INTEGRATED ACOUSTO-OPTICAL DEVICE WITH SOLID STATE QUBITS

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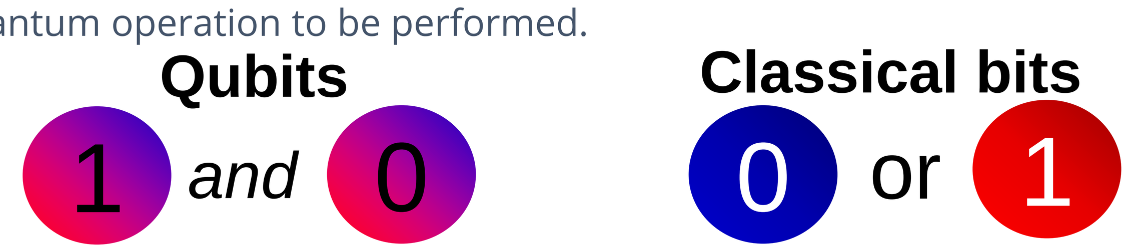
What are Qubits?

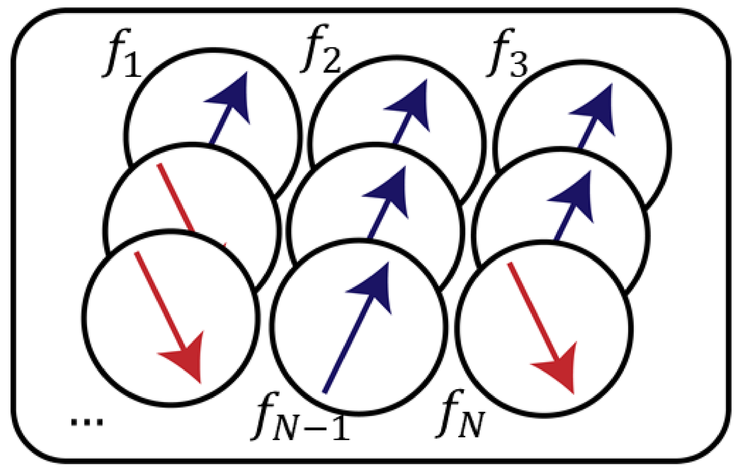
- One single qubit can represent a state between 1 *and* 0, making it possible for quantum operation to be performed.



$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle, \text{ where } \alpha^2 + \beta^2 = 1$$

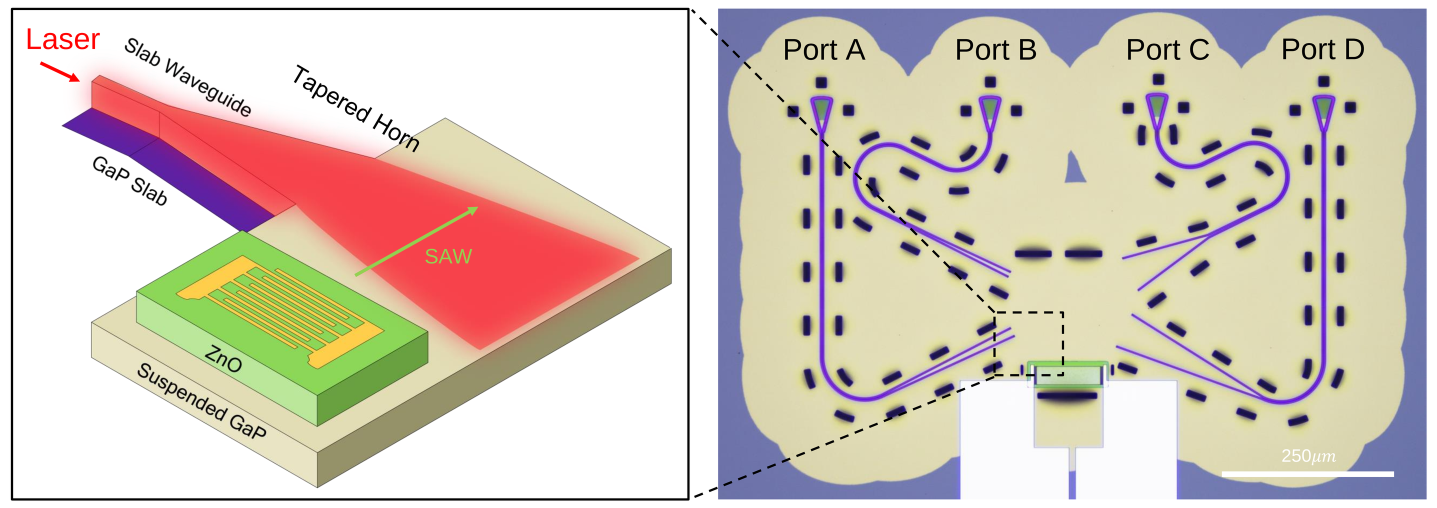
Inhomogeneity of the Solid-State Qubits

- Solid-state qubits, e.g., Diamond defect qubits, ZnO defect qubits..... Are susceptible to local environmental properties. [1]
- The differences in environmental properties lead to different qubit energy/frequency($f_1, f_2, \dots f_N$). Thus, hinder the applicability(such as entanglements) of multiple entangled qubits.



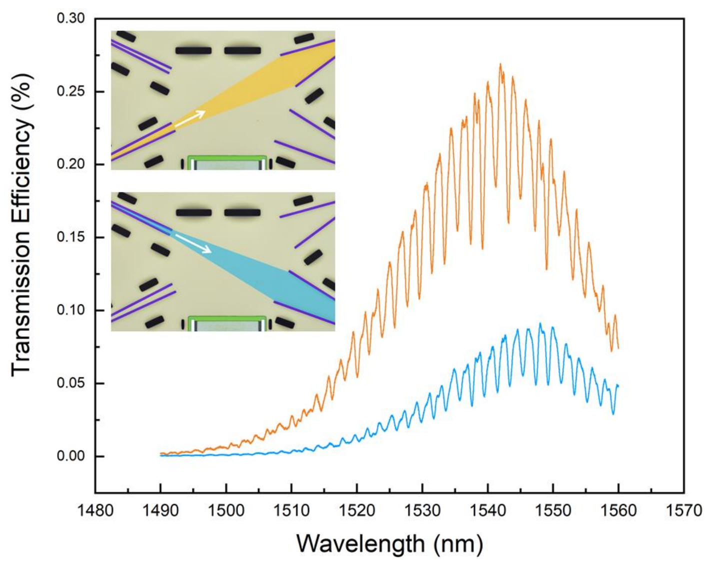
Acousto-Optics Frequency Shifter(AOFS)

- AOFS can address the frequency inhomogeneity of solid-state qubits by using acousto-optics effect to effectively shifts the energy/frequency of the photons that is emitted by the solid-state qubit to perform heralded entanglement of multiple qubits.
- The device shown below is AOFS made from Boron-doped Gallium Phosphide(BGaP) thin film. The ZnO layer is used to create traveling surface acoustic waves on BGaP.
- The input photons from port A(B) could transmit from Port C(D) when the acoustic waves are turned off. If the acoustic waves are turned on, the photon from port B would be deflected to C for the case of Anti-Stoke scattering.



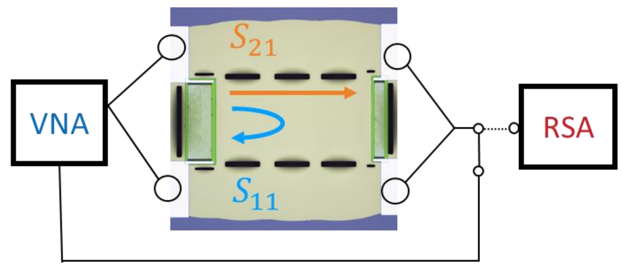
Optical Characterization

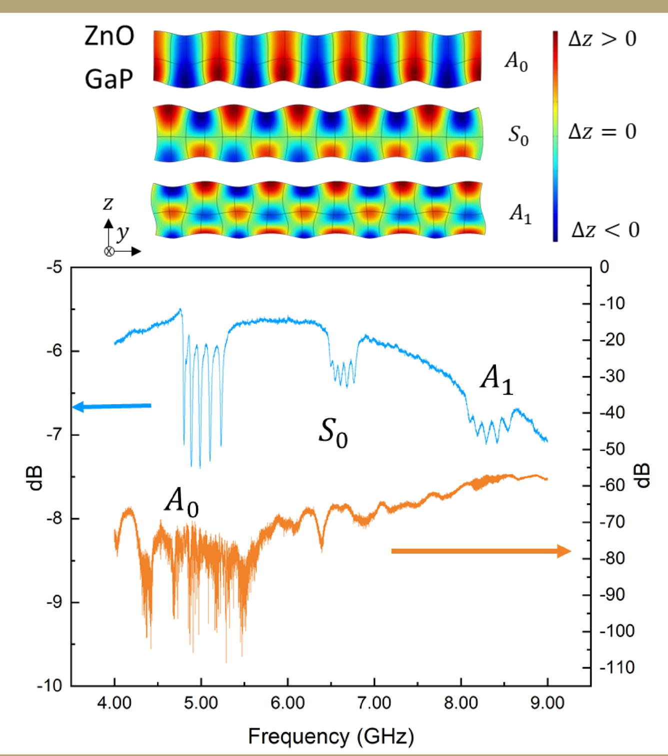
- The optical transmission characterization of port A(B) to C(D). The orange(blue) curve shows the transmission spectrum of A(B) → C(D) when the acoustic waves are turned off.
- The Fabry-Perot like resonance is the result from the optical reflection of the grating coupler from the opposite end.



Acoustic Characterization

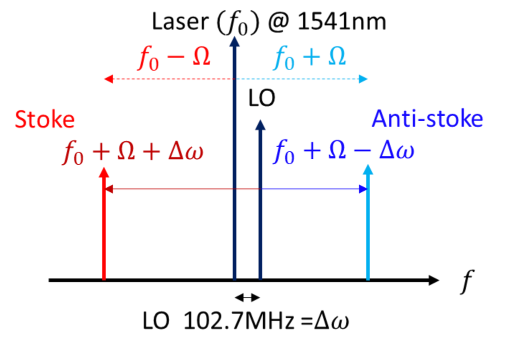
- Interdigital Transducers(IDTs) are used to generate acoustic waves on the BGaP thin film.
- In thin film materials, several different vibrational modes can be generated using a single IDT. Each mode has different mode shapes and can be label as Symmetric(S) or Anti-symmetric(A) modes.

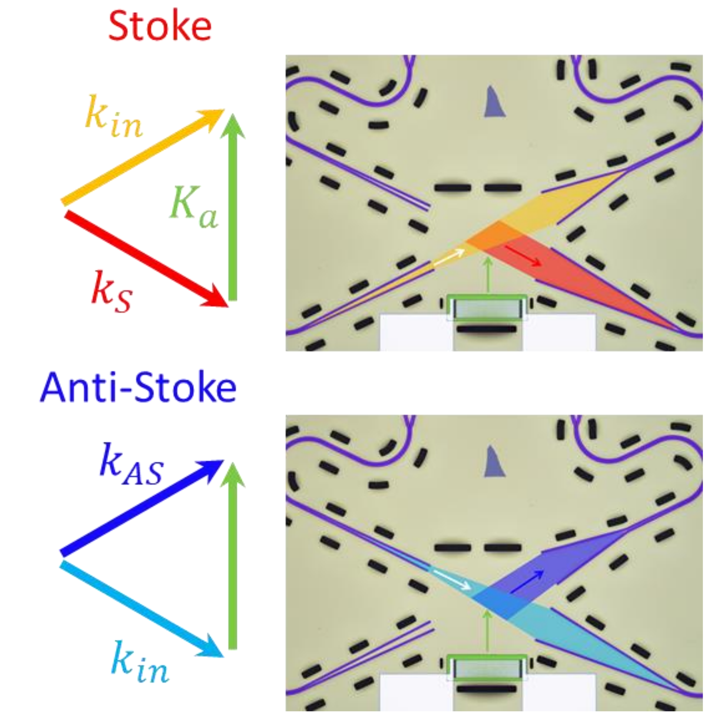




AOFS Measurement Set-up: Heterodyne Measurement

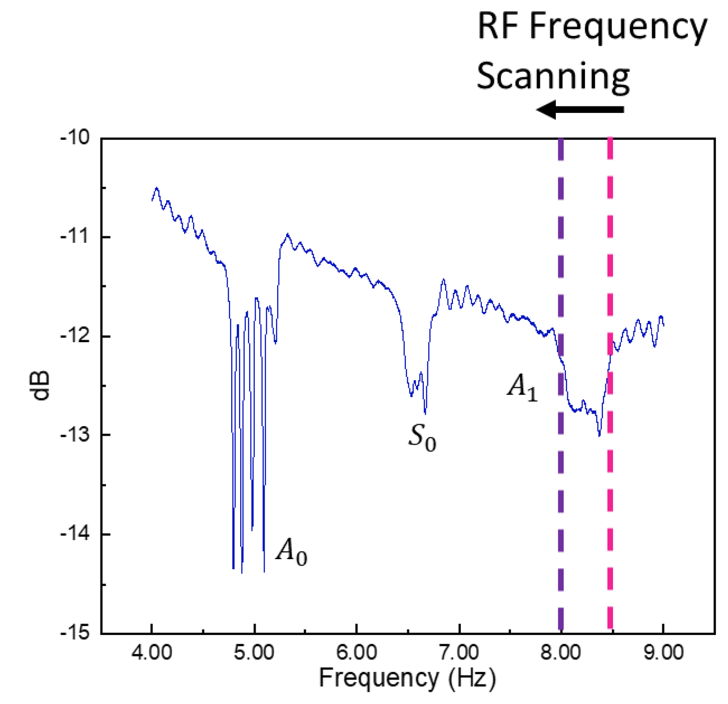
- Two different types of scattering can be performed in our AOFS device: Stoke and Anti-Stoke scattering. In Stoke(Anti-Stoke) scattering, the incident photon emit(absorbs) phonons and thus the photon energy is down-shifted(Upshifted).
- The shifted-frequency photons signal then beats with the signal from a Local Oscillator(LO) and then we could detect the heterodyne signal from the device.

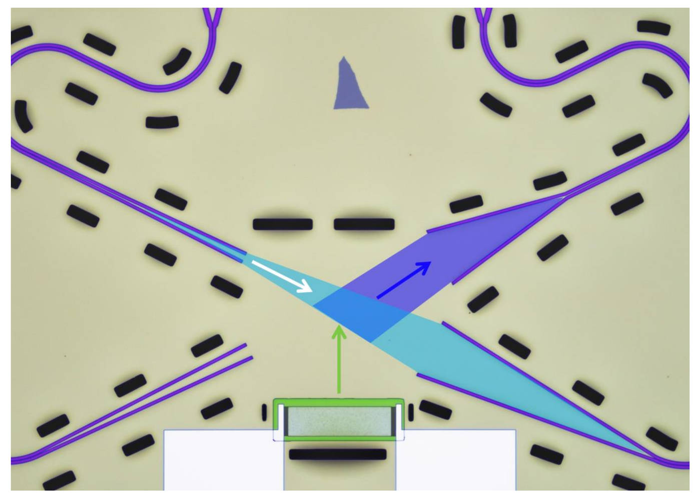


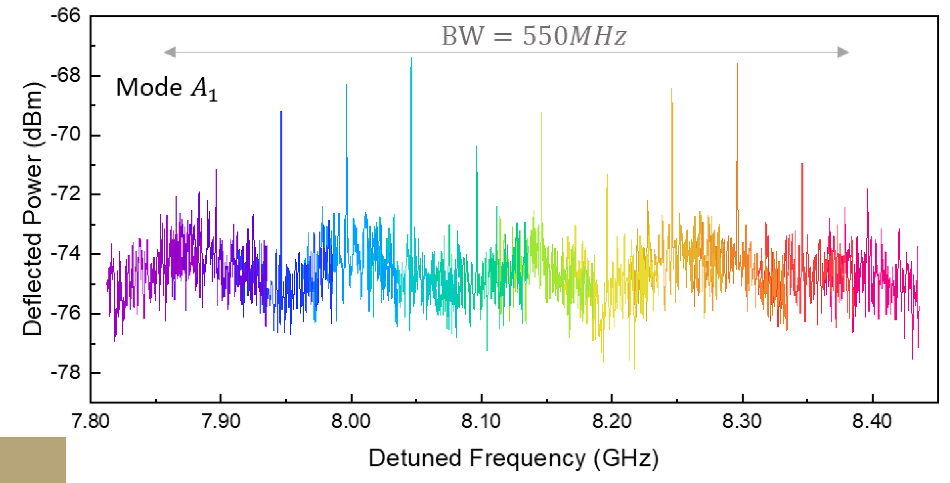


Wide-band Optical Frequency Shifting

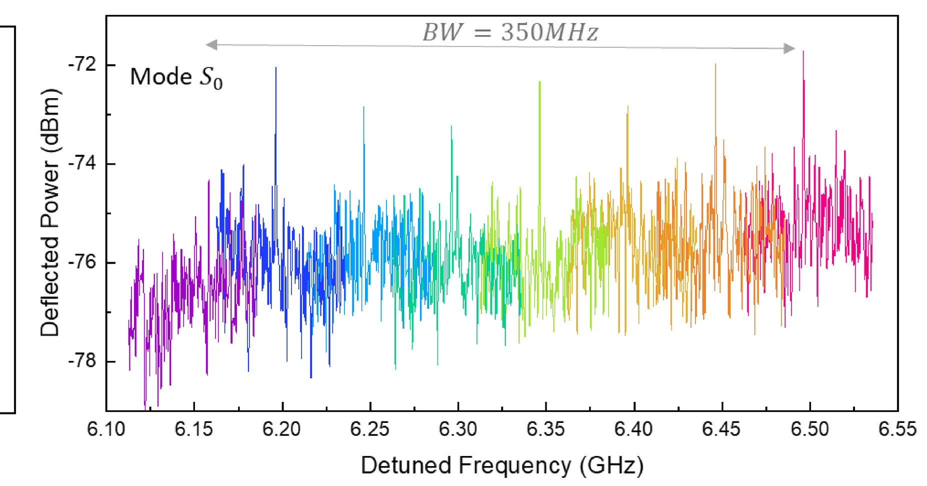
- To facilitate the integration of AOFS and solid-state qubit, we need a wide band AOFS to increase the chance of finding the desire shifting frequency that matches the photons that is emitted from the qubits.
- We can achieve 550MHz band width at 8.15GHz central frequency and 350MHz at 6.32GHz. (The typical IDT acoustic wave bandwidth are ~100MHz.)







A_1 mode, central frequency at 8.15GHz
BW = 550MHz



S_0 mode, central frequency at 6.32GHz
BW= 350MHz

Future Work, References, and Acknowledgments

- Fabricate the device on solid-state qubit substrates such as diamond with defect center.
- Increase the bandwidth furthermore with linear-chirped IDT design
- Perform heralded entanglement measurements to check if the qubits are entangled using AOFS

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[1] Schmidgall, Emma R., et al. "Frequency control of single quantum emitters in integrated photonic circuits." Nano letters 18.2 (2018): 1175-1179.

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