A Micromachined Vacuum Triode Using a Carbon Nanotube Cold Cathode

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Microwave power tube devices are essential components of modern microwave systems for wireless telecommunications, radar, electronic warfare and navigation systems. They are compact and efficient for many high-power and high-frequency applications. The use of cold cathodes in vacuum tubes promises to bring together the best features of both the vacuum tubes (high power) and the power transistors (long lifetime). We report here a novel method for fabricating fully integrated, on-chip, vacuum microtriodes using carbon nanotubes as field emitters via silicon micromachining processes. In contrast to the conventional vertical structures based on Spindt field emitter arrays that involves multi-layer deposition and precision alignment, our triodes are constructed laterally on a silicon substrate surface using MEMS (Micro-Electro-Mechanical Systems) design and fabrication principles. This approach offers greater flexibility in designing sophisticated microwave devices and circuitries, employs simpler, more reliable and more precise fabrication processes, and produces completely integrated structures. The technique combines high- performance nanomaterials with MEMS-based mature solid-state fabrication technology to produce miniaturized vacuum tube devices in an on-chip form, which could have important and far-reaching scientific and technological implications. To our knowledge, this is the first demonstration of incorporating carbon nanotube field emitters in a MEMS design to create power-amplifying vacuum devices on silicon. We have obtained a dc power gain of 16 dB from these micromachined triodes by operating the carbon nanotube cathodes at a record emission current density of 16 A/cm2. The cutoff frequency for such devices is currently at 234 MHz. With improved designs and optimized materials, we expect to achieve cutoff frequencies in excess of 20 GHz in future devices. Thus, by taking advantages of the outstanding cathode performance (e.g., low operating voltage and high emission current) from carbon nanotube emitters, the on-chip vacuum MEMS devices are potentially able to provide efficient, reliable and low cost amplification solutions to wireless communications and various other needs.