Direct Observation of Excitonic Lasing from Single ZnO Nanobelts at Room Temperature

Kazuki Bando, Taiki Sawabe, Koji Asaka, and Yasuaki Masumoto

Institute of Physics, University of Tsukuba, Tsukuba, 305-8571, Japan

Abstract. Excitonic lasing from single ZnO nanobelts was observed at room temperature, which was due to the exciton-exciton scattering processes appearing under intense light excitation. Morphologies of the nanobelts are rectangular shapes, so that crystalline facets of the nanobelts acted as the lasing cavity mirrors. We demonstrated that mode spacings correspond to cavity lengths of the respective nanobelts, and directly observed the lasing from single ZnO nanobelts by mapping of the luminescence intensity.

INTRODUCTION

Semiconductor nanostructures are recently paid much attention for applications to electric and optical devices. In particular, the nanostructures whose dimension compare with the wavelength of light are worthy of attention, since the morphology for such nanostructures sensitively affects their optical functionalities. ZnO nanostructures are well suitable to investigate such functionalities, because it can be expected that the excitonic lasing occurs even at room temperature [1,2]. Therefore, we have studied the excitonic lasing from ZnO beltlike nanostructures (nanobelts) [3,4] whose morphology is peculiar, and tried to observe directly the lasing depending on their morphology.

EXPERIMENTAL

The ZnO nanobelts were simply grown by thermal evaporation processes of the ZnO powder without catalysts [3]. Photoluminescence (PL) from the single nanobelts under weak and intense excitation conditions were obtained by using a continuous wave (cw) He-Cd laser (325 nm), the fourth harmonic generation (266 nm) of a pulsed Nd:YAG laser and pulsed XeCl excimer laser (308 nm) as excitation sources, respectively. PL images of the single nanobelts were enlarged by using a long-distance

microscope to detect the PL from only a single nanobelt from the ones dispersed on copper substrates, and the PL was detected by using a monochromator and a liquid nitrogen cooled CCD.

RESULTS AND DISCUSSION

Figure 1 shows the excitation density dependence of PL spectra at room temperature. The dimensions of the observed nanobelt are about 10 μm in length, 2 μm in width, and ~ 100 nm in thickness. In Fig. 1, the undermost PL spectrum was obtained under the weak excitation of the cw excitation. As seen in Fig. 1, a broad PL band appears, which consists of PL bands due to free excitons and their phonon replicas. The upper PL spectrum was obtained by the weakest excitation for the pulsed excitation. The PL peak position was observed at lower energy than that observed for the cw excitation. The PL band appears around 3.25 eV which is lower energy than the exciton resonance (~ 3.31 eV) by the exciton binding energy (59 meV), which indicates that spontaneous emission (P) due to the exciton-exciton scattering processes appears under intense excitation. With increasing excitation density, three sharp peaks (P_s) abruptly appear at the lower energy tail (~ 3.2 eV) of the P band above an excitation condition of ~ 350 (kW/cm²). Considering that the PL peaks appear above a certain threshold power, it is concluded that stimulated emission occurs. Upon increasing the excitation

FIGURE 1. PL spectra of the single ZnO nanobelt at room-temperature.

density further, the intensities of the sharp peaks superlinearly increase and the number of the peaks increases on the lower energy side. Then, these peaks consist of several sharp peaks whose energy spacings are constant. In addition, the energy spacings obtained from PL spectra of several nanobelts whose lengths are different from each other are also constant, depending on the lengths of the nanobelts. This clearly indicates that lasing is brought about by the self-formed cavity of the nanobelts. The cavity modes appear as the several peaks with constant energy spacings in the PL spectra. In fact, the energy spacings of the nanobelts coincided with those expected for the Fabry-Pérot cavity model [4]. It is very important that this lasing action occurs without external mirrors and the nanolaser cavity is formed by the crystalline facets alone. Although it is considered that the cavity is formed along the length of the nanobelt, the lasing was observable not only along the length of the nanobelt but also in the vertical direction of the substrate because of the scattering of the emission due to the roughness on the surface of the substrate.

In order to observe directly the lasing from the single nanobelt, mapping was performed with respect to the PL intensities. Figures 2(a), (b), and (c) show a scanning electron microscopy image of the single nanobelt, the mapping of the PL intensities performed under the cw and the pulsed excitation conditions, respectively. As seen in Fig. 2(b), the exciton PL emits throughout whole nanobelt under the cw excitation. Non-uniformity of the PL image is due to spatial distribution of the excitation. However, the mapping for the pulsed excitation condition for which the lasing occurs is obviously different from that for the cw excitation, as shown in Fig. 2(c). When the lasing

FIGURE 2. (a) Scanning electron microscopy image of the single nanobelt, (b) PL mapping for weak excitation condition, and (c) for intense excitation condition.

occurs under the pulsed excitation, the PL due to the lasing emits only at both ends of the nanobelts. This strongly supports that the self-formed cavities of the nanobelts bring about the lasing and the cavity modes are formed along the lengths of the nanobelts.

In summary, we observed excitonic lasing from single ZnO nanobelts at room-temperature. In addition, the mapping with respect to the lasing was performed, and it was demonstrated that the luminescence emitted only at both ends of the nanobelts. It was concluded that the cavity modes were formed between both end facets of the nanobelts.

ACKNOWLEDGMENTS

This work was partly supported by the Sasakawa Scientific Research Grant from The Japan Science Society and Research Project.

REFERENCES

1. Huang M. H., Mao S., Feick H., Yan H., Wu Y., Kind H., Weber E., Russo R., and Yang P., *Science* **292**, 1897-1899 (2001).
2. Johnson J. C., Yan H., Schaller R. D., Haber L. H., Saykally R. J., and Yang P., *J. Phys. Chem. B* **105**, 11387-11390 (2001).
3. Pan Z. W., Dai Z. R., and Wang Z. L., *Science* **291**, 1947-1949 (2001).
4. Bando K., Sawabe T., Asaka K., and Masumoto Y., *J. Lumin.* **108**, 385-388 (2004).