SPONSORED AND PUBLISHED BY

THE IRAQI SOCIETY FOR ALTERNATIVE AND RENEWABLE ENERGY SOURCES AND TECHNIQUES (I.S.A.R.E.S.T.)

EDITORIAL BOARD

ADVISORY BOARD

Organized by I.S.A.R.E.S.T.

SPECIAL ISSUE ON

Beating Classical and Quantum Limits in Optics

In order to submit the seminars and lectures in the up-to-date subjects for Iraqi researchers and students, this issue of the Iraqi Journal of Applied Physics (IJAP) is presenting seminar titled *"Beating Classical and Quantum Limits in Optics"* authored by Mankei Tsang.

INVITATION TO PARTICIPATE

To all they would like to submit seminars or scientific lectures during the third semester of the **I.S.A.R.E.S.T.** (July, August and September) in 2007, you are kindly requested to contact the secretary of the **I.S.A.R.E.S.T.** for date and presentation arrangements of the seminars or lectures. Please, do not hesitate to participate in our activities, this chance might be required by young scientists in our country, IRAQ, to develop and grow as well as introduce the professors and experts in field. You could find us on the post address, emails and mobile below:

Postal:

P. O. Box 55259, Baghdad 12001, IRAQ

Emails:

irq_appl_phys@yahoo.com
editor_ijap@yahoo.co.uk
odayata2001@yahoo.com

Mobile:

00964-7901274190

Beating Classical and Quantum Limits in Optics

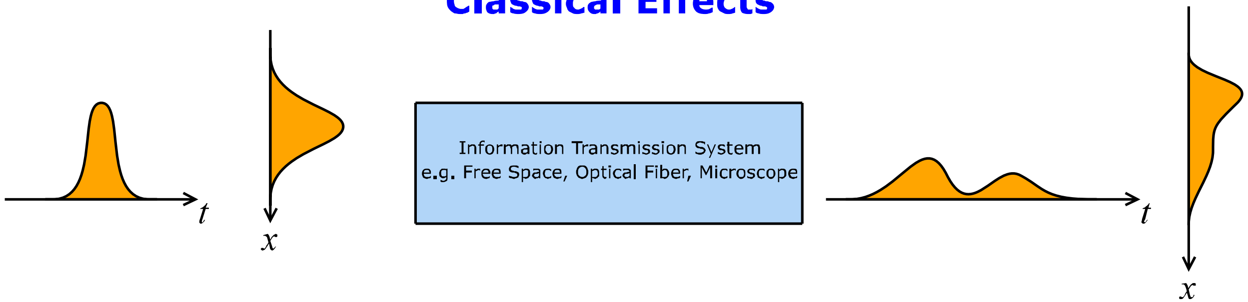
Mankei Tsang

mankei@optics.caltech.edu

Department of Electrical Engineering, Caltech

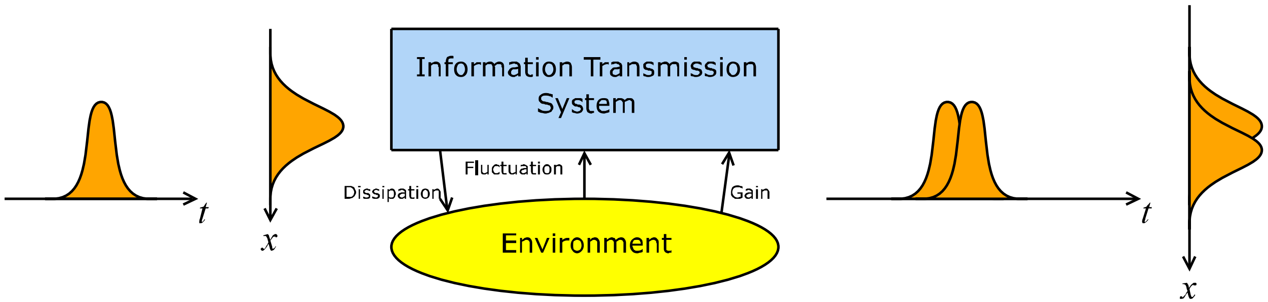
Classical and Quantum Distortions

Classical Effects



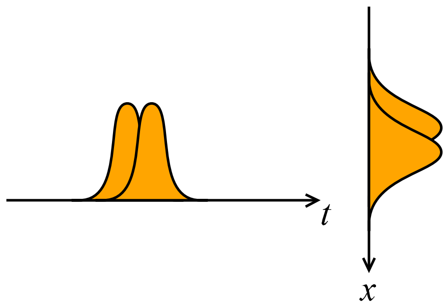
Dispersion, Diffraction, Rayleigh Criterion, Loss, Nonlinearity, ...

Quantum Decoherence



Langevin Noise, Amplified Spontaneous Emission, Gordon-Haus Timing Jitter, ...

Quantum Limits

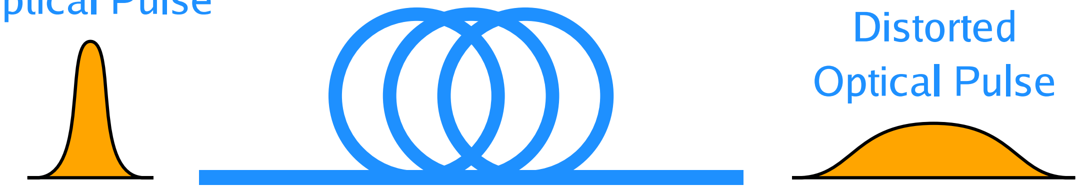


Standard Quantum Limits, Heisenberg Uncertainty Principle

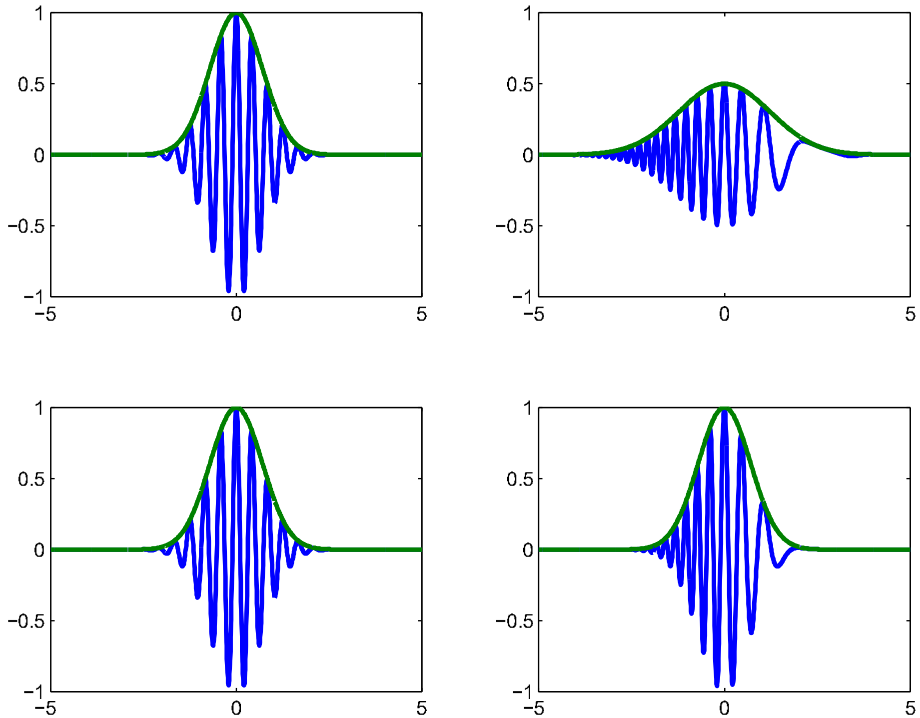
Outline

- Dispersion and nonlinearity compensation by Spectral Phase Conjugation
- Beating temporal quantum limits by Quantum Soliton Control
- Beating spatial quantum limits by Self-Focusing
- Multiphoton Absorption Rate of Quantum Lithography
- Beating resolution limits by Dielectric Slabs

Ultrashort Pulse Propagation Effects



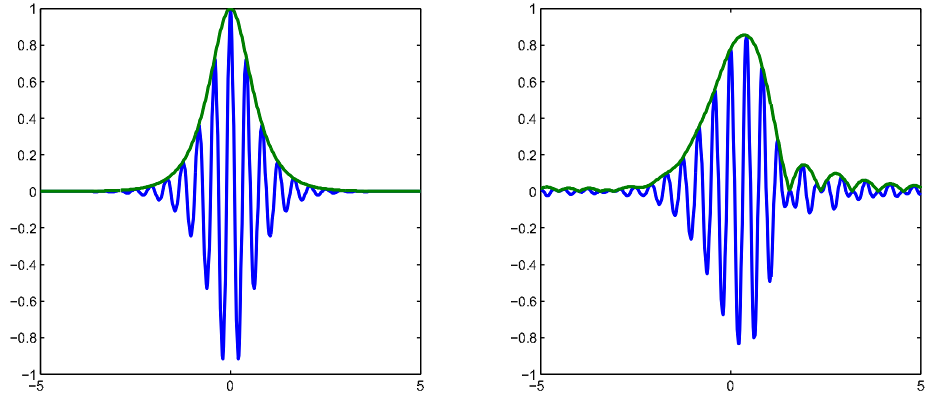
Group-Velocity Dispersion



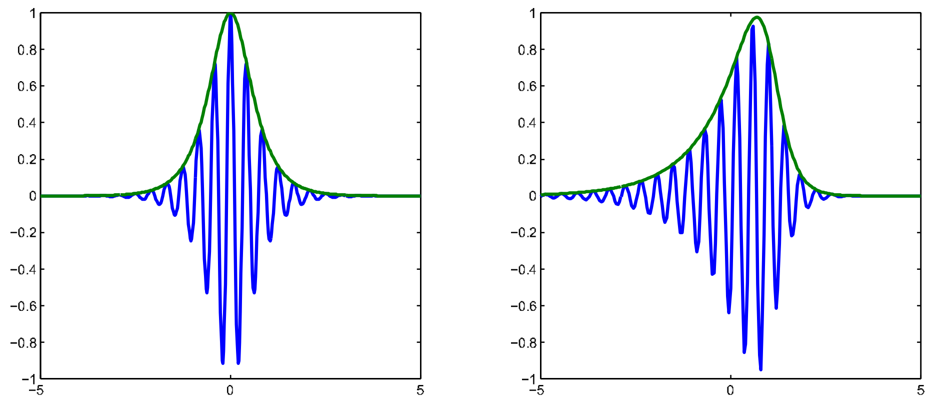
Kerr Nonlinearity ($\Delta n(t) \sim I(t)$)

High-Order Effects

Third-Order Dispersion



Self-Steepening



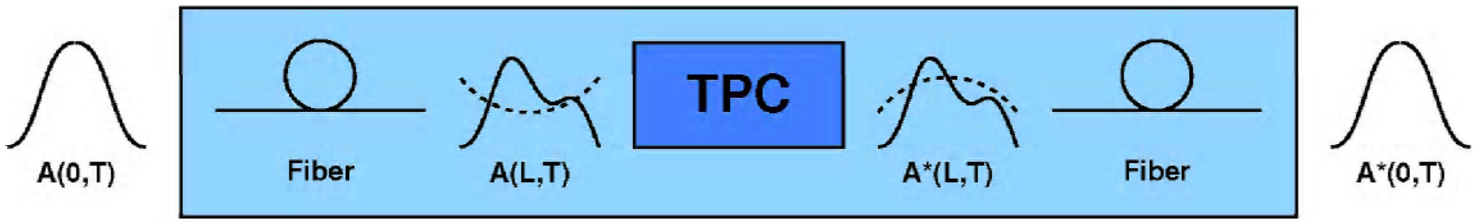
Stimulated Raman Scattering, ...

Agrawal, *Nonlinear Fiber Optics* (Academic Press, San Diego, 2001)

Ultrashort Pulse Propagation

- $$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A - \frac{i\beta_2}{2}\frac{\partial^2 A}{\partial T^2} + \frac{\beta_3}{6}\frac{\partial^3 A}{\partial T^3} + i\gamma\left[|A|^2 A + \frac{i}{\omega_0}\frac{\partial}{\partial T}(|A|^2 A) - T_R A\frac{\partial |A|^2}{\partial T}\right] \qquad (1)$$

- Perform $a(\omega) \rightarrow a^*(2\omega_0 - \omega)$, or equivalently $A(T) \rightarrow A^*(T)$, to compensate for GVD and Kerr effect and if loss, higher-order dispersion, and self-steepening can be neglected.
- Temporal Phase Conjugation (TPC)



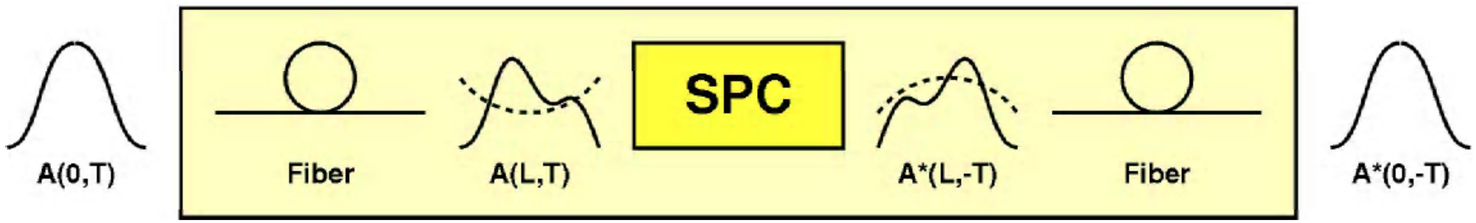
Yariv, Fekete, and Pepper, Optics Letters, **4**, 52 (1979),

Fisher, Suydam, and Yevick, Optics Letters, **8**, 611 (1983).

Spectral Phase Conjugation

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A - \frac{i\beta_2}{2}\frac{\partial^2 A}{\partial T^2} + \sum_{n=3}^{\infty}\frac{i\beta_n}{n!}\left(i\frac{\partial}{\partial T}\right)^n A + i\gamma\left[|A|^2 A + \frac{i}{\omega_0}\frac{\partial}{\partial T}(|A|^2 A) - T_R A\frac{\partial |A|^2}{\partial T}\right] \quad (2)$$

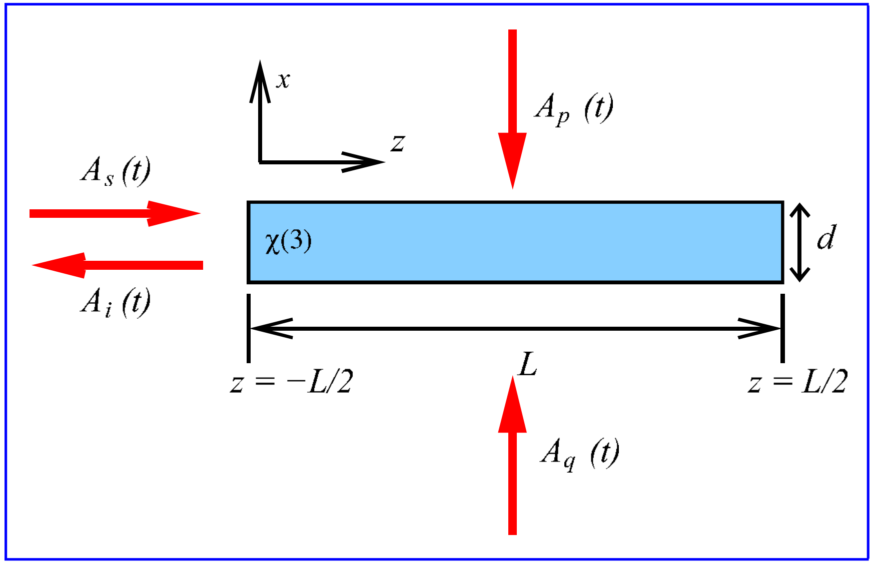
- Perform $a(\omega) \rightarrow a^*(\omega)$, or equivalently $A(T) \rightarrow A^*(T_0 - T)$, to compensate for dispersion of all orders, Kerr effect, and self-steepening if loss and stimulated Raman scattering can be neglected.
- Spectral Phase Conjugation (SPC)



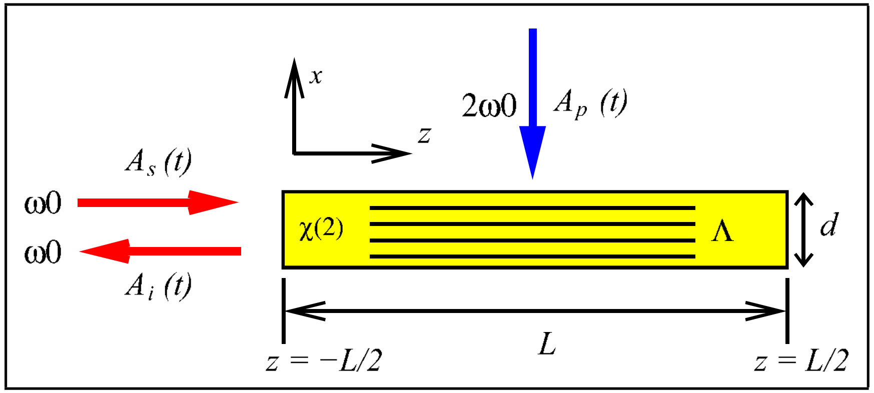
Tsang and Psaltis, Optics Letters **28**, 1558 (2003)

Methods of Performing SPC

- Tsang and Psaltis, Optics Express, **12**, 2207 (2004)

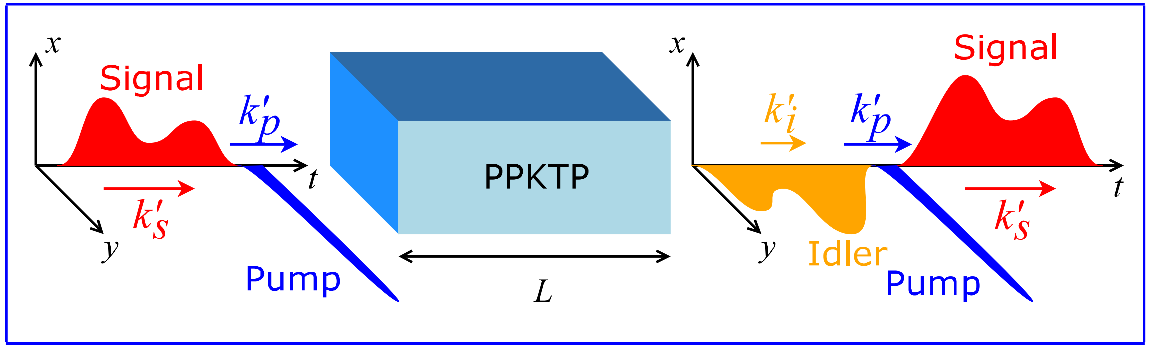


- Tsang and Psaltis, Optics Communications, **242**, 659 (2004)



SPC via Extended Phase Matching

- Tsang, JOSA B **23**, 861 (2006)



- Extended Phase Matching: Quasi-Phase Matching + Group Velocity Matching
- Quasi-Phase Matching satisfied by periodic poling of nonlinear crystals
- Group Velocity Matching satisfied by material dispersion, such as KTP at 1584 nm.

Coupled-Mode Equations

- z derivatives can be neglected if the pump pulse is short enough:

$$\frac{\partial A_s}{\partial z} + k_s' \frac{\partial A_s}{\partial t} = j\chi A_p(t - k_p' z) A_i^* \tag{3}$$

$$\frac{\partial A_i^*}{\partial z} + k_i' \frac{\partial A_i^*}{\partial t} = -j\chi A_p(t - k_p' z) A_s \tag{4}$$

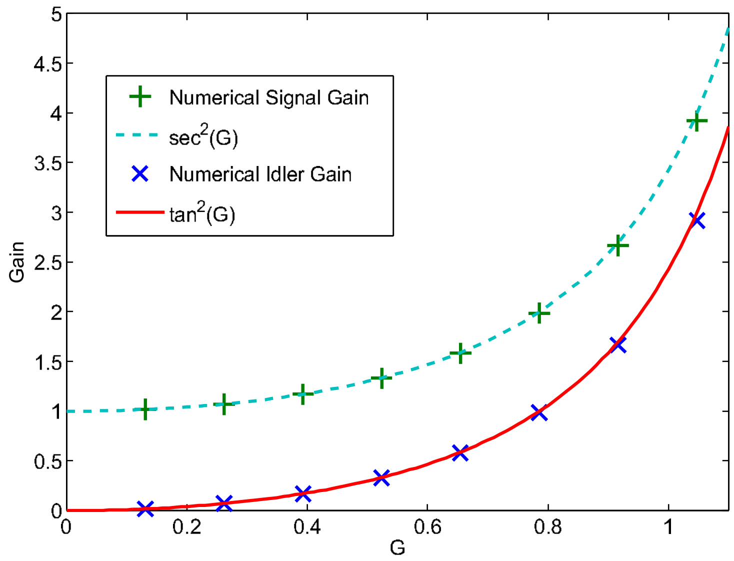
- Approximate solutions:

$$A_s(L,t) = A_s(0,t)\sec(G) + jA_i^*(0,-t)\tan(G) \tag{5}$$

$$A_i(L,t) = A_i(0,t)\sec(G) + jA_s^*(0,-t)\tan(G) \tag{6}$$

$$G = \frac{\chi}{\gamma}\int A_p(\tau)d\tau = \left(\frac{1}{1 - k_p'/k_s'}\right)\chi \int A_p(\tau)\upsilon d\tau \tag{7}$$

Mirrorless Parametric Oscillation

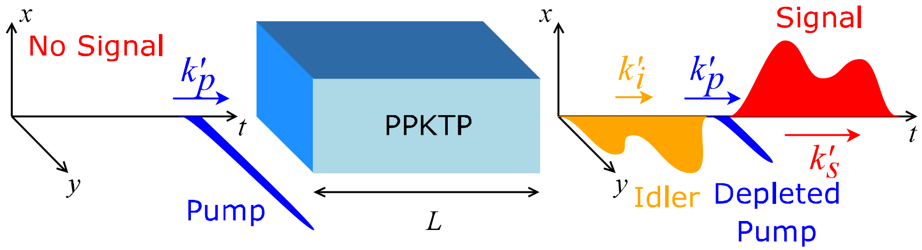
- 

$$A_s(L,t) = A_s(0,t)\sec(G) + jA_i^*(0,-t)\tan(G) \quad (8)$$

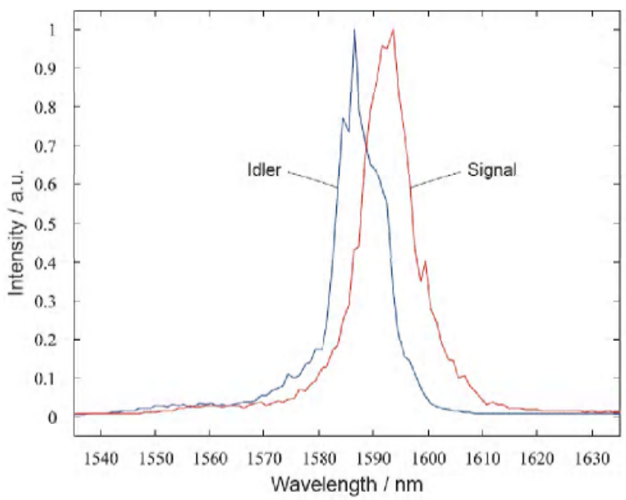
$$A_i(L,t) = A_i(0,t)\sec(G) + jA_s^*(0,-t)\tan(G) \quad (9)$$

- What happens when $G = \pi/2$, and $\sec(G), \tan(G) = \infty$?
- z derivatives can no longer be neglected, gain increases exponentially with respect to z.
- Analogous to mirrorless optical parametric oscillation

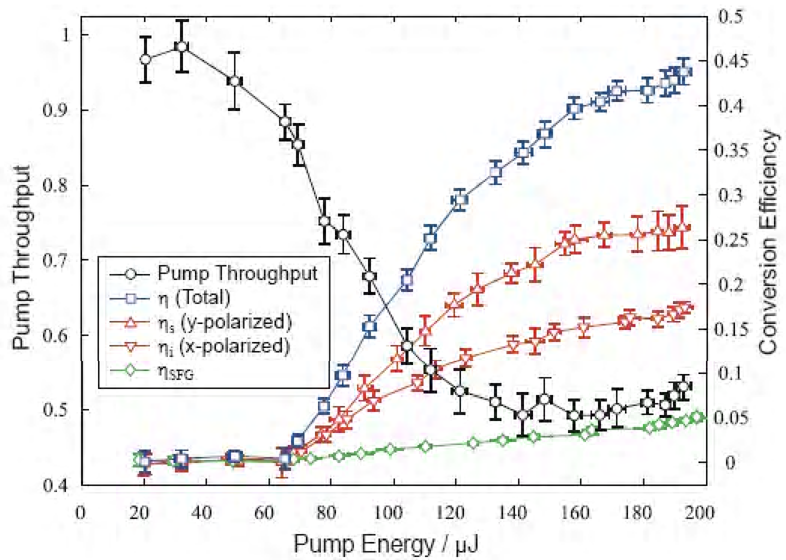
Experimental Demonstration of Mirrorless OPO



- 3cm periodically-poled KTP crystal from Raicol Crystals, dispersed femtosecond pump pulse at 792nm
- 43% down conversion efficiency, 140 dB equivalent gain

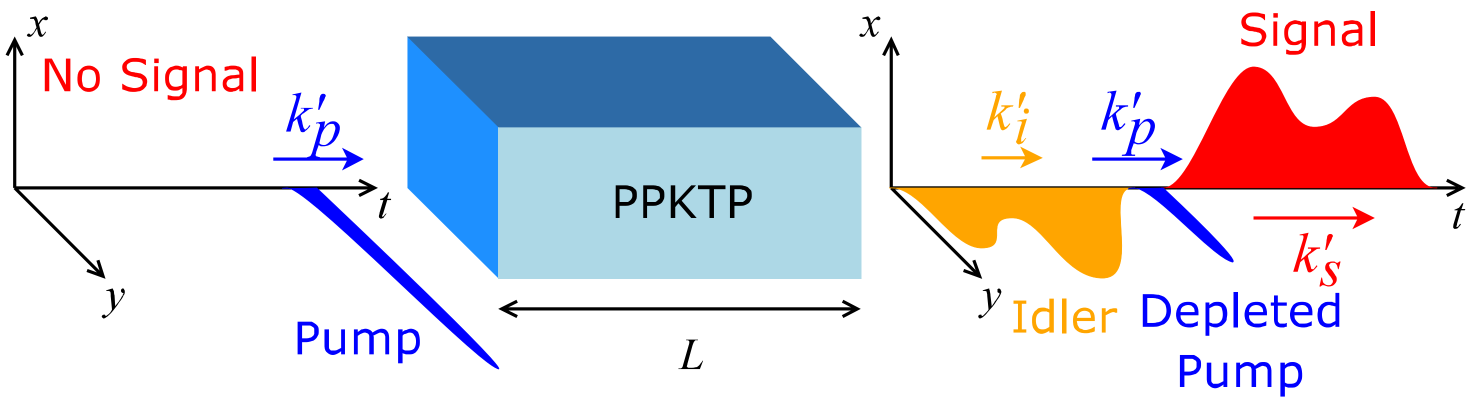


(a)



Pu, Wu, Tsang, and Psaltis, CLEO 2007, paper CMB5

Spontaneous Parametric Down Conversion



- Classical theory predicts zero output for zero input:

$$\frac{\partial A_s}{\partial z} + k'_s \frac{\partial A_s}{\partial t} = j\chi A_p(t - k'_p z) A_i^* \tag{10}$$

$$\frac{\partial A_i^*}{\partial z} + k'_i \frac{\partial A_i^*}{\partial t} = -j\chi A_p(t - k'_p z) A_s \tag{11}$$

- Quantum theory predicts entangled photon pair generation even for zero input.

Giovannetti *et al.* (MIT), Physical Review Letters,**88**, 183602 (2002),

Kuzucu *et al.* (MIT), Physical Review Letters, **94**, 083601 (2005)

Comparison with Kuzucu et al.'s experiment

- Number of generated photon pairs per pump pulse is given by $\tan^2(G)$.
[Tsang, JOSAB **23**, 861 (2006)]
- Using their parameters, $\lambda_0 = 1584$ nm, $\chi^{(2)} = 7.3$ pm/V, $n_0 = 2$, $\gamma = 1.5 \times 10^{-10}$ s/m, $T_p = 100$ fs, average pump power $= 350$ mW, diameter $= 200$ μm, and pump repetition rate $f_r = 80$ MHz, the spontaneously generated photon pairs per second is theoretically given by

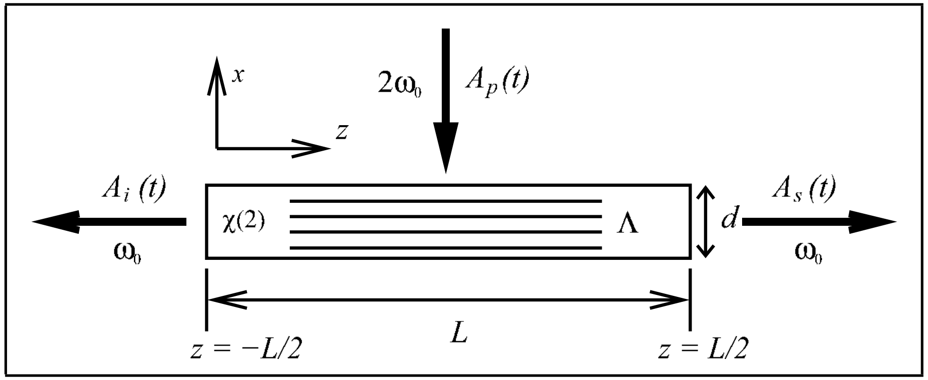
$$G = 0.2, \tag{12}$$

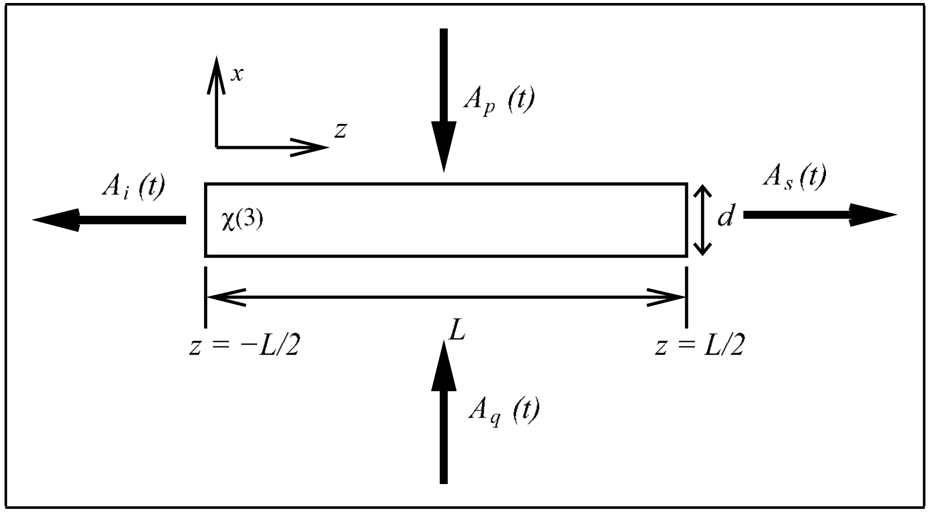
$$f_r \tan^2(G) = 3.6 \times 10^6/\text{s}. \tag{13}$$

Kuzucu *et al.* (MIT), Physical Review Letters, **94**, 083601 (2005):

> coupling efficiency into the PM fiber. From the detection efficiencies and our measurement duty cycle we estimate a single spatial fiber-optic mode pair production rate of $\sim 4 \times 10^6$/s at 350 mW of pump power.

Spontaneous Spectral Phase Conjugation



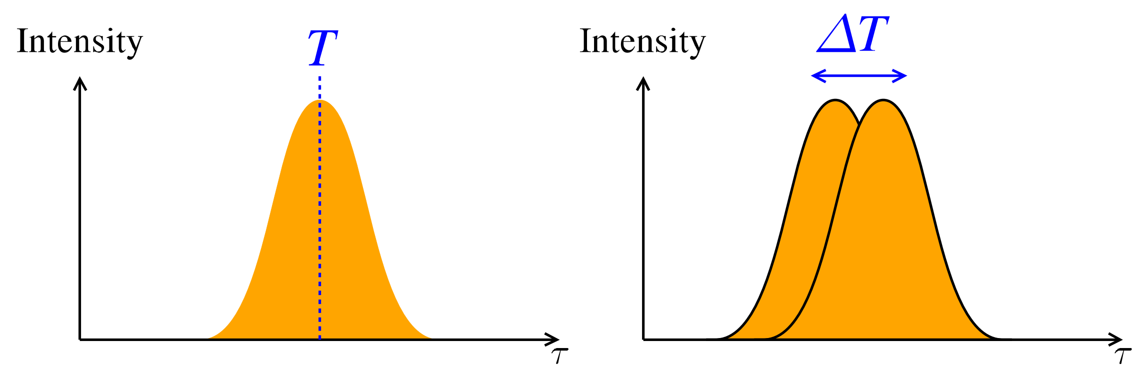


- Spontaneous SPC can also create positive frequency correlation and negative time correlation.

Tsang and Psaltis, Physical Review A, **71**, 043806 (2005)

What's Special about These Photon Pairs?

- The entangled photons are frequency correlated and time anti-correlated.
- One-way autocompensating cryptography [Walton et al., PRA **67**, 062309 (2003)], Quantum enhancement of timing accuracy [Giovannetti et al., Nature **412**, 417 (2001)].

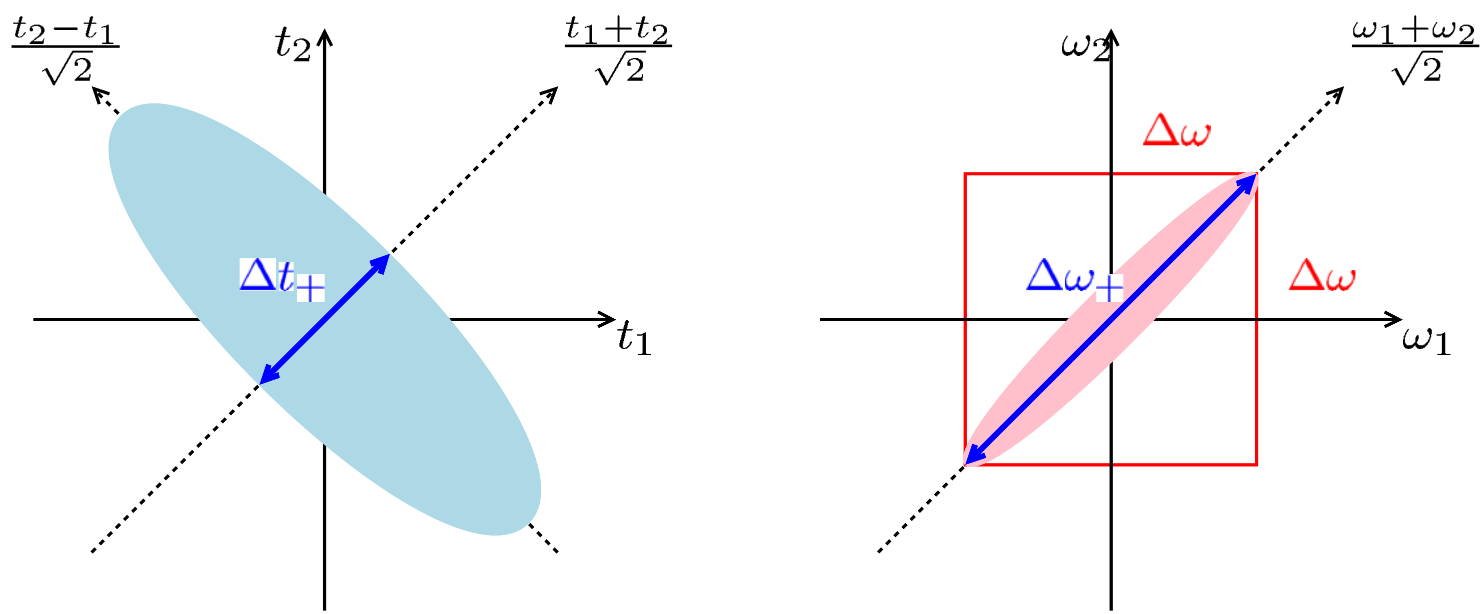


$$T = \frac{\int_{-\infty}^{\infty} t|A(t)|^2 dt}{\int_{-\infty}^{\infty} |A(t)|^2 dt} \tag{14}$$

- Time-anti-correlated photons can achieve a lower uncertainty in T for the same bandwidth.
- Useful for clock synchronization or positioning.
- Analogous to how mutual funds work: selecting negatively-correlated stocks reduces risk.

Beating the SQL of Arrival Time Accuracy

- Given some bandwidth limit $\Delta\omega$, (the red box), what is the smallest achievable $\Delta\left(\frac{t_1+t_2}{2}\right)$?



$$\Delta\left(\frac{t_1+t_2}{2}\right) \sim \frac{1}{\sqrt{2}\Delta\omega_+} = \frac{1}{\sqrt{2}(\sqrt{2}\Delta\omega)} = \frac{1}{2\Delta\omega} \quad (15)$$

- $\sqrt{2}$ enhancement with negative time correlation and positive frequency correlation.

Multiphoton Enhancement

Giovannetti, Lloyd, and Maccone, Nature **412**, 417 (2001)

- N independent photons:

$$\Delta T \geq \frac{1}{2\sqrt{N}\Delta\omega} \quad \text{(Standard Quantum Limit)} \tag{16}$$

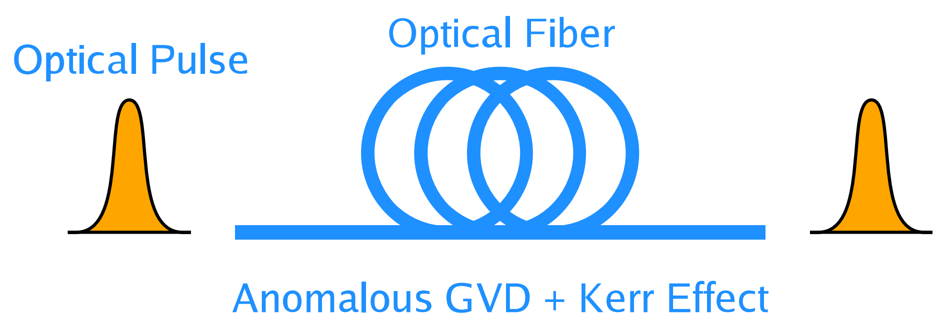
- e.g.: $W = 100$ ps, $N = 10^{10}$, $\Delta T = 1$ fs
- N negatively-time-correlated photons:

$$\Delta T \geq \frac{1}{2N\Delta\omega} \quad \text{(Ultimate Quantum Limit)} \tag{17}$$

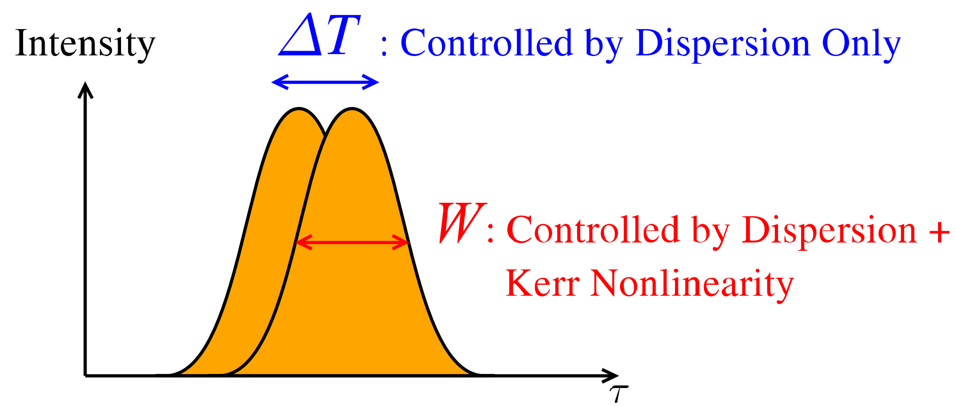
- $N = 2$ is quite useless compared to $N \gg 1$
- How to create multiphoton time anti-correlation with $N \gg 1$?

Quantum Theory of Optical Fiber Solitons

- Classical theory: soliton is a stable solitary wave due to balance between anomalous GVD and Kerr effect



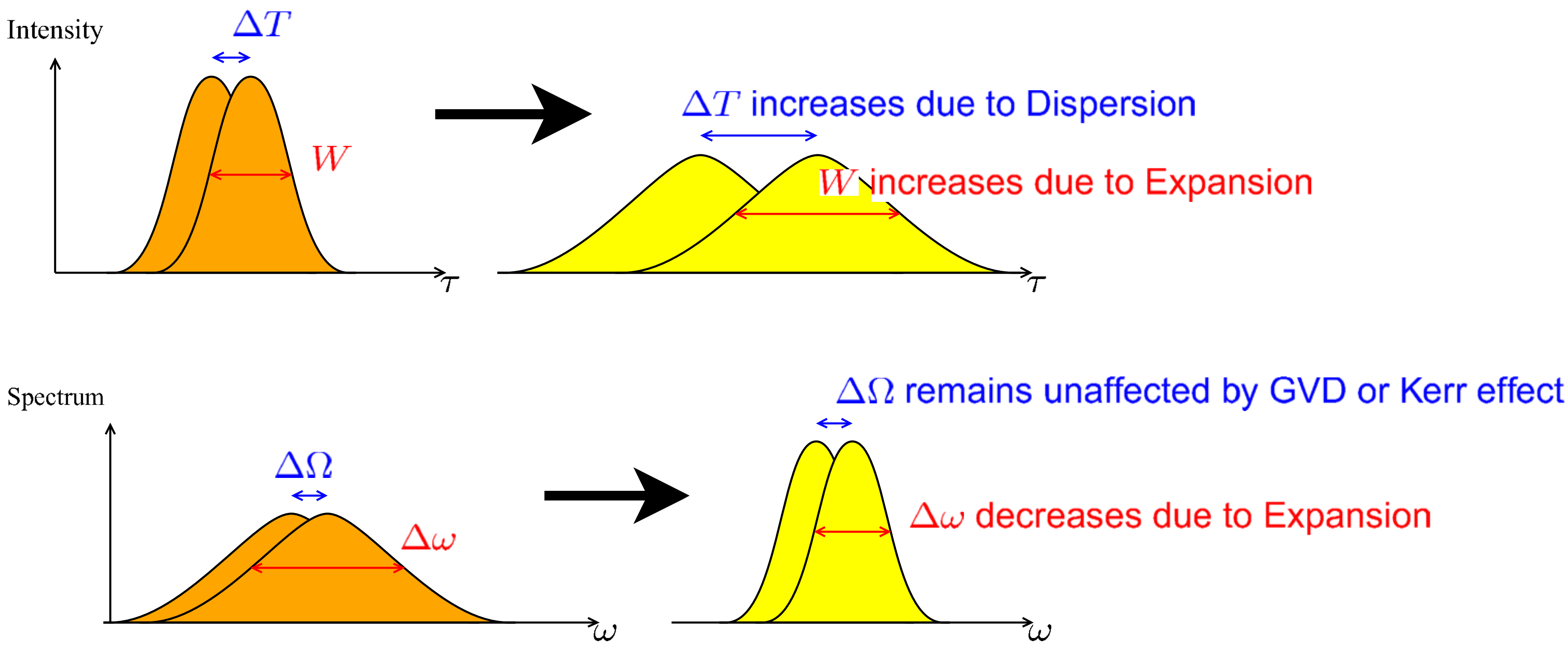
- Quantum theory: Stable pulse shape and bandwidth due to balance between GVD and Kerr effect, but the average position of the pulse is affected by dispersion only.



Tsang, Physical Review Letters **97**, 023902 (2006)

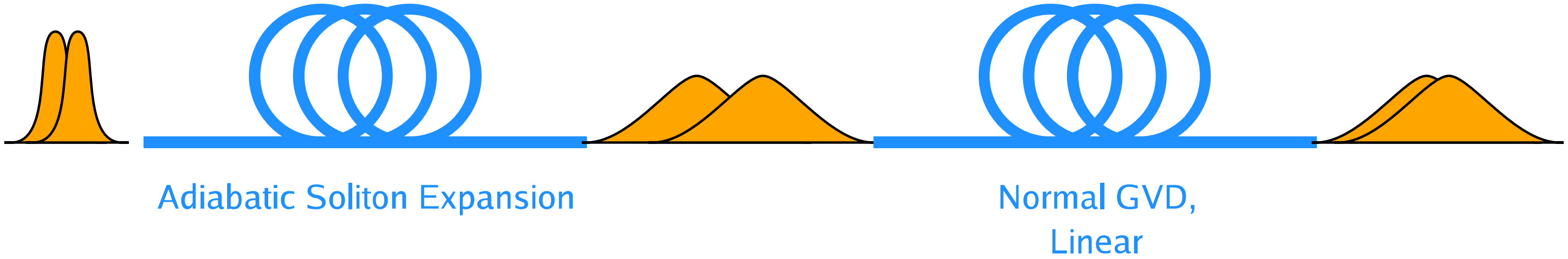
Adiabatic Soliton Expansion

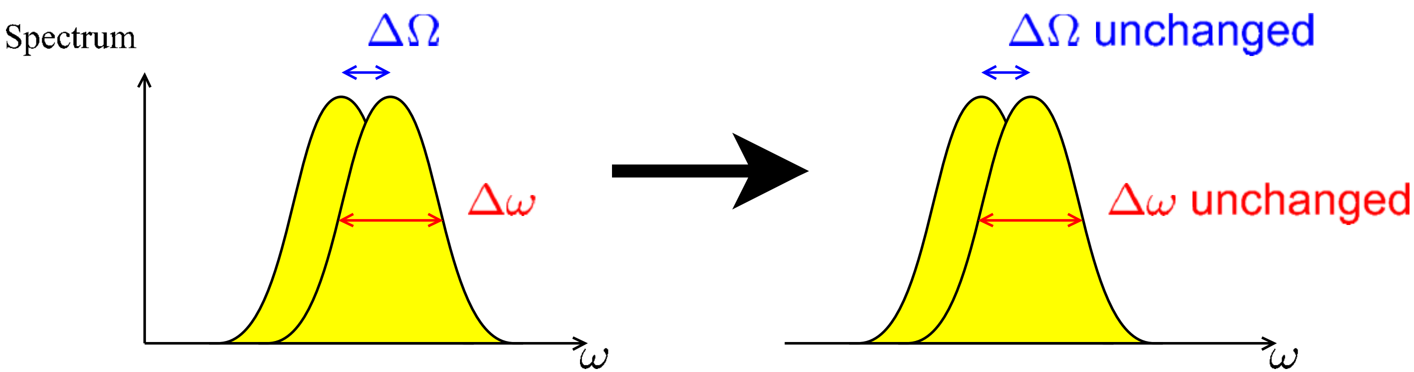
- 1. Adiabatically reduce the Kerr nonlinearity or increase the group-velocity dispersion along the fiber



Quantum Dispersion Compensation

- 2. Compensate for dispersion of T in a second fiber with $b'L' = -bL$

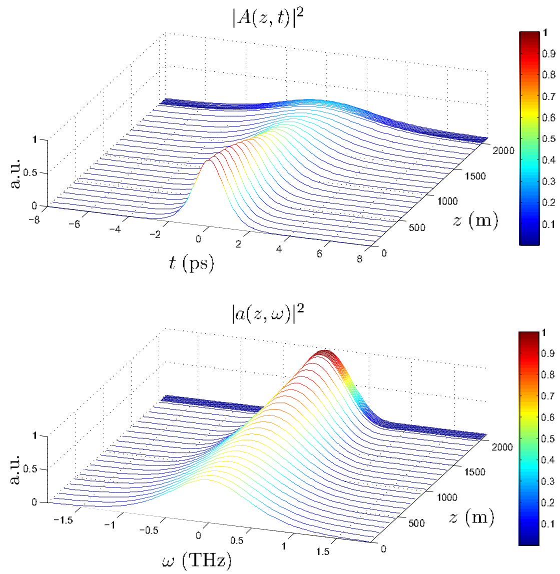


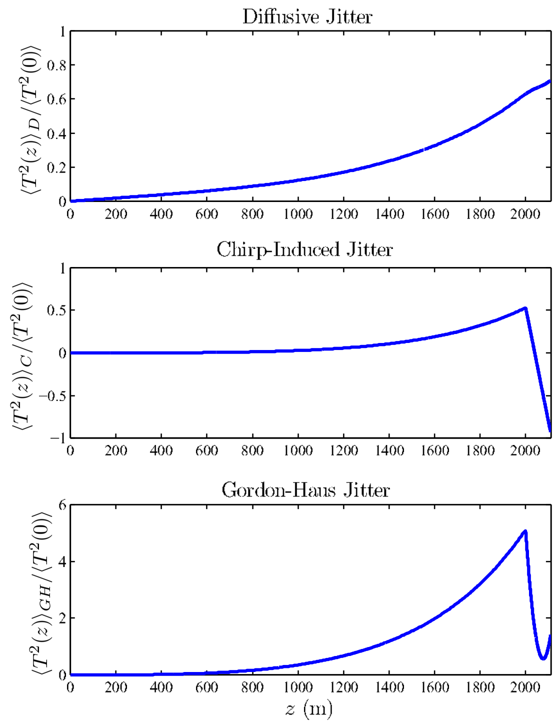


- ΔT is the same as the input, but $\Delta\omega$ is reduced, so $\Delta T < 1/(2\sqrt{N}\Delta\omega)$.
- Subfemtosecond timing jitter detection can be performed by cross-correlation measurements via sum-frequency generation or balanced homodyne measurements with a reference local oscillator pulse.

Decoherence of Adiabatic Soliton Control

- Decoherence mainly due to loss of photons. Main source of quantum noise is the Gordon-Haus timing jitter.
- The decoherence effect can be estimated numerically using a semiclassical analysis:

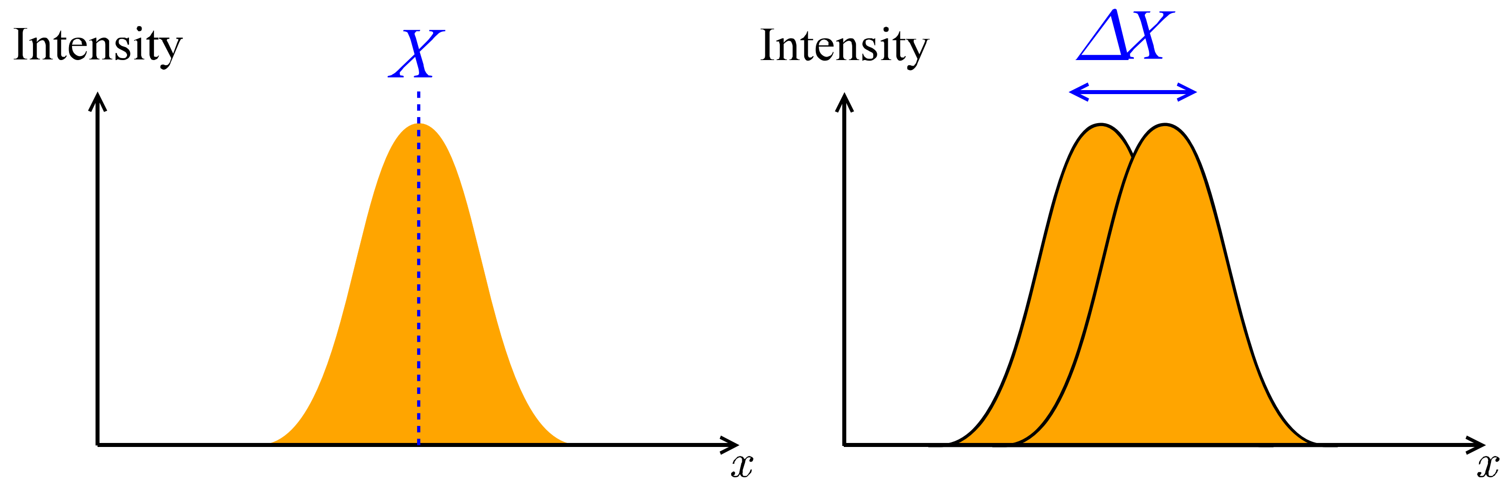




- Using realistic parameters, the achievable squeezing is predicted to be ~ 3.8 dB.
- Not great, but enough for proof-of-concept demo.

Tsang, e-print arXiv:0704.0663 [submitted]

Optical Beam Position

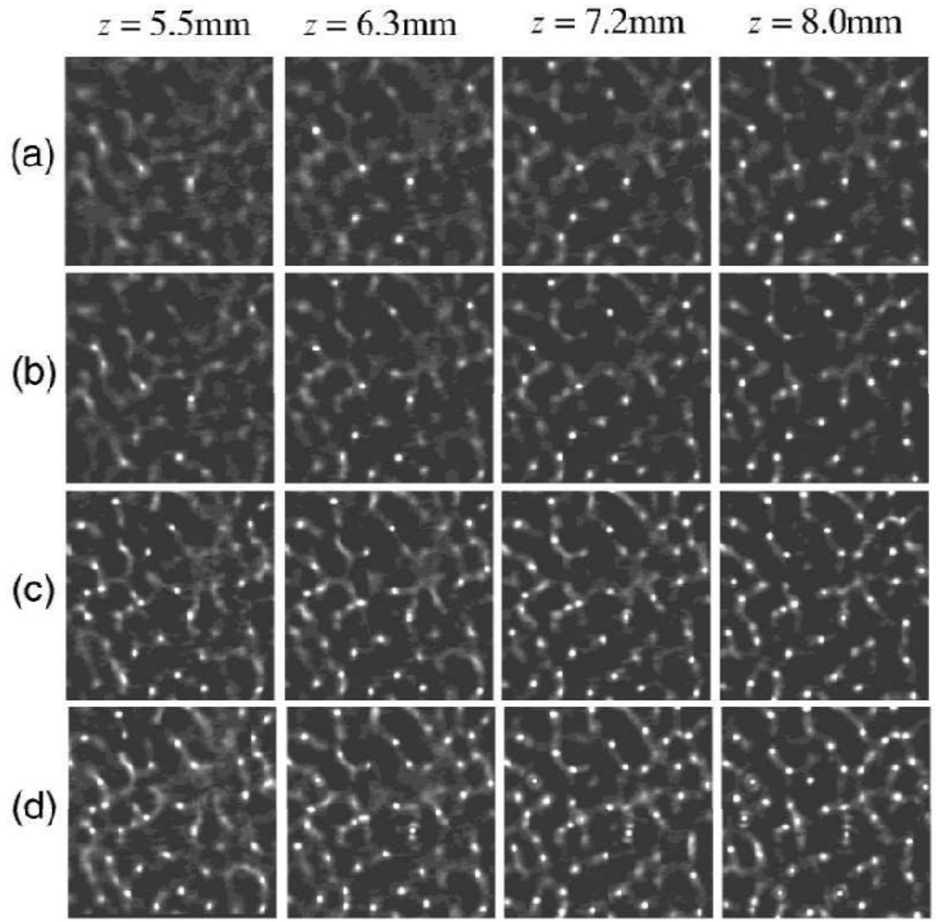


- $$\Delta X_{SQL} \sim \frac{1}{2\sqrt{N}\Delta k}, \quad \Delta X_{UQL} \sim \frac{1}{2N\Delta k} \tag{18}$$

- Important for
  - Nanoparticle Detection
  - Atomic Force Microscope
  - Lithography

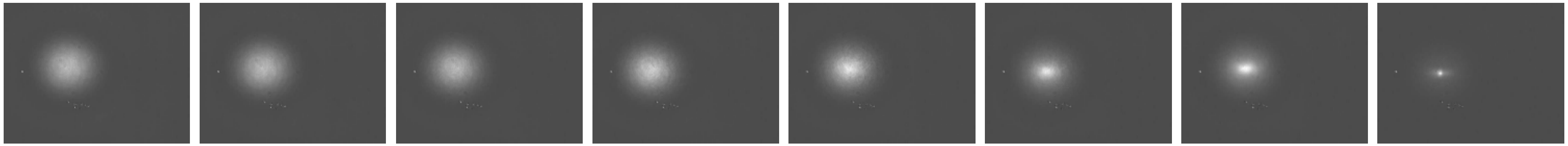
2D Self-Focusing Collapse

Balance between diffraction and Kerr effect is unstable.

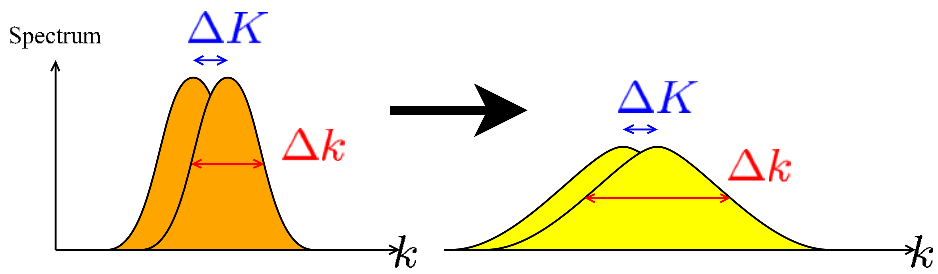


Centurion, Pu, Tsang, and Psaltis, Physical Review A **71**, 063811 (2005)

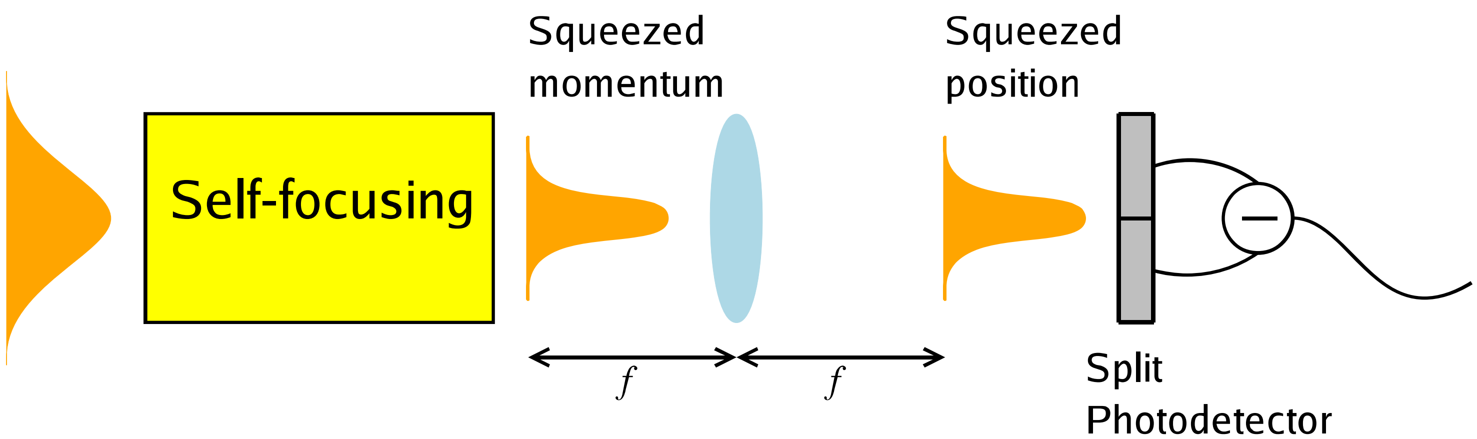
Spatial Quantum Enhancement by Self-Focusing



- increasing pulse energy $\longrightarrow$

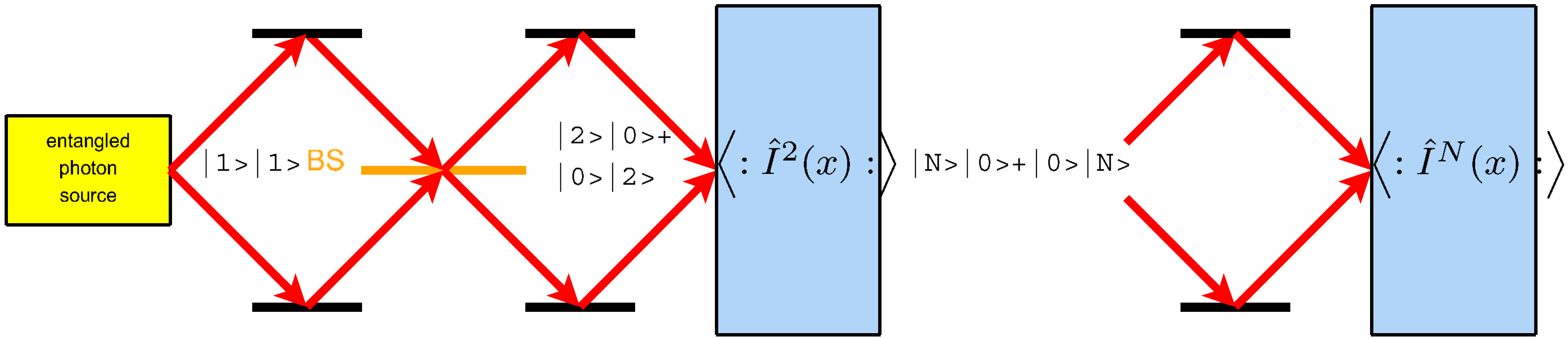


- Use a Fourier-transform lens to transform to real space



- e.g. $W = 3$ mm, $N = 10^{10}$, $\Delta X = 30$ nm

Quantum Lithography



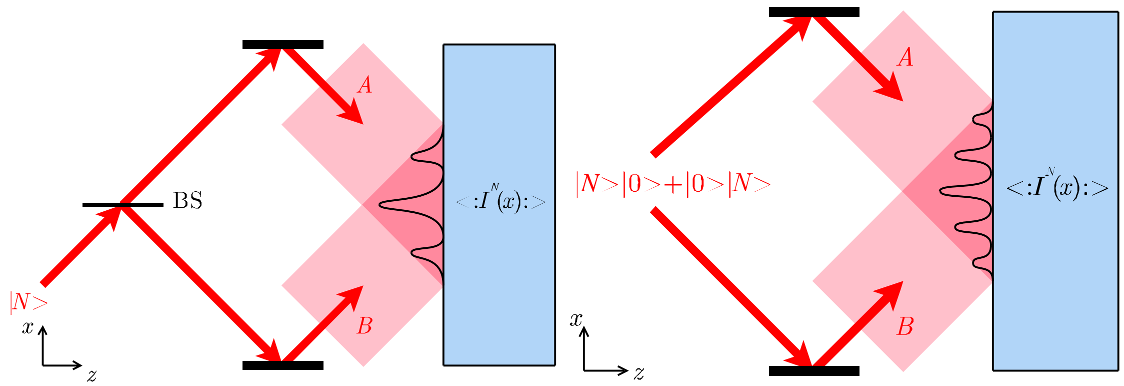
$$\left\langle : \hat{I}^2(x) : \right\rangle \sim \cos^2(2k_x x), \quad \left\langle : \hat{I}^N(x) : \right\rangle_{NOON} \sim \cos^2(N k_x x), \qquad (19)$$

Factor-of-N resolution enhancement compared to one-photon absorption or classical multiphoton lithogrpahy:

$$\left\langle : \hat{I}(x) : \right\rangle \sim \cos^2(k_x x), \quad \left\langle : \hat{I}^N(x) : \right\rangle_{classical} \sim \cos^{2N}(k_x x) \qquad (20)$$

Boto et al., Physical Review Letters 85, 2733 (2000).

Multiphoton Absorption Rate of NOON State



$$\left\langle : \hat{I}^N(x) : \right\rangle_{classical} \sim \cos^{2N}(\kappa x) \quad \left\langle : \hat{I}^N(x) : \right\rangle_{NOON} \sim \cos^2(N\kappa x) \tag{21}$$

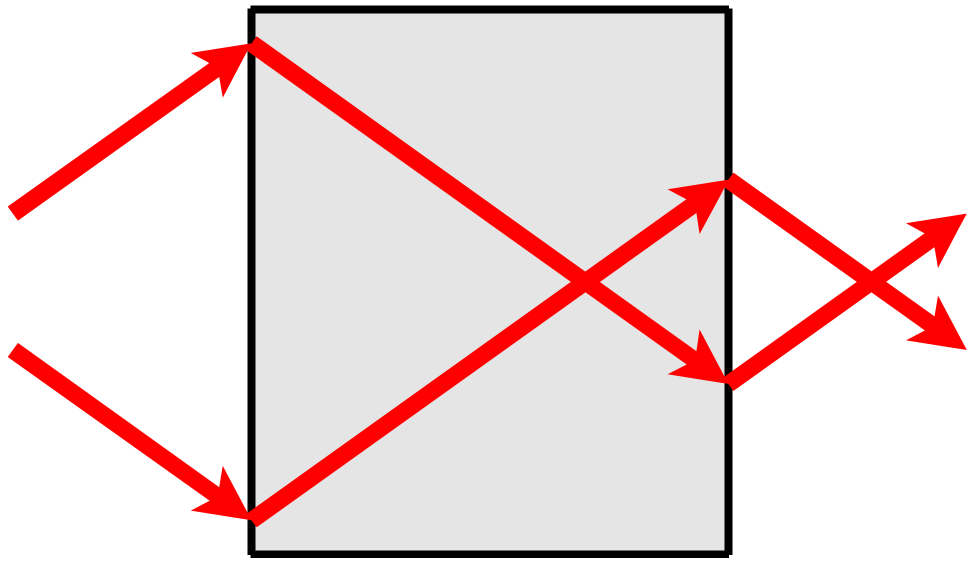
$$\left\langle : \hat{I}^N(0) : \right\rangle_{classical} = 2^{N-1} \left\langle : \hat{I}^N(0) : \right\rangle_{NOON} \tag{22}$$

- Spatial frequency correlation leads to position anti-correlation
- Photons arrive further apart from one another, less chance of all photons arriving at the same atom.
- Proof-of-concept demo of quantum lithography reported in D'Angelo *et al.*, PRL **87**, 013602 (2001), so the reduced coincidence rate can be readily tested experimentally.

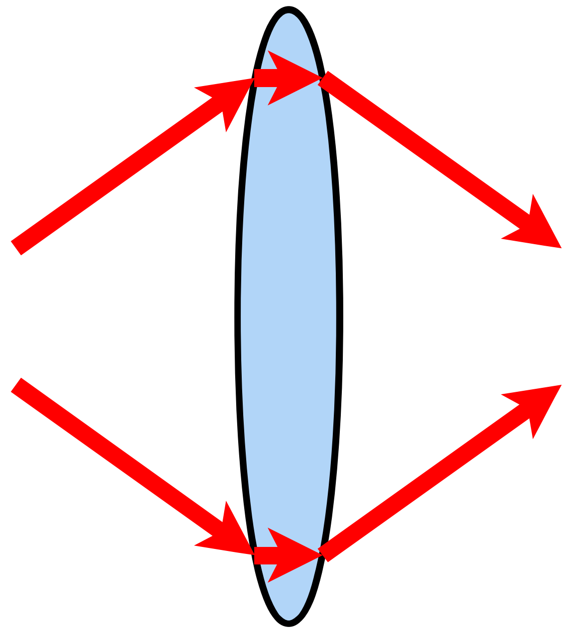
Tsang, Physical Review A **75**, 043813 (2007)

Veselago: Negative Refraction

$n = -1$

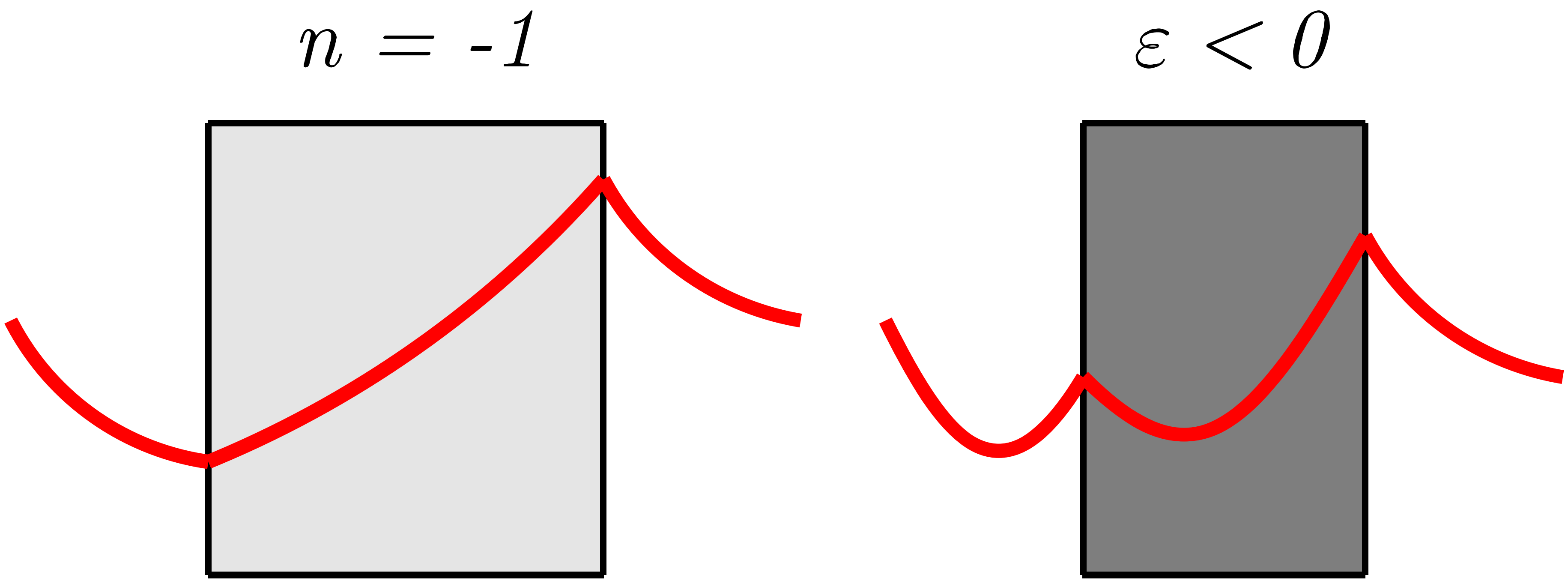


$n > 1$



Veselago, Sov. Phys. Usp. **10**, 509 (1968)

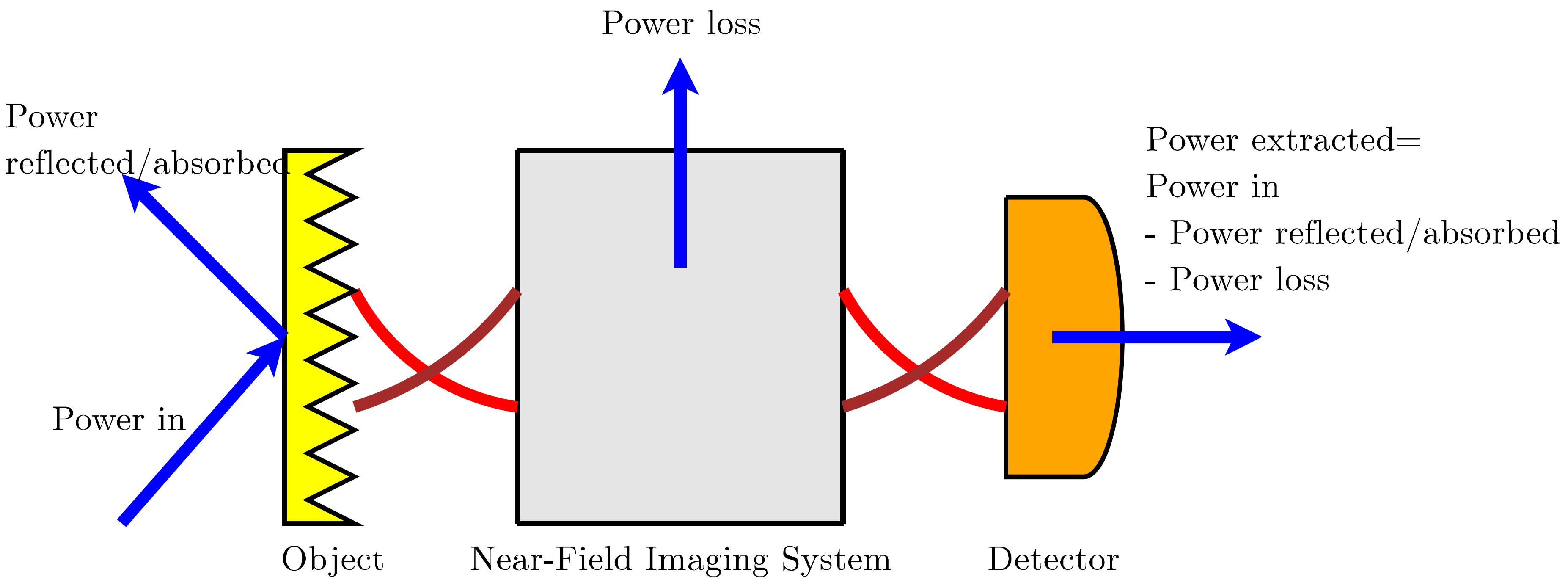
Pendry: Evanescent Wave Amplification



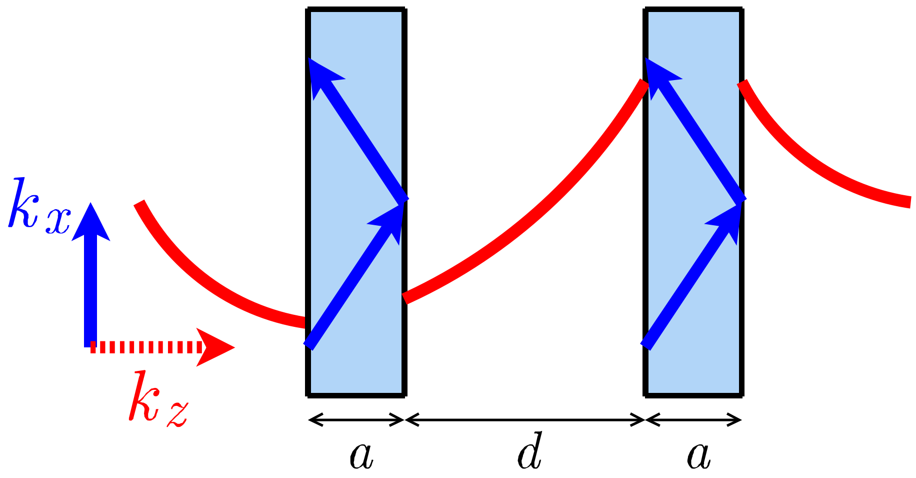
$$T \to \exp(-ik_z d), \quad R \to 0 \tag{23}$$

Pendry, Phys. Rev. Lett. **85**, 3966 (2000)

Importance of Low Loss



Two Dielectric Slabs



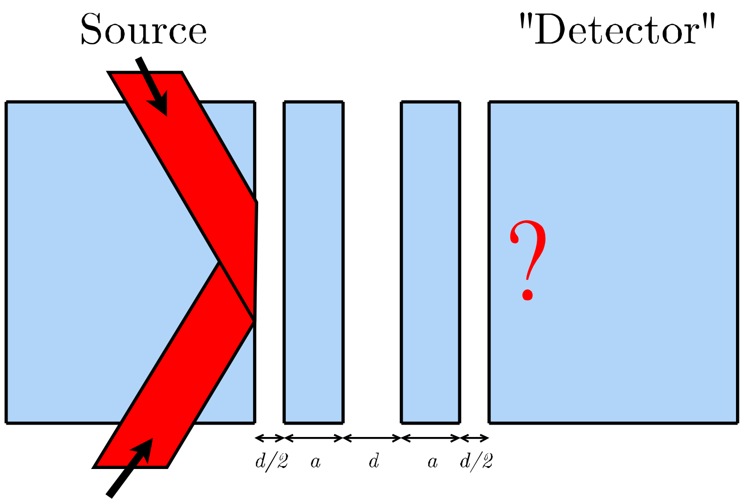
$$R = \Gamma + \frac{\tau^2 \Gamma \exp(2ik_z d)}{1 - \Gamma^2 \exp(2ik_z d)} = 0, \quad T = \frac{\tau^2 \exp(ik_z d)}{1 - \Gamma^2 \exp(2ik_z d)} = -\exp(-ik_z d) \tag{24}$$

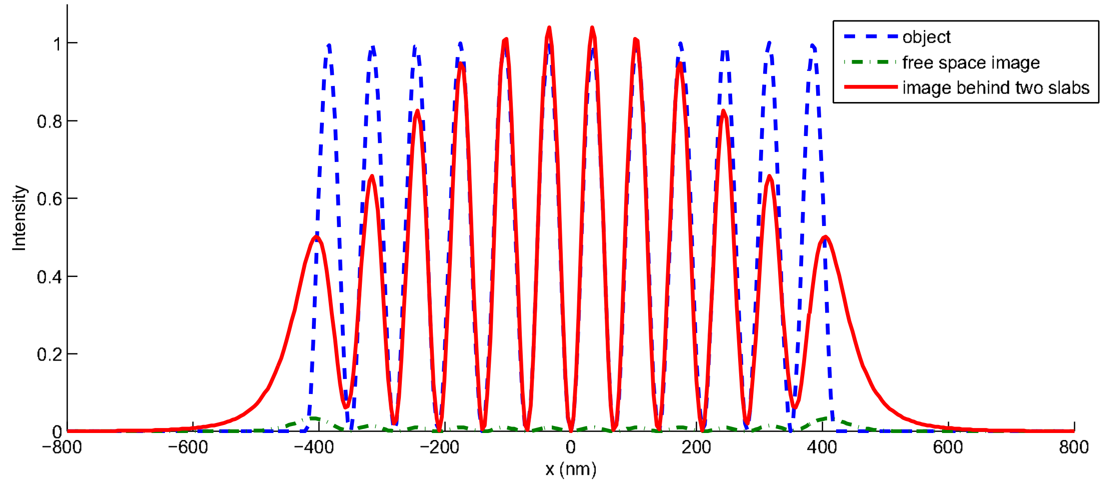
for some k_x.

Tsang and Psaltis, Optics Letters, **31**, 2741 (2006); Erratum: **32**, 86 (2006).

Numerical Example

- $\lambda = 230$ nm, $n = 2.7$, $a = 20$ nm, $d = 20$ nm, TE polarization,





- Low loss
- Many spatial modes
- High refractive index material available (transparent down to $\lambda = 230$ nm, $n = 2.7$ for diamond)
- non-contact imaging, suitable for lithography and bio-imaging

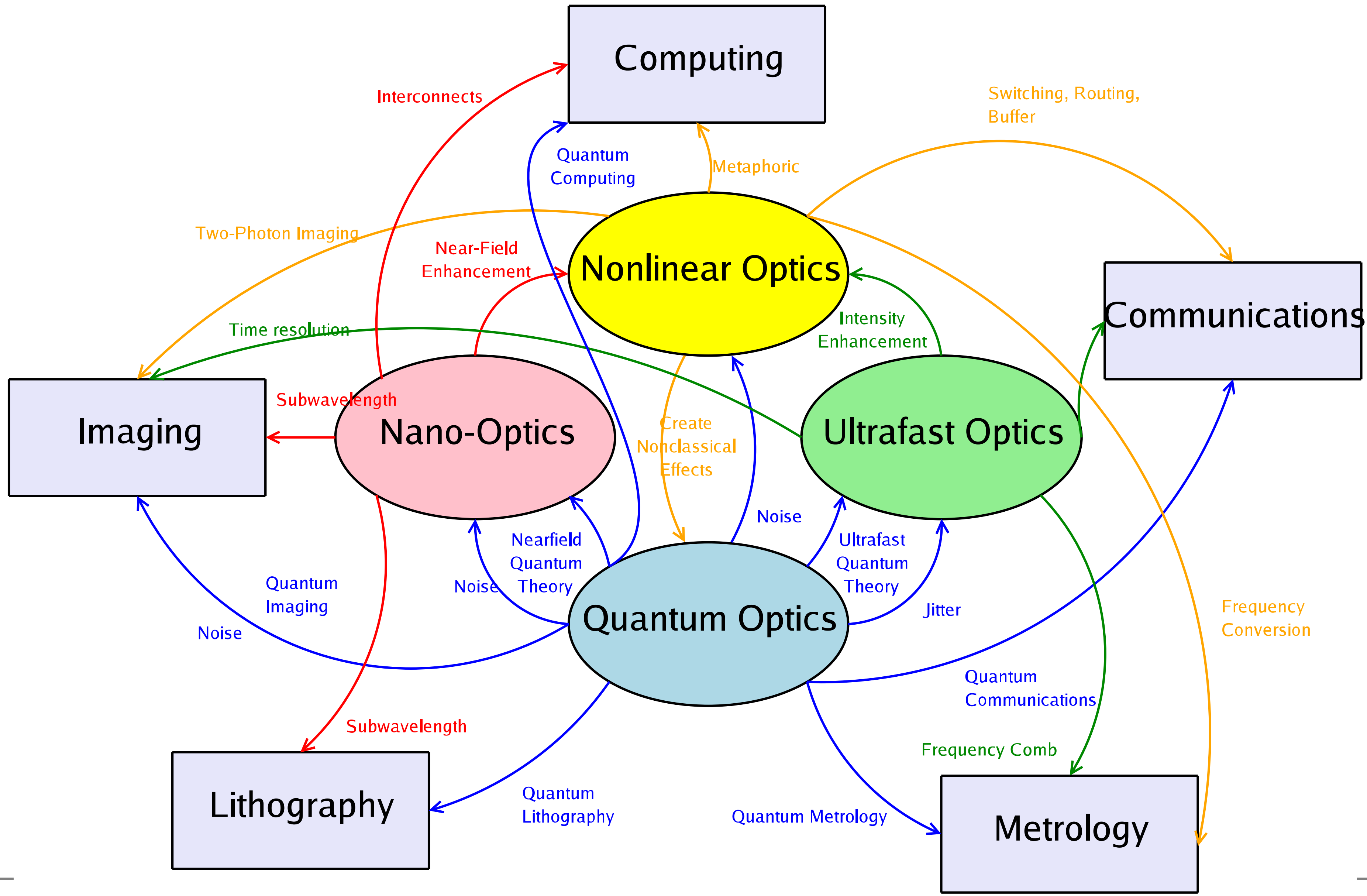
Miscellaneous

- Correspondence between Nonlinear Optics and Fluid Dynamics
  Tsang and Psaltis, e-print physics/0604149
- Reverse propagation of femtosecond pulses in optical fiber (collaboration with Fiorenzo Omenetto at Tufts)
  Tsang, Psaltis, and Omenetto, Optics Letters **28**, 1873 (2003)
- Filamentation in Kerr Medium
  Centurion, Pu, Tsang, and Psaltis, Physical Review A **71**, 063811 (2005)
- Quantum Temporal Imaging
  Tsang and Psaltis, Physical Review A **73**, 013822 (2006)

Future Work

- Quantum theory of mirrorless optical parametric oscillators
- Quantum information processing via scalar and vector solitons
- Spatial quantum information processing via spatial solitons
- Effect of loss and decoherence
- Quantum limits on spatial, temporal, and spectral information capacity of optical fields
- Beating the resolution limit of λ/n by the use of dielectrics, e.g. photonic crystals, coupled resonators
- Quantum near-field optics
- Correspondence between nonlinear optics and viscous fluid dynamics
- Application to Bose-Einstein condensates and superfluids
- Experiments

Quantum Optical Engineering



Publications

1. M. Tsang, “Relationship between resolution enhancement and multiphoton absorption rate in quantum lithography,” Physical Review A **75**, 043813 (2007).
2. M. Tsang and D. Psaltis, “Reflectionless evanescent-wave amplification by two dielectric planar waveguides,” Optics Letters **31**, 2741 (2006) [Erratum: **32**, 86 (2006)].
3. M. Tsang, “Quantum temporal correlations and entanglement via adiabatic control of vector solitons,” Physical Review Letters **97**, 023902 (2006).
4. M. Tsang, “Spectral phase conjugation via extended phase matching,” Journal of the Optical Society of America B **23**, 861 (2006).
5. M. Tsang and D. Psaltis, “Propagation of temporal entanglement,” Physical Review A **73**, 013822 (2006).
6. M. Centurion, Y. Pu, M. Tsang, and D. Psaltis, “Dynamics of filament formation in a Kerr medium,” Physical Review A **71**, 063811 (2005).
7. M. Tsang and D. Psaltis, “Spontaneous spectral phase conjugation for coincident frequency entanglement,” Physical Review A **71**, 043806 (2005).
8. M. Tsang and D. Psaltis, “Spectral phase conjugation by quasi-phase-matched three-wave mixing,” Optics Communications **242**, 659 (2004).
9. M. Tsang and D. Psaltis, “Spectral phase conjugation with cross-phase modulation compensation,” Optics Express **12**, 2207 (2004).
10. M. Tsang, D. Psaltis, and F. G. Omenetto, “Reverse propagation of femtosecond pulses in optical fibers,” Optics Letters **28**, 1873 (2003).
11. M. Tsang and D. Psaltis, “Dispersion and nonlinearity compensation by spectral phase conjugation,” Optics Letters **28**, 1558 (2003).

Conferences:

1. Y. Pu, J. Wu, M. Tsang, and Psaltis, “Ultrafast mirrorless optical parametric oscillator in periodically poled KTiOPO4 via extended phase matching,” CLEO/QELS, May 2007, paper CMB5.
2. M. Tsang and D. Psaltis, “Reflectionless evanescent wave amplification by two dielectric slabs,” OSA Annual Meeting, Oct 2006, paper FMB4.
3. M. Tsang and D. Psaltis, “Quantum lithography has a reduced multiphoton absorption rate,” OSA Annual Meeting, Oct 2006, paper LWH4.
4. M. Tsang and D. Psaltis, “Quantum temporal imaging,” CLEO/QELS, May 2006, paper QWB5.
5. M. Centurion, M. Tsang, and D. Psaltis, “Nonlinear signal processing,” Invited Talk, LEOS Annual Meeting, Oct 2005, paper TuEE2.
6. M. Tsang and D. Psaltis, “Metaphoric optical computing of fluid dynamics,” CLEO/QELS, May 2005, paper QML6.
7. M. Centurion, Y. Pu, M. Tsang, and D. Psaltis, “Phase transition in the filament generation process in a Kerr medium,” CLEO/QELS, May 2005, paper QMI3.
8. M. Tsang and D. Psaltis, “Metaphoric optical computing for fluid dynamics,” Invited Paper, Proceedings of SPIE, 5735, 1 (Apr 2005).
9. M. Tsang and D. Psaltis, “Spectral phase conjugation with cross-phase modulation compensation,” OSA Annual Meeting, Oct 2004, paper FWH44.

Preprints:

1. M. Tsang, “Decoherence of quantum-enhanced timing accuracy,” e-print arXiv:0704.0663 [submitted].
2. M. Tsang and D. Psaltis, “Metaphoric optical computing of fluid dynamics,” e-print physics/0604149.

http://mankei.tsang.googlepages.com/ mankei@optics.caltech.edu

IRAQI JOURNAL OF APPLIED PHYSICS

" INSTRUCTIONS TO AUTHORS "

A new Iraqi specialized quarterly periodical dedicated to publishing original papers and letters in:

Applied & Nonlinear Optics	Electronic Materials & Devices	Quantum Physics & Spectroscopy
Applied Mechanics & Thermodynamics	Laser Physics & Applications	Semiconductors & Optoelectronics
Digital & Optical Communications	Plasma Physics & Applications	Solid State Physics & Applications

CONTRIBUTIONS
Contributions to be published in this journal should be original research works, i.e., those not already published or submitted for publication elsewhere, individual papers or letters to editor.

SUBMISSION OF MANUSCRIPTS
Manuscripts should be submitted to the editor at the mailing address:

Iraqi Journal of Applied Physics
Managing Editor
P. O. Box 55259, Baghdad 12001, IRAQ
irq_appl_phys@yahoo.com

Iraqi Journal of Applied Physics
Editor-In-Chief
P. O. Box 55159, Baghdad 12001, IRAQ
editor_ijap@yahoo.co.uk

MANUSCRIPTS
Two copies with soft copy on a compact disc (CD) should be submitted to Editor in the following configuration:

Double-spaced one-side A4 size with 2.5 cm margins of all sides
12pt Times New Roman font
Letters should not exceed 5 pages, papers no more 20 pages and reviews are up to author.
Manuscripts presented in English only are accepted.
Authors confirm affiliations, addresses and emails. Email is necessary for correspondences.
English abstract not exceed 150 words
4 keywords (at least) should be maintained on (PACS preferred)
Author(s) should express all quantities in SI units
Equations should be written in equation form (italic and symbolic)
Figures and Tables should be separated from text
Figures and diagrams can be submitted in colors for assessment and they will be returned to authors after provide printable copies
Charts should be indicated by the software used for
Only original or high-resolution scanner photos are accepted
References are written in titles, full-name authors, names of publications, years, volumes, issues and pages (from-to)

PROOFS
Authors will receive proofs of papers and are requested to return one corrected hard copy with a WORD copy on a compact disc (CD). New materials inserted in the original text without Editor permission may cause rejection of paper.

COPYRIGHT FORM
Author(s) will be asked to transfer copyrights of the article to the Journal soon after acceptance of it. This will ensure the widest possible dissemination of information.

OFFPRINTS
Authors will receive offprints free of charge and any additional offprints can be ordered.

SUBSCRIPTION AND ORDERS
Annual fees (4 issues per year) of subscription are:

50 000 Iraqi dinars for individuals and establishments inside Iraq.
50 US$ for individuals and establishments abroad.

Fees are reduced by 25% for I.S.A.R.E.S.T. members. Orders of issues can be submitted by contacting the editor-in-chief or editorial secretary to maintain the address of issue delivery and payment way.

COPYRIGHY RELEASE

Iraqi Journal of Applied Physics (IJAP)

We, the undersigned, the author/authors of the article titled

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

that is presented to the Iraqi Journal of Applied Physics (IJAP) for publication, declare that we have neither taken part or full text from any published work by others, nor presented or published it elsewhere in any other journal. We also declare transferring copyrights and conduct of this article to the Iraqi Journal of Applied Physics (IJAP) after accepting it for publication.

The authors will keep the following rights:

1. Possession of the article such as patent rights.
2. Free of charge use of the article or part of it in any future work by the authors such as books and lecture notes without referring to the IJAP.
3. Republishing the article for any personal purposes of the authors after taking journal permission.

To be signed by all authors:

Signature:…………………………………………………date: ………………………………………..

Printed name: ……………………………………………………………………………………………..

Signature:…………………………………………………date: ………………………………………..

Printed name: ……………………………………………………………………………………………..

Signature:…………………………………………………date: ………………………………………..

Printed name: ……………………………………………………………………………………………..

Correspondence address:

………………………………………………………………………………………………………

………………………………………………………………………………………………………

Telephone:………………………Fax:…………………………………email: …………………………

Note: Please complete and sign this form and mail it to the below address with your manuscript

The Iraqi Journal of Applied Physics,
P. O. Box 55259, Baghdad 12001, IRAQ
Email: *irq_appl_phys@yahoo.com* or *editor_ijap@yahoo.co.uk*
Mobile: +964-7901274190