Track-II, Abstract ID: B010

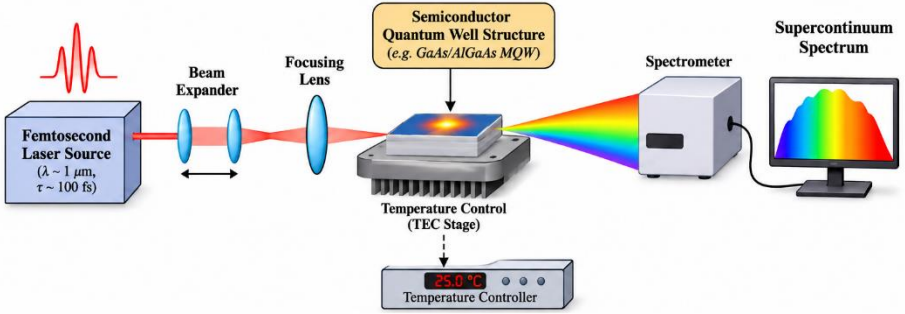
Multi-octave Supercontinuum Generation at Mid-Infrared by Non-Gaussian Pulses in Semiconductor Quantum Wells

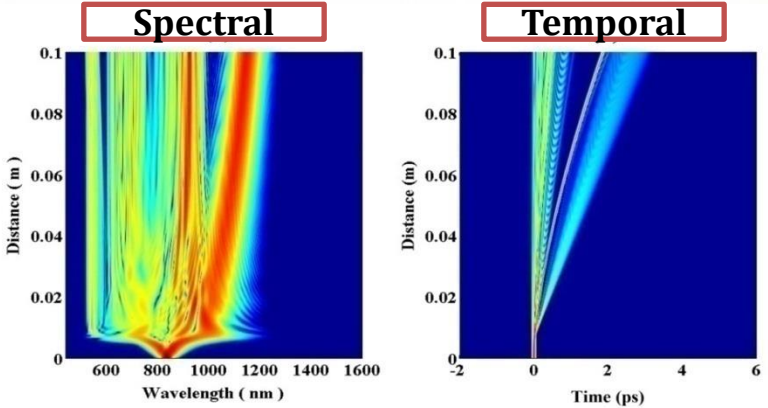
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@ PANE 2026, Bodoland University, 18–20 November 2026

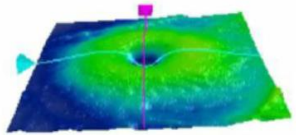
Supercontinuum (SC) Generation

SC generation is a nonlinear optical phenomenon where a narrow-band laser pulse propagates through a nonlinear medium (like photonic crystal fibers, semiconductor waveguides, or bulk crystals) and broadens its spectrum, creating a continuous range of wavelengths - a **"supercontinuum".**

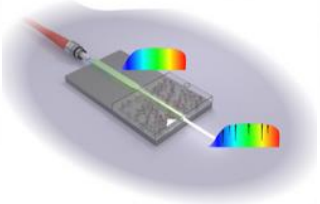




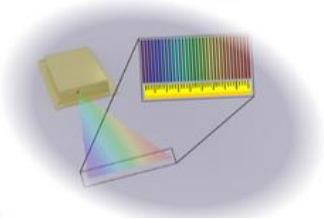
Applications:



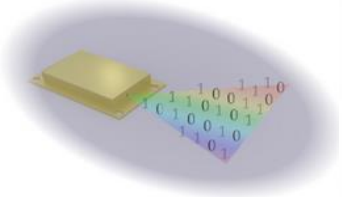
Optical Coherence Tomography



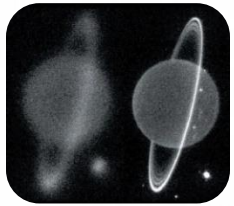
Spectroscopy



Optical Metrology



Telecommunications

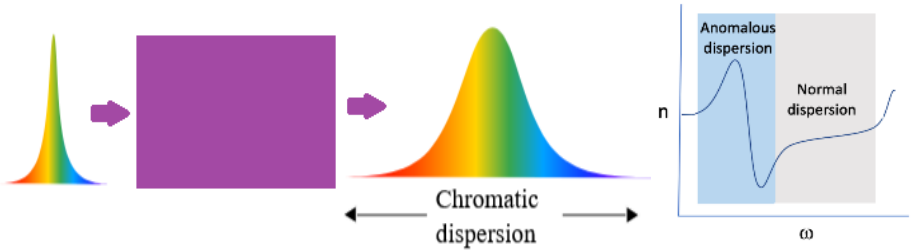


Astrophotonics

Key Mechanisms for SC generation

Dispersion (Linear Effect)

A linear phenomena: Variation of R.I. with frequency.



Two dispersion regimes:
Normal (β_2>0)and **Anomalous** (β_2<0).

Normal : Low frequency components propagate faster than high frequency components.
Anomalous : High frequency components propagate faster than the low frequency one

Dispersion parameter $D = -\frac{2\pi c}{\lambda^2}\beta_2$

Self-phase modulation (Nonlinear Effect)

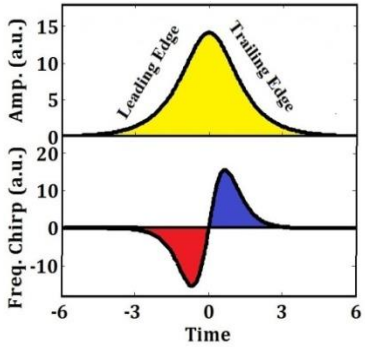
Kerr nonlinear phenomena that leads to generation of new frequencies: $n(I) = n_0 + n_2 I$

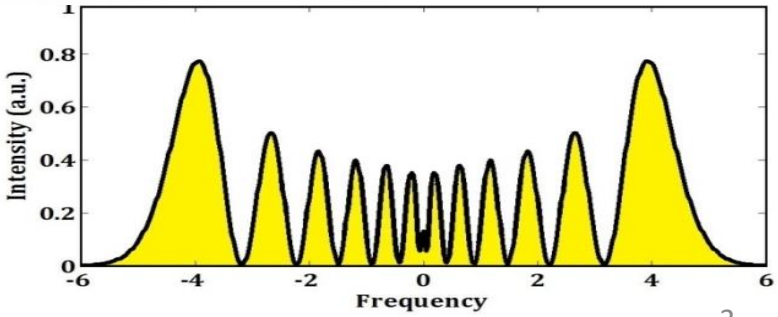
Optical pulse:

$$E(z,t) = E(0,t)\ \exp\left[i\phi_{nl}(z,t)\right]$$

Frequency Chirp:

$$\delta\omega = -\frac{\partial \phi_{nl}}{\partial t}$$

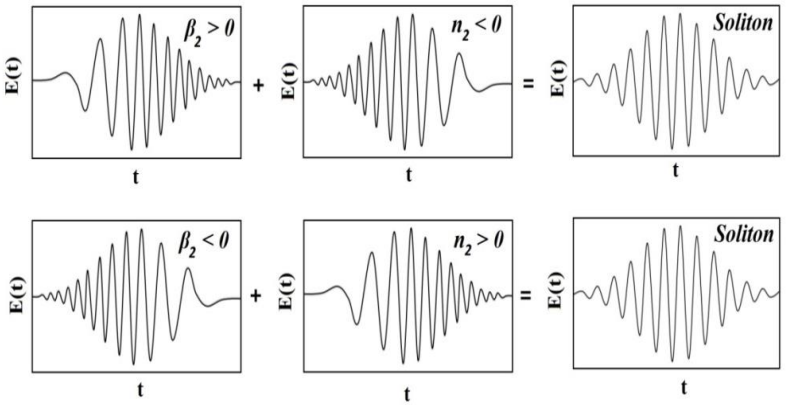




Interplay of Dispersion & Nonlinearity: Mechanisms for SCG

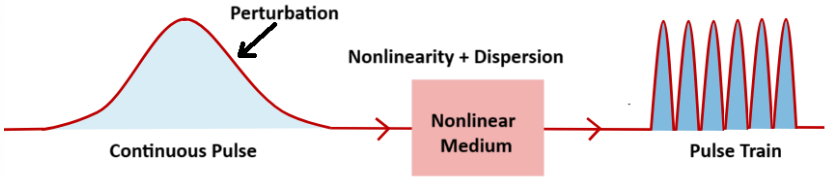
Optical Soliton

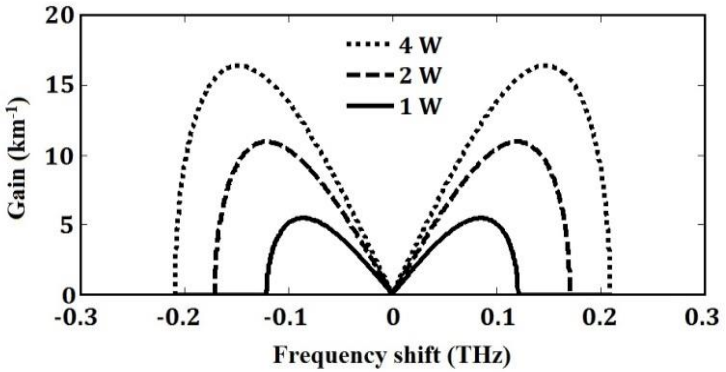
- Optical solitons are the light pulses that neither broaden nor squeeze in both temporal and spectral domain.
- Delicate balance between the normal (anomalous) dispersion and positive (negative) nonlinear effect leads to the formation of soliton.



Modulation instability

Deviations from a periodic waveform reinforced by nonlinearity, leading to the generation of spectral-sidebands.





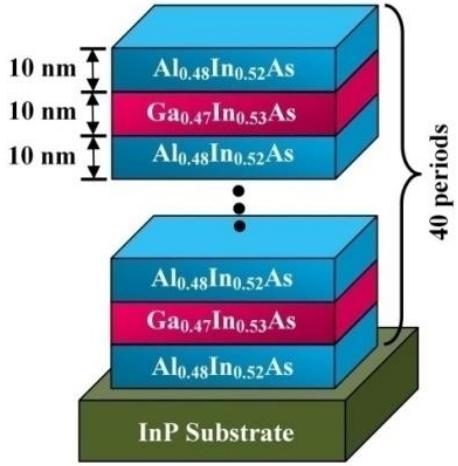
The Semiconductor Quantum Well (SQW)

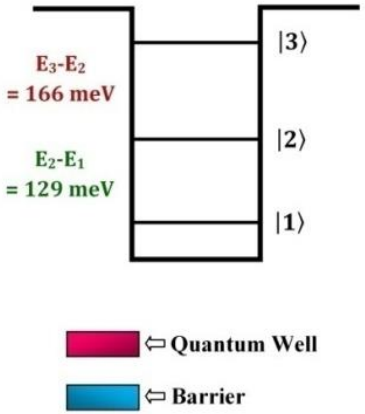
Advantages of QW

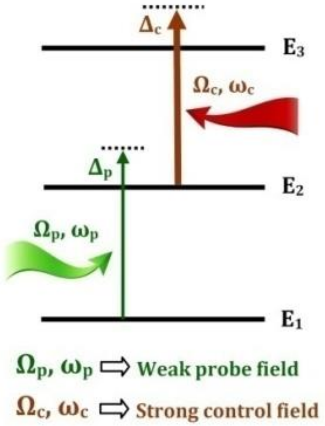
- Solid system,
- Large electric dipole moment,
- Large nonlinear coefficient,
- Flexibility in device design,
- Easily integrated with other s/c devices.

QW Description:

- Grown by Molecular Beam Epitaxy method
- On a lattice matched InP substrate
- A GaInAs SQW of 10 nm,
- Separated by AlGaAs barriers of 10 nm
- 40 couple well periods







Governing Equations

Density Matrix method under slowly varying envelope approximation

Susceptibilities:

First order or Linear $\rightarrow$ $\chi^{(1)} = -\frac{N|\mu_{12}|^2}{\hbar\varepsilon_0}\frac{X(0)}{Y(0)}$

Third order or Kerr $\rightarrow$ $\chi^{(3)} = \frac{N|\mu_{12}|^4}{4\hbar^3\varepsilon_0}\frac{(|\Omega_c|^2 + |X(0)|^2)X(0)}{|Y(0)|^2 Y(0)}$

N – Carrier density
μ_{12} - Dipole moment

$$X(\omega) = \left(\omega + \Delta_p - \Delta_c + i\frac{\gamma_{21}}{2}\right) \qquad Y(\omega) = \left(\omega + \Delta_p + i\frac{\gamma_{31}}{2}\right)\left(\omega + \Delta_p - \Delta_c + i\frac{\gamma_{21}}{2}\right) - |\Omega_c|^2$$

Nonlinear Schrödinger Equation (NLSE):

$$i\frac{\partial A}{\partial \xi} - \frac{1}{2}K_2(0)\frac{\partial^2 A}{\partial T^2} - \frac{i}{6}K_3(0)\frac{\partial^3 A}{\partial T^3} + \frac{1}{24}K_4(0)\frac{\partial^4 A}{\partial T^4} + \gamma|A|^2 A = 0$$

$$K(\omega) = K(0) + K_1(0)\omega + \frac{1}{2}K_2(0)\omega^2 + \frac{1}{6}K_3(0)\omega^3 + \frac{1}{24}K_4(0)\omega^4 \ldots$$

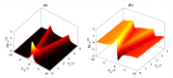
Dispersions $K_n(0) = \left.\frac{d^n K(\omega)}{d\omega^n}\right|_{\omega=0}$ Nonlinearity $\gamma = \frac{2\mu_{13}^2}{cn\varepsilon_0 S_0 \hbar^2} W = \frac{2\omega_p \hbar^2}{c|\mu_{12}|^2}\chi^{(3)}$

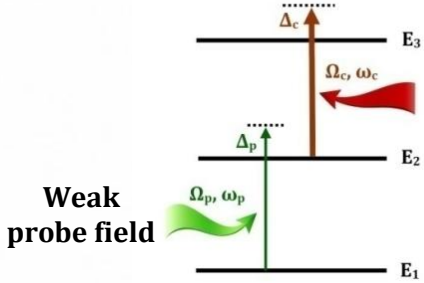
Ref.: *Quantum Optics* by Scully and Zubairy (1996)

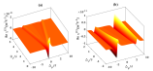
Linear and Nonlinear Optical Properties

Linear Absorption and Formation of EIT

Profile of Nonlinearity under control field effect





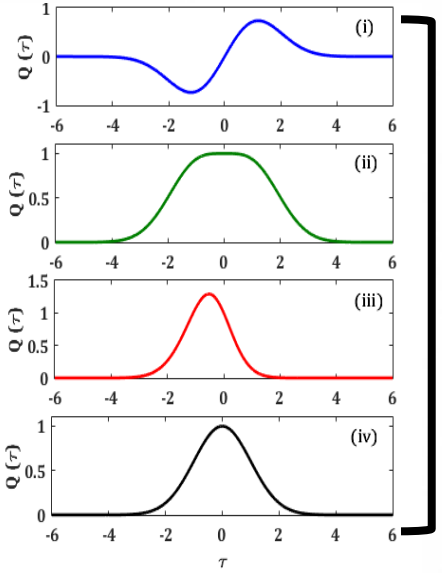


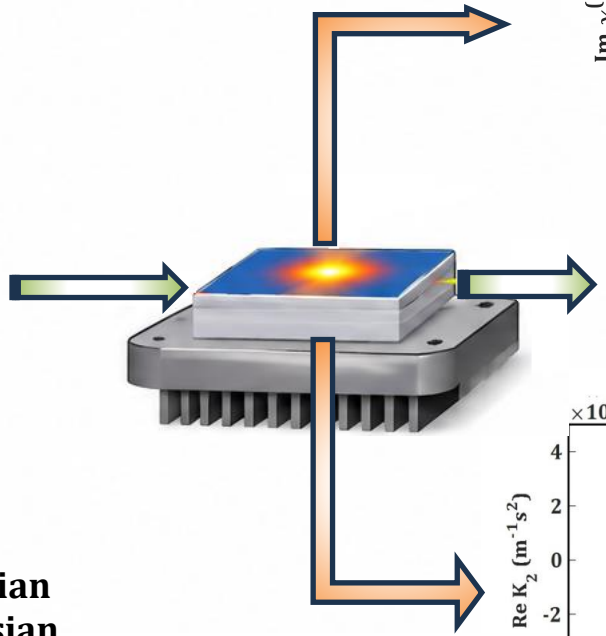
Linear Dispersion and change of group velocity

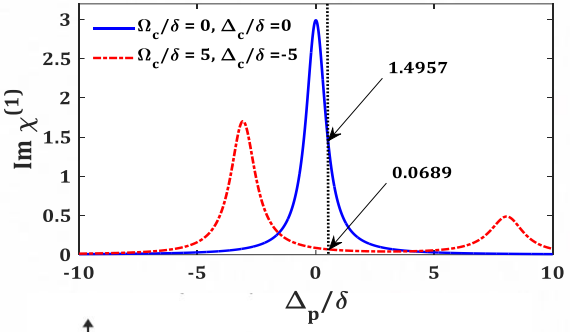
Manipulation of Nonlinearity by control field detuning

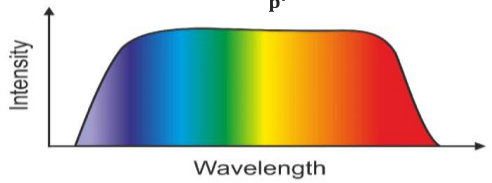
Nonlinearity & Dispersion for SCG under EIT

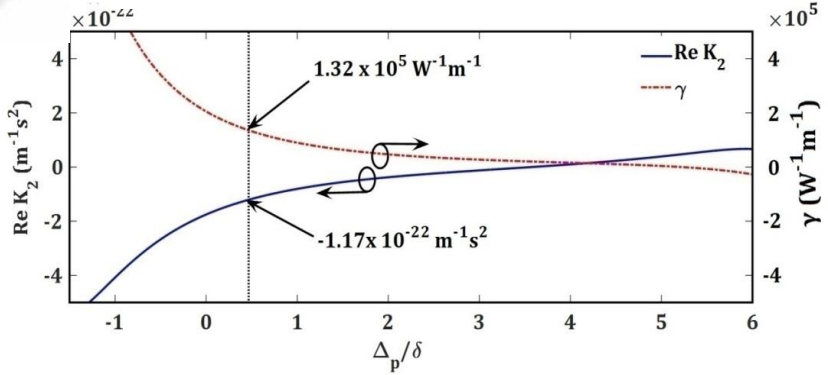
Pulse forms









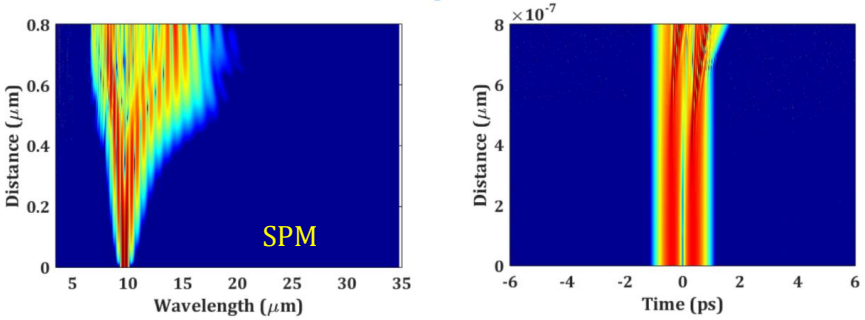


(i) sinhyperbolic-Gaussian
(ii) Coshyperbolic-Gaussian
(iii) Tanhyperbolic-Gaussian
(iv) Gaussian (for comparison)

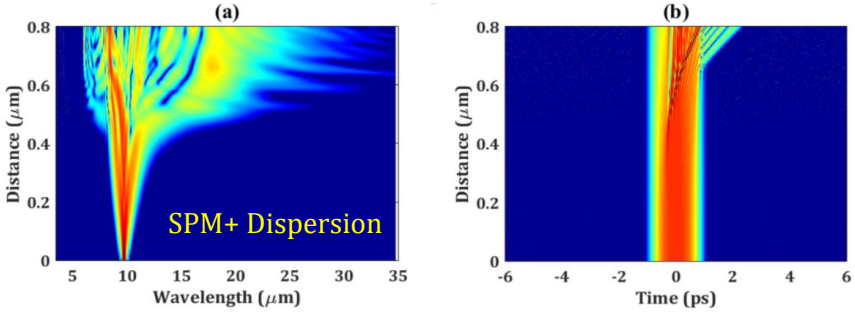
Supercontinuum Generation by different pulses

Pulse duration: 100 fs, Pump wavelength = 9.963 µm

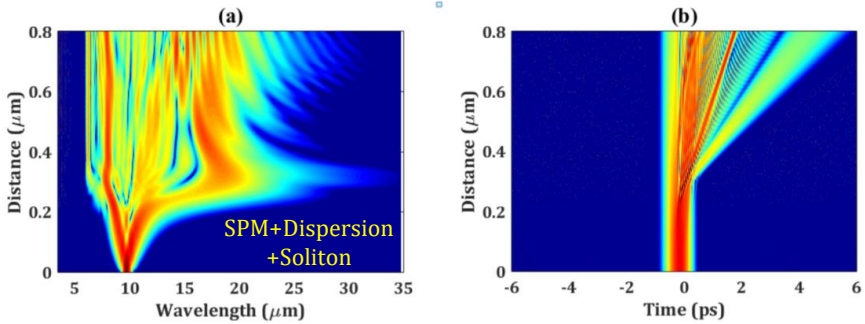
Pulse form: (i) sinhyperbolic-Gaussian



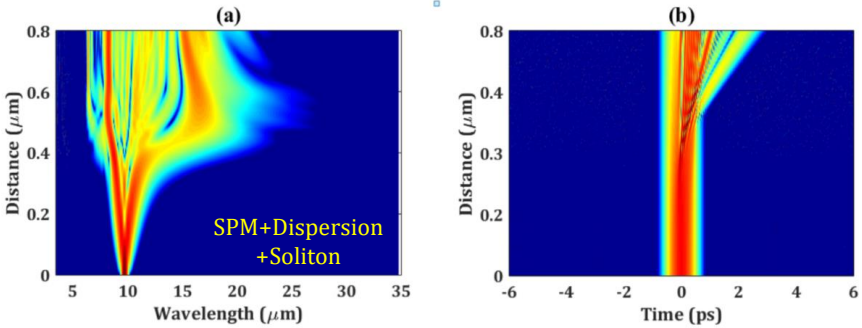
Pulse form: (ii) coshyperbolic-Gaussian



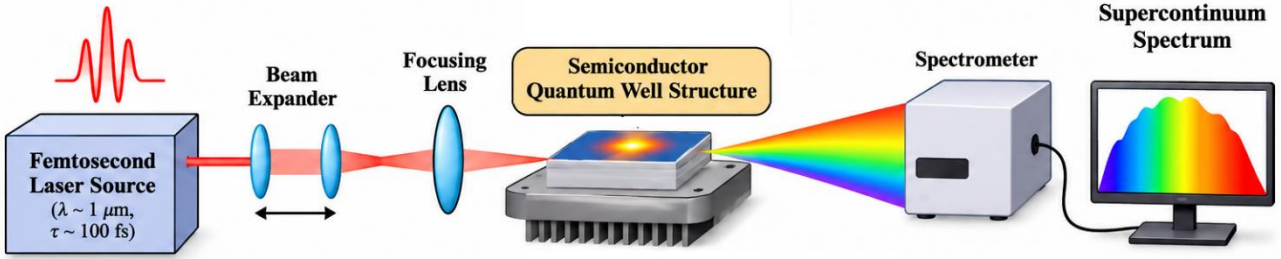
Pulse form: (iii) tanhyperbolic-Gaussian



Pulse form: (iv) Gaussian (for comparison)



Supercontinuum Spectra produced by different pulses

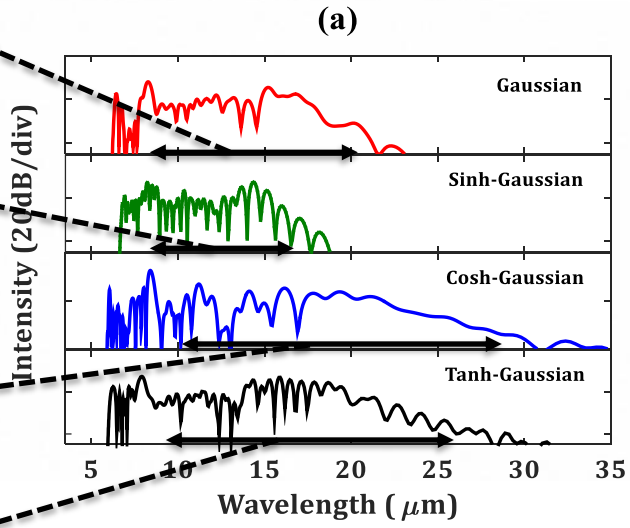


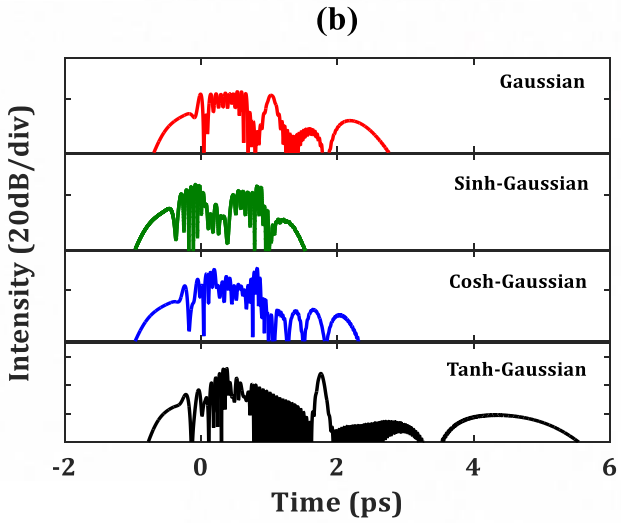
17 μm ($6 - 23\ \mu m$) 1.94 octaves

11 μm ($7 - 18\ \mu m$) 1.36 octaves

29 μm ($6 - 35\ \mu m$) 2.54 octaves

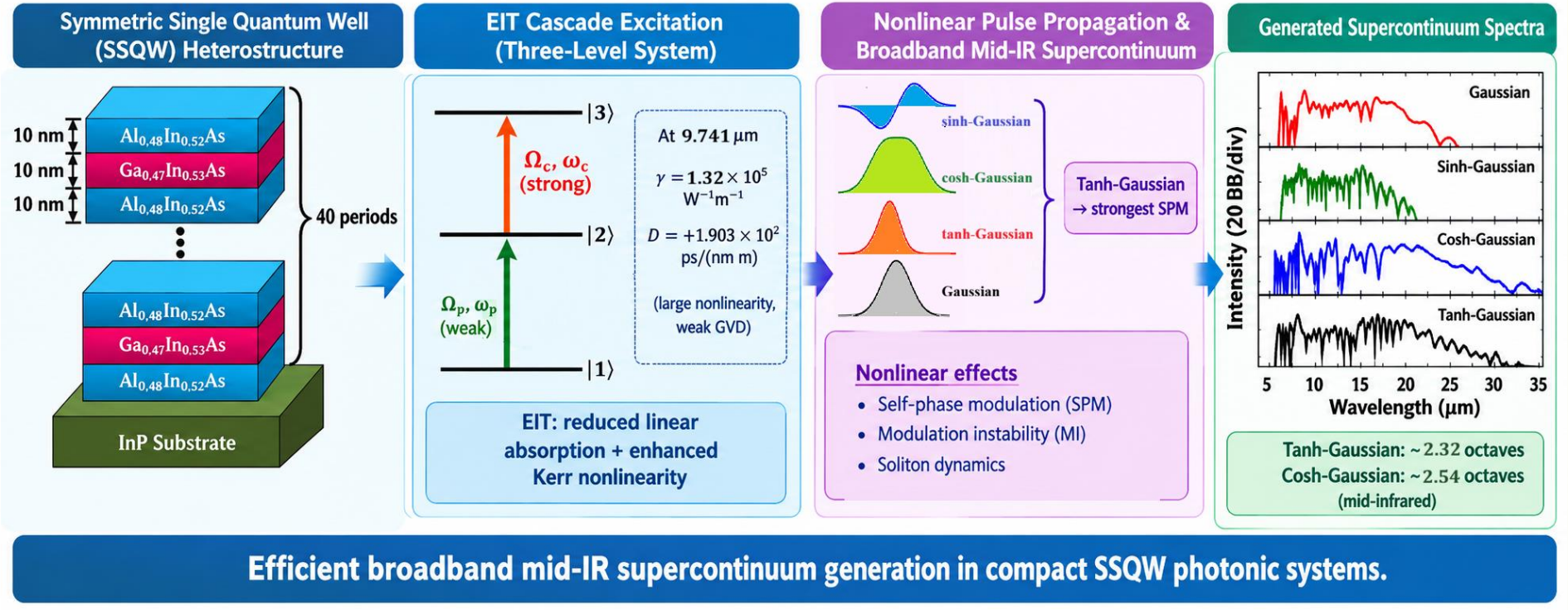
24 μm ($6 - 30\ \mu m$) 2.32 octaves





$$N_{oct} = log_2(\text{upper wavelength/lower wavelength})$$

Conclusion



Efficient broadband mid-IR supercontinuum generation in compact SSQW photonic systems.

Thank you

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