



















zero at the band edge and at  $k \sim 0.42$  ( $2\pi/a$ ) (Fig. 2a). Lasing in a plasmonic band mode seems to behave very classically with a sharp threshold, as seen in the pump vs. intensity characteristics of the representative device in Fig. 8c. Although we cannot know the mode volume and theoretical quality factor of the band mode laser, we estimate the product  $F\beta = 0.016$  from simple fitting by rate equation analysis. Thus, the spontaneous emission coupling is greatly reduced relative to a localized defect mode seen in Fig. 7.

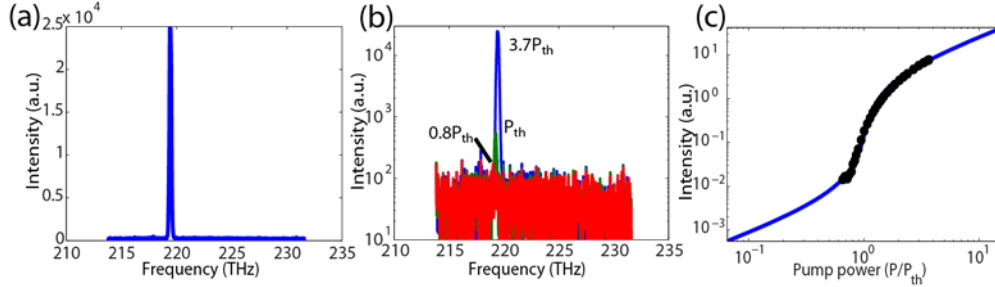


Fig. 8. We show laser characteristics from band D. (a) We show a lasing spectrum obtained at a peak pump power of 380 kW/cm<sup>2</sup>. (b) The semi-log scale pump-dependent spectra for the band-mode. (c) The L-L curve shows that the bandedge mode has a sharper threshold than the  $\gamma$  defect mode. The threshold pump power for this device is 55kW/cm<sup>2</sup> of peak power.

## 6. Discussion and Conclusion

This particular demonstration of a SPPC-based nanolaser highlights only the beginning of this technology's potential. In the future, plasmonic crystals, like their photonic counterparts, should be able to confine plasmons to one-half of a wavelength ( $\lambda_{sp}/2$ ). Thus, single-sided SPPCs should be able to squeeze electromagnetic mode volumes to less than  $0.01 (\lambda_0/n)^3$  at visible frequencies, where  $n = 3.5$  and the surface plasmon is propagating at a gold/semiconductor interface. In the near-infrared frequency range, using single-hole defects will further reduce the mode volume of our cavities. Utilizing better fabrication techniques without a lossy titanium layer should further allow our nanolaser to operate in the  $\alpha$  mode, which is 3 times smaller in electromagnetic mode volume. Metal-semiconductor-metal geometries coupled with plasmonic crystals will also be able to squeeze mode volumes much below the limit of a single-sided surface plasmon at near-infrared frequencies [9,15]. Finally, SPPC's (especially metal-semiconductor-metal geometries) promise facile implementation of electrically-driven nano-emitters coupled to plasmonic waveguides since the metal can also serve as contacts [28].

In summary, we have successfully shown the operation of a plasmonic crystal defect laser within a plasmonic bandgap based upon semiconductor technology. This laser benefits from small mode volumes with  $V_{eff} = 0.3(\lambda_0/n)^3$  at  $\lambda_0 = 1342$  nm, making it 10 times smaller than a similar mode in a photonic crystal of the same physics dimensions. This initial demonstration of a nanolaser based on plasmonic crystals should enable to use of these structures to generate coherent plasmons and control them in great detail, making them suitable as a future nanophotonics platform. The integration of the nanolaser with a plasmonic crystal while maintaining ultra-small mode volumes makes a plasmonic crystal defect laser a strong contender as a coherent light source for nano-opto-electronics in the future and enables the use of plasmonic crystals as a tool for mode volume engineering for all nano-light-emitters.

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