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Metallic nanocavity-enhanced second harmonic generation from a $KNbO_3$ nonlinear nanowire

Sung-Yong Kang [a], Jonghwa Shin [b,*], Kwang-Yong Jeong [a], Chang-Min Lee [a], Ki-Ju Yee [c], Yong-Hee Lee [a,d]

[a] *Department of Physics, KAIST, Daejeon, Republic of Korea*
[b] *Department of Materials Science and Engineering and KI for the NanoCentury, KAIST, Daejeon, Republic of Korea*
[c] *Department of Physics, Chungnam National University, Daejeon, Republic of Korea*
[d] *Department of Nanoscience and Technology (WCU), KAIST, Daejeon, Republic of Korea*

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Abstract

We propose and experimentally investigate a self-aligned metallic nanocavity that can enhance second harmonic signals from a single $KNbO_3$ nanowire. With pump beams in the spectral proximity of the metallic nanocavity resonance, second harmonic intensity is observed to be >1800 times stronger than that of a typical bare nanowire under the same illumination conditions. By studying spectral features and polarization characteristics, we confirm that the nonlinear enhancement originates from the locally intensified electric field of a surface plasmon-polariton mode. This simple and robust scheme represents a powerful platform to study single nanowire nonlinearity.

Keywords: Optical nonlinearity enhancement; Surface plasmon; Nanocavity; Nonlinear optics; Harmonic generation

1. Introduction

Nonlinear optical processes are of fundamental importance in optical science and its various applications. Diverse fields from information technology and biological imaging to molecular chemistry and environmental sensing can benefit from efficient optical nonlinearity. However, the nonlinear coefficients of naturally occurring optical material are not sufficiently large and, hence, a large interaction volume or high excitation power is required to generate acceptable levels of nonlinear signals. If the effective nonlinearity of existing material can be increased, the expected benefits would be manifold.

Recent advances in metallic optics are opening ways to achieve such an effective enhancement [1–3]. Due to abundant charge carriers in metal, electric field distribution can be manipulated in a deep-subwavelength scale. For example, various metallic structures have been designed to enhance electric fields by several orders of magnitude over a subwavelength region of space [4–7]. These structures can be called "plasmonic antennas" since incident photons couple with the oscillation of electrons to form surface plasmon-polaritons with the help of the structures. The locally intensified electric field induces much stronger nonlinear polarization and even very high-order nonlinearity can be observed [8]. However, most of the metallic

* Corresponding author. Tel.: +82 42 350 3331.
E-mail address: qubit@kaist.ac.kr (J. Shin).

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structures proposed so far require alignment of the metallic element with the nonlinear medium with subwavelength accuracy, since the size of the region in which electric fields are enhanced is several times smaller than the wavelength. Thus, the fabrication process typically requires high-resolution, sequential methods such as electron beam or focused ion beam lithography and presents challenges to adopting the proposed systems to practical applications.

On the other hand, various single-crystal nanowires have been successfully grown in the last decade [9–11]. Nanowires' small transversal dimensions, which are typically around one hundred nanometers, offer new possibilities to explore. For example, ultra-compact wavelength converters or local light sources are among potential applications. However, the weak nonlinearity of existing material is hindering full utilization of the small form factor's advantages [12–16]. Among available nanowires, potassium niobate ($KNbO_3$) shows one of the largest nonlinear optical coefficients [12]. Therefore, the combination of a $KNbO_3$ nonlinear nanowire and a plasmonic nanocavity is potentially a very good platform to achieve efficient optical nonlinearity. In the following sections, we numerically and experimentally confirm this idea.

2. Metallic nanocavity-embedded nonlinear nanowire

Our self-aligned metallic cavity system comprises a nanowire on a transparent substrate, on which a metal layer is deposited (Fig. 1(a)). The metal layer is thicker than the wire and totally encloses it except the bottom surface of the nanowire, which is in contact with the substrate. The proposed configuration exploits the small dimensions of the nanowire itself to achieve nano-scale optical confinement and enhancement. Therefore, the fabrication steps are simple and straightforward. Potassium niobate and silver are selected as the nonlinear nanowire and metal material, respectively, in

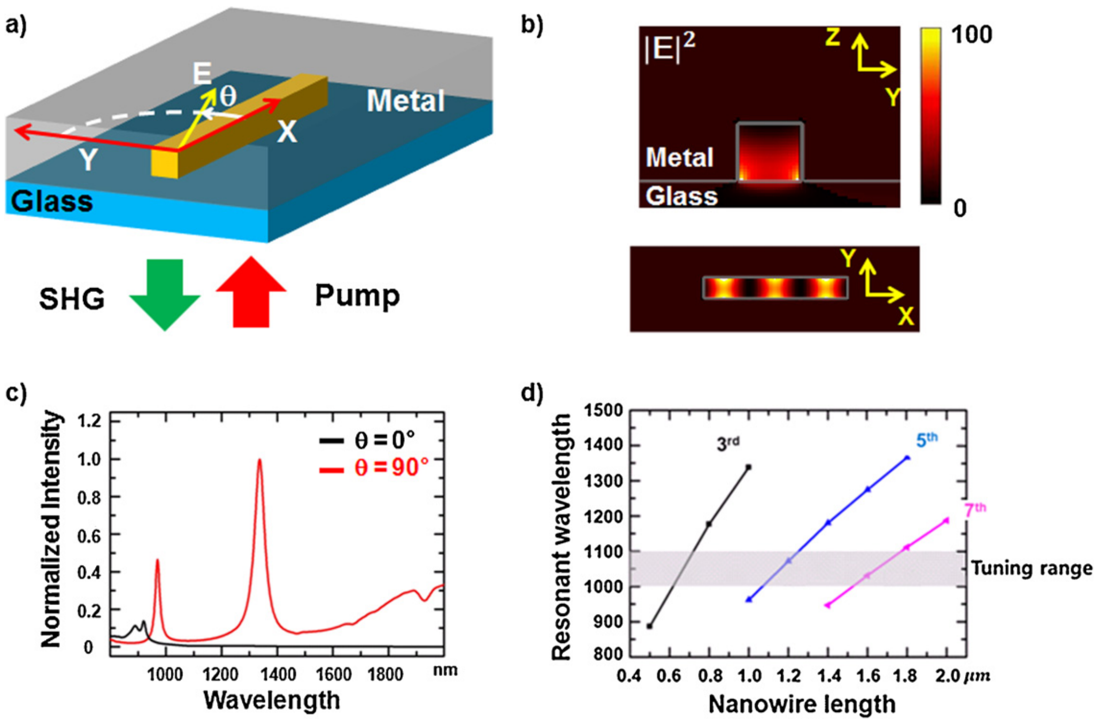

Fig. 1. Properties of the metallic nanocavity. (a) Structure and coordinates. The polarization angle of the pump beam is defined in the x–y plane. (b) Calculated electric field intensity distribution (normalized to that of the pump light) of the resonant mode at 1337 nm, on a plane (top) perpendicular and (bottom) parallel to the nanowire axis. The pump light is a plane wave polarized in the y-direction. (c) Volume-integrated electric field intensity inside a nanocavity-embedded nanowire under (black line) x-polarized and (red line) y-polarized illumination, as a function of the pump wavelength. Both curves are normalized to the maximum value at 1337 nm under y-polarized illumination. (d) Nanowire length dependence of resonant wavelengths. The order of the modes corresponds to the number of electric field intensity maxima along the nanowire axis. Gray region indicates the primary wavelength tuning range of the excitation light used in this work. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)