Design of 2D Si photonic nanocavity with InP nanowire for current injection at the telecom band

NTT Nanophotonics Center[1], NTT Basic Research Labs[2]

○(B) Edward Chen[2], Masato Takiguchi[1,2], Shota Kita[1,2], Akihiko Shinya[1,2], Masaya Notomi[1,2]
E-mail: edward_chen_v8@lab.ntt.co.jp, takiguchi.masato@lab.ntt.co.jp

Nanowire (NW) lasers for on-chip light sources are highly desirable, as their compact nature allows for a wide range of photonic applications. However, subwavelength semiconductor NWs prove to be difficult as they cannot support photonic Fabry-Pérot resonances and typically have poor light confinement not suitable for room-temperature cw lasing. Some studies have focused on plasmonic NW lasers to squeeze light into subwavelength volumes at the cost of diminutive quality factors (Q). Rather, another possibility to improve the properties of subwavelength NWs, is to embed it in a Si photonic crystal (PhC) grooved waveguide [1] to achieve both a high Q and large light confinement (Γ_{nw}) at the telecom band. Recently, we demonstrated cw NW (ϕ100 nm) lasers on a Si PhC platform under cryogenic conditions using cw photo pumping. However, due to inhomogeneous NW structures and fabrication errors, only a Q of 9200 was measured [2]. Accordingly, our target is to optimize a nanocavity mode concentrated in the NW, capable of achieving cw lasing by current injection with accountancies for variable NW lengths and diameters.

In this study, we propose and theoretically demonstrate InP NWs (ϕ100 nm – 200 nm), embedded in various 2D Si PhC cavities for current injection cw lasers (Fig.1). The PhC has a photonic bandgap in the telecomm band for future integration into optical communication systems. Our design uses a modified L3 type cavity [3] with a single row defect channel. Finite element method (FEM) simulation was used to determine the Q and Γ_{nw} of the cavity mode. From this, we are able to achieve a cross pattern mode profile (Fig. 2a) with slight resemblance to a waveguide mode profile, but having stronger field confinement inside the NW. The holes along the row defect are not etched completely through, allowing for more flexible tuning. The inner 3 holes on both sides of the L3 cavity along the channel are scaled and shifted proportional to the lattice constant to increase Q. However, this specific tuning has many drawbacks, namely increased complexity during fabrication possibly introducing a range of defects altering the performance of the cavity. PhC fabrication aside, we also determined the effect varying radii (d_{nw}) and lengths (L_{nw}) of the NWs have on Q and Γ_{nw} (Fig. 2a, 2b) still within subwavelength dimensions. The last criteria that we determined, was the addition of gold composite contact pads to allow for current injection. Typically, gold has a large absorption coefficient relative to InP, roughly by 10,000 times, and is capable of reducing Q significantly. The extent of reduction is determined by the separation distance L, width, and thickness of the pads (Fig. 3) corresponding to its proximity around the cavity. To this end, we extensively explored the various dimensional and intrinsic parameters that directly affect the performance of our purposed device, using Q and Γ_{nw} as metrics. To clarify, Γ_{nw} is the field energy confined in the NW over the total system energy. All PhC designs have the same lattice constant (420 nm) and air hole radius (118 nm), differing only by channel depth and width. With a highly optimized structure, including contact pads, we can achieve a maximum Q of ~ 4.0×10^4 and Γ_{nw} of ~ 20%. Even with smaller diameter NWs, Γ_{nw} of ~10% can be obtained, indicating our design allows for better tolerance in NW dimensional imperfections.

This work was supported by JSPS KAKENHI Grant Number JP15H05735.

References
[1] M. D. Birowosuto et al., *Nature Mat.* **13**, 279–285 (2014)
[2] Masato Takiguchi et al., *APL Photon.* **2**, 046106 (2017)
[3] Eiichi Kuramochi et al., *Opt. Lett.* **39**, 5780-5783 (2014)

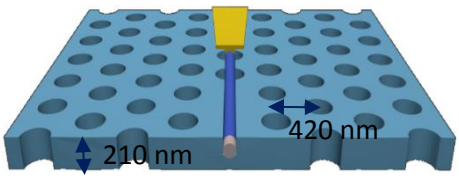

Fig. 1 2D cross sectional of NW embedded into Si PhC L3 cavity along groove with gold composite contact pads for current injection.

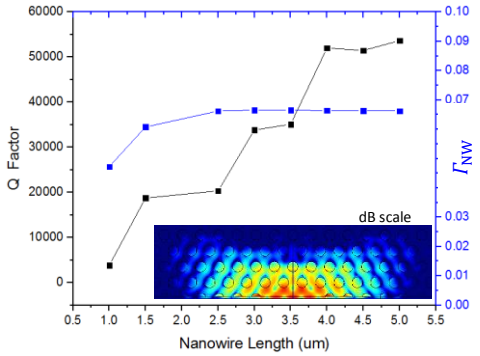

Fig. 2a Q (black) and Γ_{nm} (blue) with changing L_{nw}. Bottom right; the cavity mode profile.

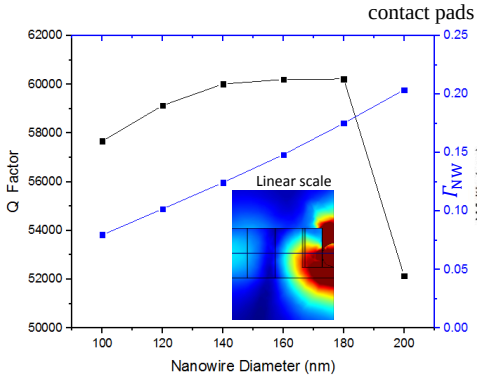

Fig. 2b Q (black) and Γ_{nw} (blue) with changing d_{nw}. Bottom; 2D cross sectional of field profile of NW inside groove at the specific cavity mode.

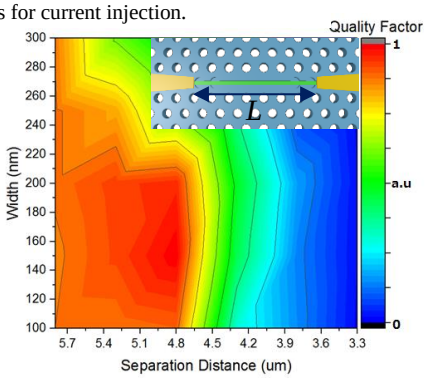

Fig. 3 Q relative to separation distance (L) and the width of the contact pads. Pads have fixed thickness (140 nm) from our previous fabrication dimensions. Top Right; NW (green) between gold contacts in PhC.