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# Optical characterization of hierarchical ZnO structures grown with a simplified vapour transport method

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**Abstract**
A new ZnO micro/nanostructure morphology in the form of micro-torches was grown in the family of ZnO hierarchical structures by a simplified thermal chemical vapour transport and condensation method using a vertical furnace. It is formed by two basic parts: a three-dimensional (3D) crystal base and one-dimensional (1D) nanorods nucleated from this base. Mechanisms of this micro/nanostructure growth are suggested to be governed by the change of the ZnO vapour supersaturation level during the crystal growth. Micro-Raman analysis demonstrates good crystal lattice quality, independent of the micro/nanostructure morphology. Differences in the luminescence characteristics inherent to the different parts of the micro/nanostructure are expected to be useful for the development of micro/nano-optoelectronic devices.

## 1. Introduction

Nanosized semiconductors have attracted much attention during the last decade due to their modified electrical and optical properties that are suitable for the fabrication of nanoscale electronic and optoelectronic devices. Among others, ZnO is an important semiconducting and piezoelectric material which has high potential for applications such as field emission devices, optoelectronics, piezoelectric sensors, transducers and resonators. Due to the possibility of multiple and switchable growth directions of the wurtzite structure and the high ionicity of its polar surfaces [1], ZnO provides conditions for the formation of a rich micro/nanostructure diversity, including wires [2, 3], rods [4], ribbons [5], belts [6], tubes [7, 8], discs [9], tetrapods [10, 11], combs [12–14], rings [15], springs [16] propeller arrays [17], sleeve-fishes [18] and castles [19]. Due to the peculiar physical properties of one-dimensional (1D) structures and of hierarchical self-assembled 2D and 3D structures, as well as their potential for a variety of applications, these micro/nanostructures are currently intensively synthesized and studied. The rich variety of structures combined with their wide bandgap of 3.37 eV and a large exciton binding energy of 60 meV opens new opportunities for optoelectronic and photonic applications. The large exciton binding energy ensures that excitonic emission is significant at room temperature. Exciton-related stimulated emission and optically pumped laser action in ZnO epitaxial films [20, 21] and micron-sized rods [2, 22] have been observed at room temperature

A new fascinating application of ZnO nanostructures, namely the development of random lasing, was recently demonstrated by Cao *et al* on ZnO powders [23–25]. Random lasers on ZnO powders and nanostructures were also demonstrated by other researchers [26, 27]. Recently, random laser diodes have been produced in a nanocomposite/ZnO heterojunction [28, 29].

A multitude of synthesis methods, such as various wet chemical methods [30–37], sol–gel methods [38, 39], metal organic chemical vapour deposition (MOCVD) [40–42], electrochemical deposition [43] and metal-catalysed vapour–liquid–solid (VLS) growth [44–46], has been applied for the fabrication of ZnO micro/nanostructures. Apart from VLS growth, a related thermal chemical vapour transport and condensation method without metal catalysts has been employed [1, 18, 47–52]. The high-temperature solid–vapour deposition process usually involves using an experimental

 