Direct Write Electron Beam Lithography for Top-down Fabrication of sol-gel based ZnO micro-nano FETs

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Abstract

ZnO is wide bandgap optically transparent semiconductor with piezoelectric and gas sensing properties making it suitable for various functional device applications. Lack of positional control in device fabrication limits industrial integration of conventionally grown ZnO nanowire devices. Sol-gel processing of ZnO films is also widely investigated as a low-cost processing route. Using nano-patterning of ZnO by Direct Write Electron Beam Lithography (EBL) on sol-gel precursor as a negative tone resist[1–3], precise positioning of ZnO nano-devices can be realized; while their nano-crystalline nature can increase sensing performance. We demonstrate the electrical characteristics of ZnO micro-nano FETs fabricated using direct write EBL on zinc neodecanoate and zinc naphthenate precursors.

The precursor resist is diluted in toluene and spin coated on a pre-cleaned Si/SiO_2(100nm) substrate. The electron beam exposure crosslinks the resist, which renders exposed areas insoluble in toluene developer. We have achieved nanoscale patterns with aspect ratios up to ~500. On annealing in air at 500°C, the patterns decompose into ZnO which show nano-sized grain structure and shrinkage due to mass loss. Finally, source-drain electrodes (L=5µm) are deposited by standard lithography and lift-off. The schematic of process flow is shown in Figure 1, along with SEM images of as-developed and annealed patterns. As shown in Figure 2, transmission line measurements on unpatterned ZnO films revealed sheet resistivity of 3.8MΩ/sq and specific contact resistance of $1.11x10^{-2}\Omega.cm^2$. We fabricated micro-FETs (W=40µm) by patterning zinc neodecanoate precursor and annealed them in different atmosphere. As reported in Figure 3, devices treated in forming gas (5% H_2 in N_2) showed higher linear mobility (0.54 $cm^2/V.s$) due to passivation of electronic traps. We also prepared devices with zinc naphthenate precursor at similar conditions. Furthermore, we fabricated nano-FETs (W=500nm and 100nm) using both the precursor resists and observed marked performance increase over micro-FETs. Figure 4 depicts transfer characteristics of nano-FETs, showing linear mobility up to ~32.17 $cm^2/V.s$ with ~10^5 on-off ratios for 100nm width device. These transistors form the basis for further investigation towards gas sensing applications.

References:

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[2] M.S.M. Saifullah, K.R. V. Subramanian, D.-J. Kang, D. Anderson, W.T.S. Huck, G.A.C. Jones, and M.E. Welland, *Adv. Mater.* **17**, 1757 (2005).

[3] G.A.C. Jones, G. Xiong, and D. Anderson, *J. Vac. Sci. Technol. B Microelectron. Nanom. Struct.* **27**, 3164 (2009).

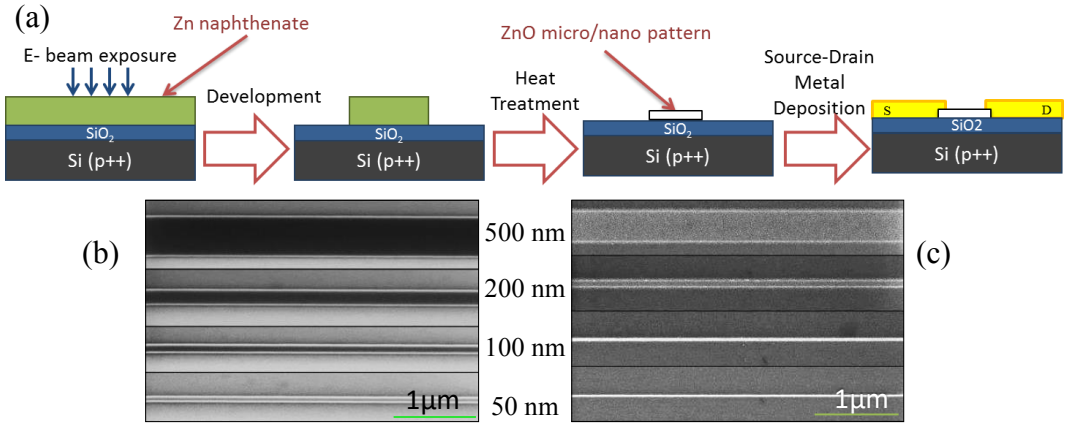

Figure 1: (a) Fabrication sequence for direct write EBL ZnO micro-nano FETs (b) SEM images of zinc naphthenate nano-patterns (c) SEM images of ZnO nano-patterns after decomposition showing nano-grains and linewidth shrinkage

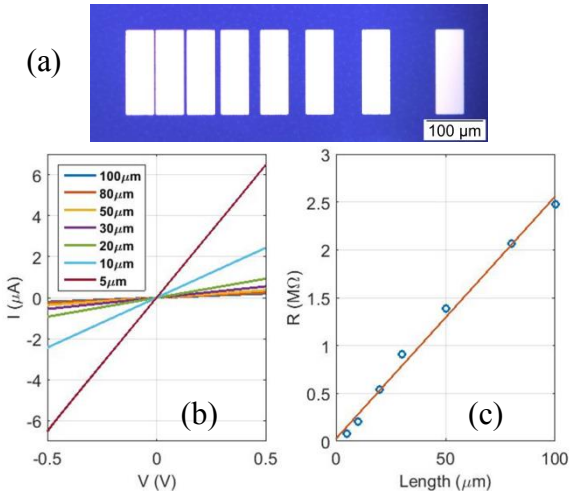

Figure 2: (a) Optical image of TLM electrode pattern (b) Current-voltage characteristics showing ohmic metal contacts (c) Resistance vs. electrode length plot to calculate channel sheet resistivity and specific contact resistance

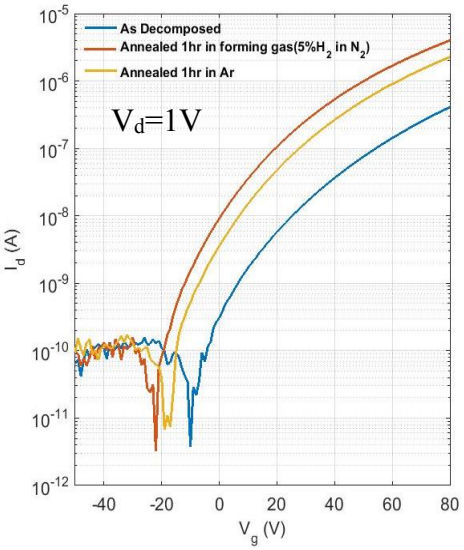

Figure 3: Transfer characteristics of ZnO micro-FETs (W=40µm) fabricated using zinc neodecanoate and annealed in different atmospheres

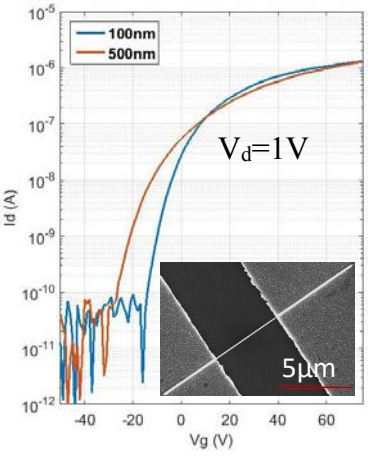

Figure 4: Transistor characteristics of 500nm and 100nm ZnO devices fabricated using zinc naphthenate. Inset shows SEM image of 100nm device (scale bar is 5µm)