Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Electrically pumped random lasing based on Au-ZnO nanowire Schottky junction

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As a reference to Au-ZnO nanowire Schottky diode random laser, ZnO p-n homojunction random laser device was fabricated based on nitrogen-doped nanowires. The nanowires were grown on top of an undoped ZnO seed layer by using N_2O as the dopant source. Due to unintentional donors such as oxygen vacancies and hydrogen species, the undoped seed layer showed intrinsic n-type property[1] while the nitrogen-doped ZnO nanowires exhibited p-type behavior. A similar device with different ZnO seed thin film, morphology of the nitrogen-doped ZnO nanowires, etc. was reported elsewhere.[2]

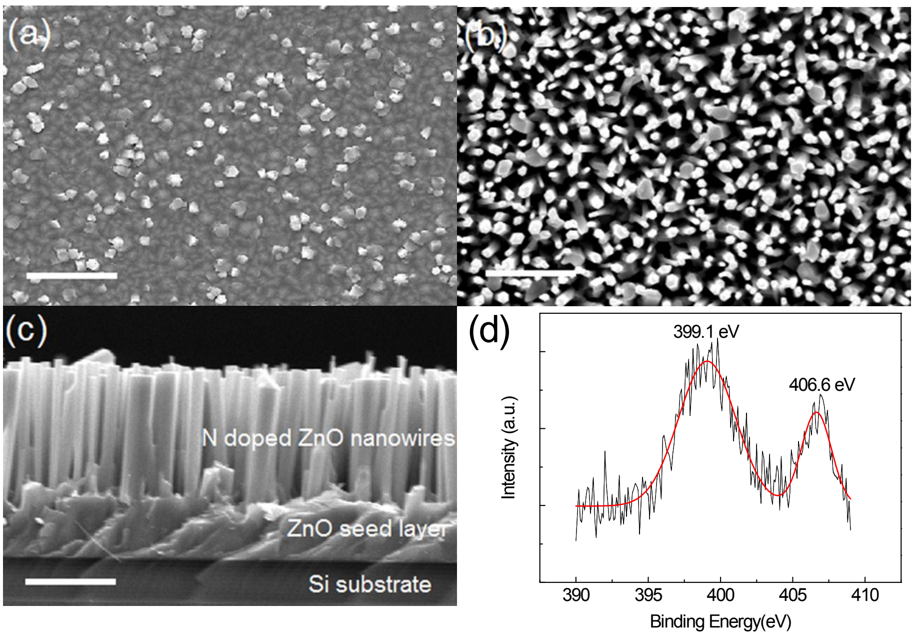

Fig.S1: (a) SEM image of the undoped ZnO seed film. (b) Top-view SEM image of nitrogen-doped ZnO nanowires. (c) Side-view SEM image of the nanowires. The scale bar is 2 μm. (d) XPS spectrum of N 1s related peaks from as-grown nanowires.

Fig.S1a shows a SEM image of the undoped ZnO seed layer. The thin film exhibits compact column structures, which originate from ZnO preferential growth along c-axis. Figs.S1b and S1c show top- and side-view SEM images of nitrogen-doped ZnO nanowires grown on seed layer, respectively. The average diameter and length is 200 nm and 2.5 μm, respectively. Fig.S1d shows X-ray photoelectron spectroscopy (XPS) spectrum. Two evident N 1s related peaks at 399.1 eV and 406.6 eV are observed. The lower energy peak at 399.1 eV is attributed to oxynitride[3] resulted from the rearrangement of nitrogen atoms in the ZnO lattice to form oxynitride ($ZnO_{1-x}N_x$). The higher binding energy peak at 406.6eV is assigned to NO_3^{2-} radical,[4,5] which is usually observed in oxygen rich growth condition. This result indicates the effect of N doping on the formation of p-type ZnO nanowires.

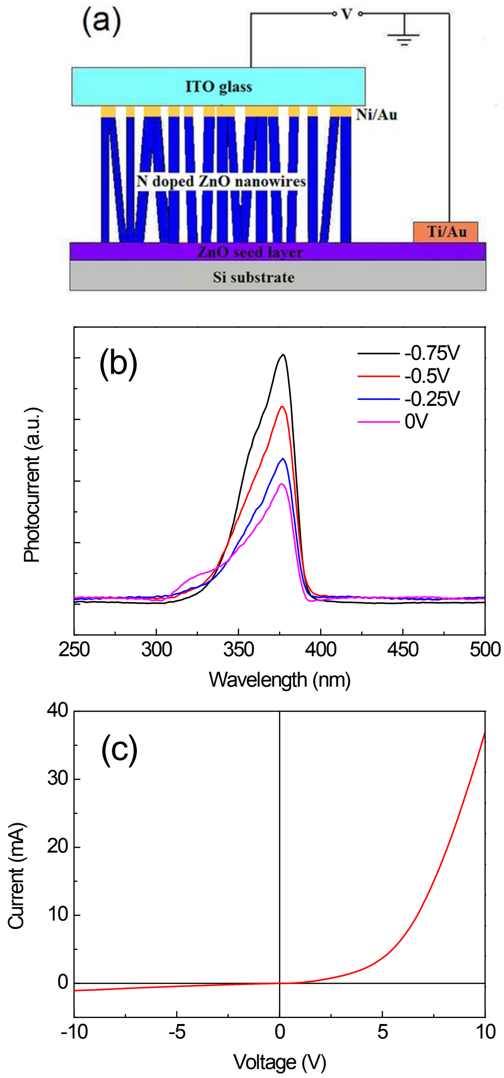

Fig.S2: (a) Diagram of the p-n homojunction random laser device. The p-n junction forms at the interface of nitrogen-doped nanowires and undoped seed layer. (b) Photocurrent spectra measured under zero and reverse biases. (c) I-V curve measured in dark, exhibiting good rectifying behavior and large turn-on voltage.

Fig.S2a shows a schematic of the ZnO p-n homojunction random laser diode device structure. The undoped ZnO thin film served as n-type segment and the nitrogen-doped nanowires are p-type segment. The p-n junctions are formed at the interface of the seed layer and nanowires. Ni/ Au (2 nm/5 nm) was evaporated on top of the nanowires and annealed by rapid thermal annealing (RTA) process to form Ohmic contact. Photocurrent (PC) measurement was conducted and the spectra are shown in Fig.S2b. At 0 V, the PC peak is at around 376 nm and steeply cuts off at 390 nm, which correlates to bandgap characteristics of ZnO. Moreover, the PC increases with the increase of reverse bias as a result of the widen space-charge region and enhanced carrier generation. The PC results confirm the realization of the p-n homojunction. Fig.S2c shows I-V result from the p-n homojunction. The curve exhibits rectifying behavior and the turn-on voltage is relatively large at 5 V, revealing the p-type properties of nitrogen doped ZnO nanowires and the formation of the p-n junction.

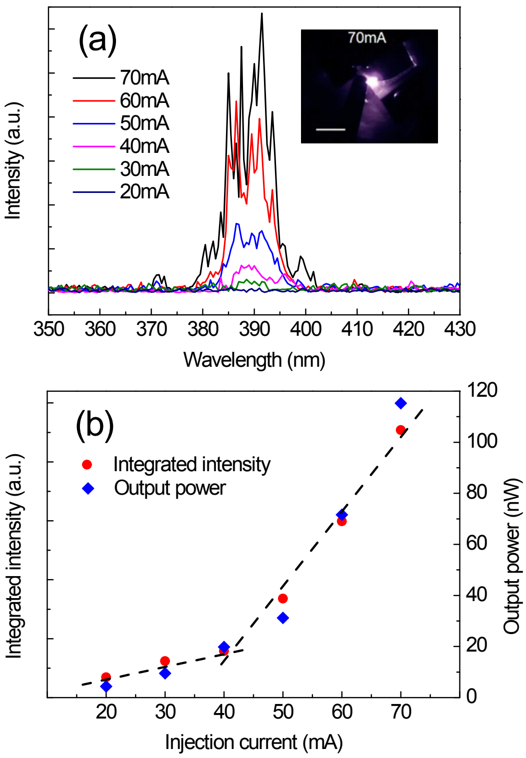

Fig.S3: (a) EL spectra of the laser device operated at drive current from 20 mA to 70 mA. Inset is a photograph of the emitting device driven at 70 mA and the scale bar is 1 cm. (b) Integrated intensity and output power as a function of injection current. Dashed line is a guide to the eye.

The random laser device was then driven by different injection current. Good EL behavior was detected and shown in Fig.S3a. Broad emission peaks centered at 390 nm can be seen at low injection currents, which is due to the near band edge emission. Randomly distributed sharp peaks appear in the spectra at drive current above 50 mA and the line width is as narrow as 1 nm. Inset in Fig.S3c is the photograph of the illuminated laser diode driven at 70 mA, showing evident bright light spot with violet halo. The integrated intensity and output power are also plotted as a function of injection current in Fig.S3b and the data reasonably follow the same trend. The threshold current is about 40 mA and the output power is as high as 118 nW at an injection current of 70 mA.

References

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