

## **IPT5110 Nonlinear Optics**

國立清華大學 光電光程研究所/電機工程學系

Prof. 黃衍介

class schedule: T2T3T4

Spring, 2016

Class location: 台達 Delta 210

Teaching Assistant: 廖宸樑 [jhs710041@gmail.com](mailto:jhs710041@gmail.com), 林孟緯

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### 一、課程說明

The scope of this course covers most nonlinear optical phenomena associated with the 2<sup>nd</sup> and 3<sup>rd</sup> order optical nonlinearities. Near the end of the semester, high harmonic generation and plasma nonlinearity in the relativistic regime will also be introduced. To assist learning, this course begins with some review on the linear electromagnetic theory and then gradually moves into the nonlinear regime. This approach is to accommodate more and more undergraduate students taking this course.

Student's participation plays a key role in this course. All students are required to give 5-6 in-class presentations to earn their grades during the whole semester.

Seeing is believing. Students are also required to carry out 4 nonlinear optics laboratories and turn in lab reports in English.

### 二 指定用書

1. Class handouts (available at 水木書苑 or <http://www.hope.nthu.edu.tw>)

### 三、參考書籍

0. David K. Cheng, Field and Wave Electromagnetics 2nd Ed., Addison Wesley, 1989.
1. 近代實驗光學，東華書局，黃衍介 著。
2. Nonlinear Optics by E.G. Sauter, John Wiley & Sons, 1996.
2. Fundamental of Photonics by Saleh & Teich, John Wiley & Sons, Inc.
3. Nonlinear Optics by R.W. Boyd, Academic Press.
4. Optical Waves in Crystals by Yariv and Yeh, John Wiley & Sons, Inc.
5. Quantum Electronics, by Yariv, John Wiley and Sons, Inc.

#### 四、教學方式

##### **Homework assignment**

Doing homework is a team work in this course.

- (1) Each 3 students form a study group.
- (2) Each week, members in a study group are required to work together on a set of 30 slides, approximately 1 slide for 1 page of the course reader.
- (3) Mark your name on the slides prepared by you.
- (4) Before the class, all students have to email their slides in the pdf format to the teaching assistant and Prof. Huang. The file size can't exceed 1 Mb.
- (5) Each student has to bring a memory stick to the class and get ready for a presentation.
- (6) My slides are available on the course website for your reference only. Try to design your own slides. Don't copy my slides directly into your homework.

##### **Presentation**

In each class, I **randomly** draw 3-4 students, each giving half an hour presentation and host a Q&A session by using approximately 10 slides. *Note that you could have to use the other member's slides in your group for your presentation. This means you do have to work together with your team members on ALL the slides.* A presenter's performance will be graded by both the professor and the fellow students in the audience. Each student is expected to give 5-6 presentations in a semester.

##### **Laboratories**

During the semester, students are required to carrying out 4 experiments on the 2<sup>nd</sup> floor of the HOPE Laboratory. Each student is asked to turn in a laboratory report, due in 10 days from the first day you work on the experiment. Detailed description for the laboratory sessions is given below.

##### **Exams**

There will be a mid-term exam and a final exam. All exams are open books/notes. Details of the exams will be announced later.

#### 五、教學進度

1. Electromagnetic waves in the linear regime (D. K. Cheng, Huang)
2. Electromagnetic Wave in Anisotropic Media (Ch. 2 by Sauter, Ch. 6 by S&T, Ch. 4 by Y&Y)
3. Nonlinear Susceptibility (Ch. 1 by Boyd, Ch. 1 by Sauter)
4. Electro-optics (Ch. 3 by Sauter, Ch. 18 by S&T, Ch. 7 by Y&Y, Ch. 10 by Boyd)
5. Acousto-optics (Ch. 20 by S&T, Ch. 9 by Y&Y, Ch. 7 by Boyd)
6. Second harmonic generation (Ch. 2, 4 by Sauter, Ch. 19 by S&T)

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7. Other Frequency Conversions using 2nd-order Nonlinearity (Ch. 4&5 by Sauter, Ch. 2 by Boyd, Ch. 19 by S&T, Ch. 12 by Y&Y)
  8. Quasi-phase-matching nonlinear optics (handout)
  9. Third-order Nonlinear Processes: third-harmonic generation, conjugate waves, Brillouin scattering, and Raman Scattering (Ch. 6 by Sauter, Ch. 18 by Yariv, Ch. 19 by S&T)
  10. DC and AC Kerr Effect (Ch. 7 by Sauter, Ch. 19 by S&T)
  11. High harmonic generation and plasma nonlinear optics

Week 0 (Feb. 15<sup>th</sup>) first meeting

Week 1 (Feb 22<sup>nd</sup>) : up to page 30 of the course reader

Week 2 (Feb 29<sup>th</sup>): up to page 60

Week 3 (March 7<sup>th</sup>): up to page 90

Week 4 (March 14<sup>th</sup>): up to page 115

Week 5 (March 21<sup>st</sup>) –up to page 140

Week 6 (March 28<sup>th</sup>): (no lecture/presentation) laboratory: electro-optics

Week 7 (April 4<sup>th</sup>): no class

Week 8 (April 11<sup>th</sup>): up to page 165

Week 9 (April 18<sup>th</sup>): up to page 190 (take-home Midterm exam)

Week 10 (April 25<sup>th</sup>): up to page 215

Week 11 (May 2<sup>nd</sup>) : up to page 240 (laboratory: Non-critically Phase-matched SHG)

Week 12 (May 9<sup>th</sup>): up to page 265

Week 13 (May 16<sup>th</sup>): up to page 290 (laboratory: Optical Parametric Generation)

Week 14 (May 23<sup>rd</sup>): up to page 318

Week 15 (May 30<sup>th</sup>): up to page 351

Week 16 (June 6<sup>th</sup>): up to page 382 (laboratory: Stimulated Raman Scattering)

Week 17 (June 13<sup>th</sup>) – Final Exam

## 六、成績考核

Homework	20%
presentation	25% (15% graded by peers)
laboratory report (due 10 days after experiment)	25%
midterm exam	15%
Final exam	15%

Q&A – reference for score adjustment (Prof. Huang will keep a record of questions asked by you during and off the class)

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*IPT5110 Spring, 2016*

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七、講義位址 chapter files available at <http://www.hope.nthu.edu.tw> (passcode to access: 20155110) and bound copies available at 水木書苑 by March 2<sup>nd</sup>

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### Presentation Grading Sheet

Grader's name: \_\_\_\_\_

Grader's ID #: \_\_\_\_\_

Date (mm/dd/yyyy): \_\_\_\_\_

1<sup>st</sup> presenter's name:

A+	A	A-	B+	B	B-	C	D	X
(90-100)	(85-89)	(80-84)	(77-79)	(73-76)	(70-72)	(60-69)	(1-59)	(0)

2<sup>nd</sup> presenter's name:

A+	A	A-	B+	B	B-	C	D	X
(90-100)	(85-89)	(80-84)	(77-79)	(73-76)	(70-72)	(60-69)	(1-59)	(0)

3<sup>rd</sup> presenter's name:

A+	A	A-	B+	B	B-	C	D	X
(90-100)	(85-89)	(80-84)	(77-79)	(73-76)	(70-72)	(60-69)	(1-59)	(0)

4<sup>th</sup> presenter's name:

A+	A	A-	B+	B	B-	C	D	X
(90-100)	(85-89)	(80-84)	(77-79)	(73-76)	(70-72)	(60-69)	(1-59)	(0)

5<sup>th</sup> presenter's name:

A+	A	A-	B+	B	B-	C	D	X
(90-100)	(85-89)	(80-84)	(77-79)	(73-76)	(70-72)	(60-69)	(1-59)	(0)

## IPT5110L Nonlinear Optics Lab

**Location:** 2<sup>nd</sup>-floor 高能光電實驗室 teaching laboratory

**Experiment 1 Electro-optic Modulation (TA: 謝忻)**

Measurement: Measure the half-wave voltage of an electrode-coated lithium niobate

Instruments & Components: HeNe laser or a frequency-doubled Nd laser, function generator, voltage amplifier (transformer) with DC voltage offset, polarizer, silicon detector

**Experiment 2 Non-critically phase-matched Second harmonic generation in lithium niobate (TA: 林孟緯)**

Measurement: Identify the crystal axis, Sinc curve (temperature bandwidth for various crystal lengths), conversion efficiency (nonlinear coefficient), angular bandwidth

Instruments & Components: Diffuser, HeNe laser, 1064 nm PQS laser, prism or filter, oven+controller, crystals, silicon detector, oscilloscope, printer, rotation stage

**Experiment 3 Optical Parametric Generation (OPG) (TA: 廖辰樑)**

Measurement: Measure the wavelength tuning curves as a function of the temperature, output signal + idler power vs. pump power, OPG spectral width vs pump energy.

Instruments & Components: 1064-nm passively Q-switched laser, monochromator, oven+controller, crystals, silicon detector, oscilloscope, waveplate etc.

**Experiment 4 Stimulated Raman Scattering (SRS) (TA: 林孟緯)**

Measurement: Measure the Stokes shift of a silica fiber, determine the Raman gain, and observe multiple Stokes generation.

Instruments & Components: 1064-nm passively Q-switched laser, monochromator, optical fiber, silicon detector etc.

### Arrangement of the Lab Experiment

1. Each lab group consists of 3-4 students at most, supervised by 1-2 TAs from Huang's group.
2. Each group takes one day from the 5 weekdays for doing the experiments. For example, Group 1 takes each Monday for doing the experiments.
3. If failure of any instrument and component is due to **apparent carelessness or lack of common sense** in experiments, 5% of the final grade is deducted from the very student who causes the failure and 2% of the final grade is deducted from

each of the other group members.

4. All the experiments have to be completed in one week for each assignment. The lab report has to be turned in 10 days from the day you do the experiment.

### Requirements on Lab Reports

1. The report has to be written in **good** English.  
The lab report has to include the following sections
  - i. Purpose of the experiment
  - ii. Principle of the experiment
  - iii. **Comparison between experimental data with theoretical curves/prediction.**  
(offer reasonable explanations to any discrepancy)
  - iv. Conclusions of the experiment
2. All laboratory reports have to be written in the two-column format of *Optics Letters*. See <http://www.osa.org> for the official format. Usually there are 4 graphs in each letter paper. A letter paper is limited to 4 pages/4 figures.
3. The grading policy is as follows
  - a. Format 20%
  - b. English 40%
  - c. Content 40%
4. Past-deadline reports are not accepted. Please observe the deadline for each report.
5. Email an electronic copy of your report in the WORD format to Prof. Huang at [ychuang@ee.nthu.edu.tw](mailto:ychuang@ee.nthu.edu.tw) by the deadline. Use **name\_ID\_#ofexperiment.doc** as your file name. The file size can't exceed **1 Mb**.

## IPT5150L Nonlinear Optics Lab Group Signup Sheet

Spring, 2016

Monday	Tuesday	Wednesday	Thursday	Friday
Name, ID, phone #	Name, ID, phone #	Name, ID, phone #  黃建彰 <b>0988033170</b>  Raul Robles 0989906031  <b>Teaching assistants</b>	Name, ID, phone #  周郁凱 <b>0921908030</b>  錢奕帆 <b>0916458132</b>  陳柏勳 <b>0937953633</b>	Name, ID, phone #