Nearly Lasing Actions from Metal-Oxide-Semiconductor Structure on Si

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Si is the most important material for integrated-circuit industry. It is also very attractive for applications in optoelectronics. However, the indirect-bandgap nature of Si makes it inefficient as a light source and so limits its applications in optoelectronics. Many efforts had thus been devoted to overcoming this obstacle. [1]-[4]. In this work, we discover that SiO_2 nanoparticles could significantly improve electroluminnescencne (EL) at Si bandgap energy from metal-oxide-silicon (MOS) structures for orders of magnitudes. Furthermore, the nanoparticle-modified MOS exhibits nearly lasing actions like the threshold behavior and resonance modes.

The nanoparticle-modified MOS structure is schematically shown in Fig. 1. The formation procedure is briefly described as follows. SiO_2-nanoparticles held in isopropyl alcohol solution were spun on Si wafer and then dried. Then Al metal was evaporated onto the top of the nanoparticles and silver paint was applied on top of Al metal to hold a gold wire for electrical contact. Afterwards, Al was again evaporated onto the back side of the Si wafer for another electrical contact. Although the silver paint blocks some portion of light, the measured efficiency is near 10^{-4}.

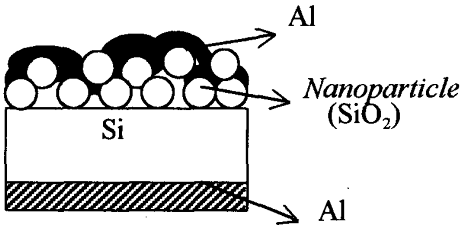

Fig. 1 A schematic of the nanoparticle- modified MOS structure

The SiO_2 nanoparticle between Al and Si causes two effects. First, it makes carriers nonuniformly tunnel through the oxide layer. This equivalently provides two-dimensional confinement for the tunneled carriers. Second, it causes nonuniform band bending of Si toward the oxide layer in the forward bias,, leading to three-dimensional potential wells for carrier confinement in the accumulation layer. With the two effects, electrons and holes have the similar spatial confinement near the Si/SiO$_2$ interface, so electrons and holes are localized in the same region, similar to excitons. The probability of radiative recombination is then increased because the process is now more like two-particle (phonon vs. electron-hole pair) collision than three-particle (electron, hole, phonon) collision.

With the enhanced radiative recombination, nealy lasing action like the threshold behavior and resonance modes are observed. Curve (a) in Fig. 2 shows a sudden increase of the output power after the threshold current (~ 12 mA). The corresponding spectrum at 50 mA is shown in Fig. 3. The measurements are under cw operation at room temperature. No resonance modes are observed for all of the devices without the threshold behavior. The details will be discussed.

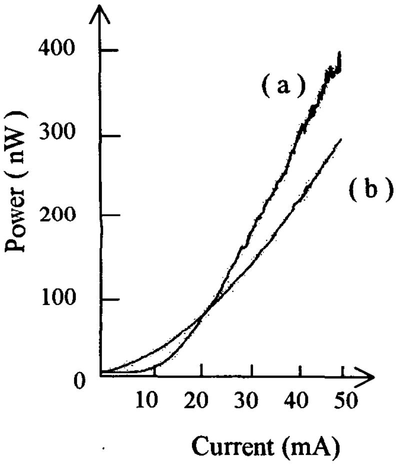

Fig. 2 Room-temperature L-I curves:
(a) the device with threshold.
(b) the device without threshold.

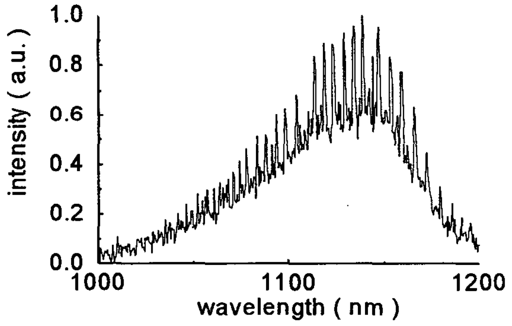

Fig. 3 Measured spectrum with resonance modes

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