Improving the Efficiency of Upconversion Material with Slot Modes in Silicon NanoblockArrays

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Upconversion (UC) materials can be used toharvest near-infrared (NIR) light and convert it into visible light. Inprinciple, such property of UC materials can improve the operation spectralrange and efficiency of optical devices like solar cells. However, theupconversion efficiency of typical UC materials, such as $NaYF_4$:Yb^{3+}/Er^{3+} (a well-known UC material absorbing 970nm light and emitting660nm) is too low to apply on such devices.

We propose a structure for improving thisUC process by using high refractive-index silicon nano-block arrays equippedwith low refractive-index UC slots in between. In this structure, the slot modeis induced on low index UC slot area, and this increases the absorption oflight. Furthermore, spontaneous emission is increased by Purcell effect ofhigher-order slot modes.

To increase absorption and spontaneousemission of UC material, we match the induced resonant wavelengths of ourstructure with the absorption and emission wavelengths of the UC material bycontrolling height and width of the silicon nano-blocks and the slot thicknessof the UC material.

Our result from the finite-differencetime-domain simulation shows two slot modes in the UC slot area. The 2nd-orderslot mode has 970nm resonant wavelength, and the 3rd-order at 660 nm.

In the proposed structure, the absorptionrate at 970 nm was increased by almost 25 times from that of the referencelayer. Also, the average spontaneous emission rate was increased by a factor of9.6 for all polarization.

To summarize, a silicon nano-block array with UCmaterial slots can improve the efficiency of UC process by 240 times. Thisimprovement can be applied to practical optical devices using visible lightsuch as solar cells