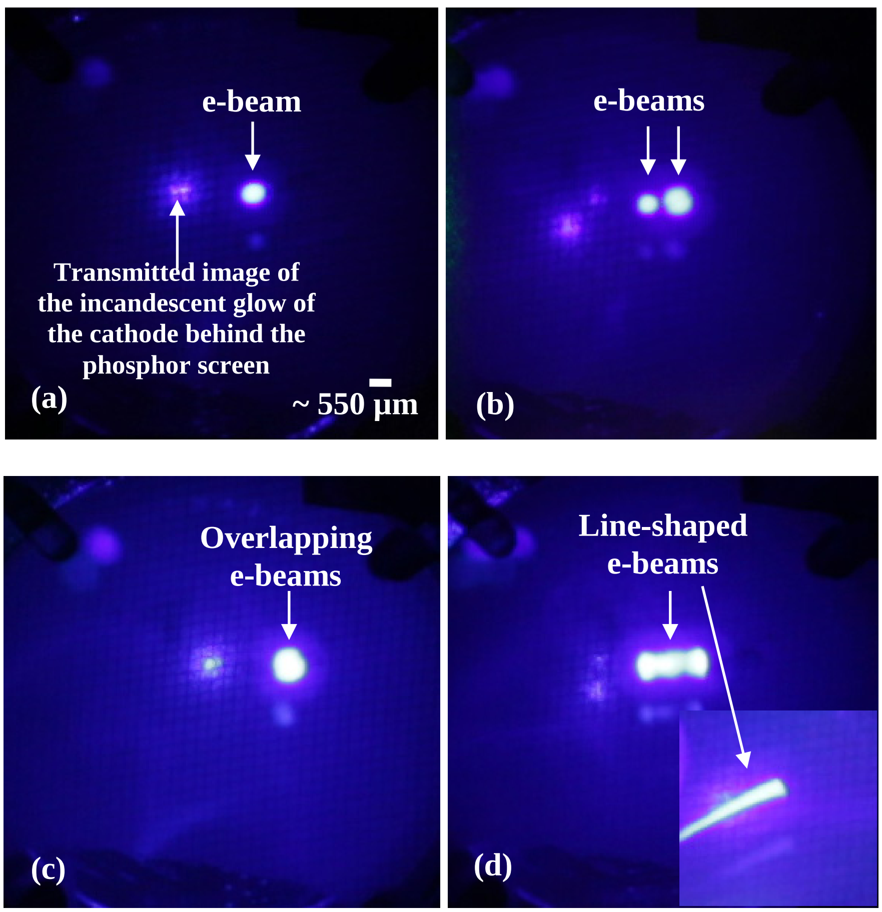

Figure 2: e-beam on the phosphor screen. (a) single e-beam (V = 2000 V, λ = 532 nm, R ~ 250 μm, P = 18 mW). (b) two and (c) overlapping e-beams (V = 2000 V, λ_1 = 532 nm and λ_2 = 1064 nm, R_1 ~ 250 μm and R_2 ~ 525 μm , P_1 = 23 mW and P_2 = 18 mW). (d and inset) line-shaped e-beams generated by passing the laser beam through a cylindrical lens (V =2000 V, λ = 532 nm, P = 256 mW).