Technical University of Denmark

Localized Surface Plasmon on SiC with Ag Nanoparticles

Wei, Yi; Fadil, Ahmed; Ou, Haiyan

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Wei, Y., Fadil, A., & Ou, H. (2016). Localized Surface Plasmon on SiC with Ag Nanoparticles. Paper presented at 11th European Conference on Silicon Carbide and Related Materials, Halkidiki, Greece.

Localized Surface Plasmon on <6H> SiC with Ag Nanoparticles

Yi Wei[a*], Ahmed Fadil, Haiyan Ou[b*]

Department of Photonics Engineering, Technical University of Denmark, DK-2800,

Kgs. Lyngby, Denmark

[a]E-mail: ywei@fotonik.dtu.dk [b]E-mail: haou@fotonik.dtu.dk

Silicon-carbide (SiC) is a promising luminescent material since it can be applied as a substrate and wavelength conversion material for white light-emitting diode (LED) [1]. However, little work has been done on inducing localized surface plasmon (LSP) on bulk SiC surface for efficiency improvement, whereas massive accomplishments have been carried out for luminescence enhancement of quantum well based LEDs by LSP coupling [2].

In this paper, we will demonstrate our attempt on inducing LSP on N-doped <6H> bulk SiC surface. The aim is to increase the donor-acceptor pairs (DAP) recombination rate by achieving a coupling with the LSP modes of metallic nanoparticles (NPs). DAP are expected to couple with LSP before being captured by non-radiative recombination centers [3]. The LSP-DAP coupling, which is a new path of recombination, can be very quick due to the large density of states of surface plasmon modes [4]. This way, the internal quantum efficiency (IQE) is expected to be improved.

The as-grown bulk <6H> SiC wafers (Nitrogen: 5.37×10^{18}[cm^{-3}], Boron: 9.5×10^{17}[cm^{-3}]) were supplied by TanKeBlue, and 4 different thickness of Ag thin films (5[nm]/10[nm]/15[nm]/20[nm]) were deposited on different SiC bare samples by e-beam evaporation. Finally, Ag NPs were self-assembled after rapid thermal annealing at 350[°C] for 15[min].

The photoluminescence (PL) was excited by a diode laser with λ=375[nm]; The transmittance was measured by an integrating sphere with a white light source; For time-resolved photoluminescence (TRPL) measurement, the samples were excited by a pulsed laser source with a pulse repetition rate of 416.7[KHz]. Note that we were using front excitation and front detection (the plane with Ag NPs was considered to be front side) for both PL and TRPL measurements.

Fig. 1 shows the top-view scanning electron microscope (SEM) images of annealed Ag NPs each with different Ag thin film thickness. The calculated average diameter of Ag NPs for each deposited Ag thin films are: (a) 26.8[nm], (b) 74.9[nm], (c) 135[nm] and (d) 188[nm] respectively.

The PL spectra of the samples are shown in Fig. 2(a). All SiC samples with Ag NPs are observed to have a lower PL intensity than the as-grown SiC. Transmittance spectra of each SiC sample with Ag NPs are shown in Fig. 2(b), where the normalization is relative to the as-grown SiC transmittance. The dips in the spectra indicated the existence of LSP resonances, and it is found that λ_{LSP} redshifts with the size increase of Ag NPs, where λ_{LSP} of sample "Ag_20nm" is predicted to be around infrared region. Since the λ_{peak} in PL spectra is located closest to λ_{LSP} of sample "Ag_10nm", it is supposed to induce more efficient LSP coupling with DAP in the substrate [4], whereas it had the lowest PL value. This is because of the non-radiative loss caused by the absorption of photons in the Ag NPs with existing LSP mode [5]. From macroscopic view, SiC samples with Ag NPs in our experiment did induce LSP, but LSP caused more absorption than scattering of energy [2]. Therefore the emission fraction [6] of SiC substrate needs to be improved further.

Fig. 2(c) shows the results of TRPL measurement and the corresponding exponential fitting curves, and Table 1 gives detailed results of exponential decay fitting with normalized amplitude , related time constant for each order and amplitude weighted photon lifetime (t_{Av}) [7], which indicate three different recombination channels in SiC [8]. We find that τ_3 has the most obvious percentage of descending as t_{Av} decreases, which is the minimal decay time indicating the fastest recombination channel. Meanwhile, as A_3 increases with decreased t_{Av}, it is believed that LSP has introduced more DAP into the fastest recombination channel, where A_3 has been improved from 1.76% to over 70%,

* corresponding author

revealing that over 65% of DAP have been switched from slow recombination channel to fast recombination channel. The improvement of the fastest recombination channel could be explained by immediate electron transfer from Ag NPs upon photoexcitation of plasmon band [9], where an injected electron will be recombined with the hole on the interface between Ag NPs and substrate, with a lifetime of less than 1[ns].

In conclusion, we successfully induced LSP mode on SiC substrate and found that it can switch over 65% of DAP from slow recombination channel to fast recombination channel, indicating a promising method worthy to be further investigated to improve the IQE of SiC based LEDs.

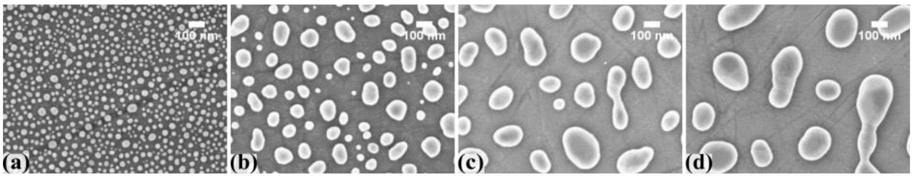

Fig. 1. The top view SEM images of annealed Ag NPs on <6H> SiC substrate with as-deposited Ag thin films of: (a) 5[nm]; (b) 10[nm]; (c) 15[nm]; (d) 20[nm].

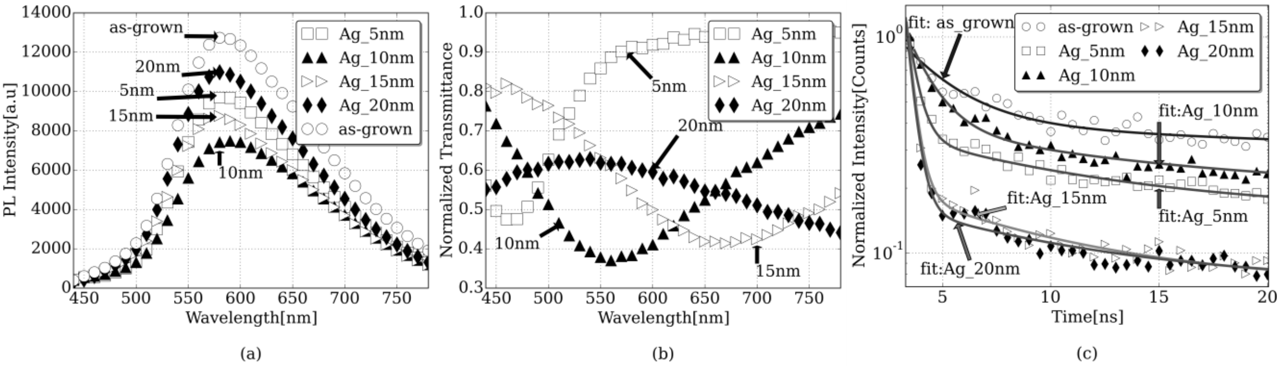

Fig. 2. Characterization of SiC samples with Ag NPs: (a) PL measurements; (b) Normalized transmittance; (c) Normalized TRPL curves and their corresponding exponential fittings.

Table 1. Exponential decay fitting results for each sample.

	A_1_norm[%]	τ_1[ns]	A_2_norm[%]	τ_2[ns]	A_3_norm[%]	τ_3[ns]	t_{Av}[ns]
As-grown	93.59	318.4	4.65	25.31	1.76	2.387	82.2
Ag_5nm	10.79	255.3	17.87	8.33	71.34	0.465	29.4
Ag_10nm	16.54	267.5	21.43	10.3	62.04	1.221	47.2
Ag_15nm	4.26	268.1	9.61	7.12	86.13	0.3672	12.4
Ag_20nm	3.97	280.3	6.97	8.05	89.05	0.3706	12.0

Acknowledgements. This study was supported by Innovation Fund Denmark (No. 4106-00018B).

References

[1] Ou, H., et al., (2014). *European Physical Journal B*, 87(3), 1-16.
[2] Fadil, A., et al., (2014). *Scientific Reports*, Vol. 4, 6392.
[3] Jang, L., et al., (2012). *Optics Express*, 20(3), 2116–2123.
[4] Okamoto, K., et al., (2005). *Applied Physics Letters*, 87(7), 071102.
[5] Sun G., et al., (2011). *IEEE Journal on Selected Topics in Quantum Electronics*, 17(1), 110-118.
[6] Wang, J. Y., et al., (2007). *Applied Physics Letters*, 91(23), 233104.
[7] Wahl, M. (2007). *Technical Note-Time-Correlated Single Photon Counting*.
[8] Fan, J. Y., et al., (2011). *Applied Physics Letters*, 98(8) , 081913.
[9] Long, R., et al., (2014). *Journal of the American Chemical Society*, 136(11), 4343–4354.