ECE 492
Future Electronic Devices from Condensed Matter Physics Topics

Spring 2017

Instructor: Stephen Wu

Location: CSB 523
Time: Tuesday & Thursday 3:25-4:40 PM
Office hours: Friday 9:00-10:00 AM CSB 417
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Objectives

Looking beyond just next-generation technology, we explore what electronics could look like on the 25+ year timescale. We will take basic topics and trends in condensed matter physics and look at their potential contribution to the landscape of electronics in the near-term future. New concepts in physics have led to dramatic effects on the world of electronics technology, like the discovery of solid-state transistor in 1947 ushering in the current world of microelectronics. The question now becomes, what topics exist today that could lead to the same transformative change in our lifetimes?

Topics: 2D Electronic Materials, Spintronics, Magnetoelectric Memory, Straintronics, …

Grading & Course Structure

The course structure will consist of lectures explaining basic concepts to enable you to understand the relevant current research topics in both next generation electronic devices and condensed matter physics. This will be supplemented by instructor led discussions of the previous week's assigned readings.

Interspersed between lectures will be 30 min journal club style presentations assigned to students on current cutting edge papers based on topics learned from lecture, questions and discussion from audience will be mandatory.

A final paper will be due near the end of the semester amounting to a literature review of a single topic of the student's choice (with approval from instructor), with final presentation.

25% Participation
50% Presentations
25% Final Project

Resources

Reading assignments will be assigned every week from literature and books freely available from the UR Library online.

"Emerging Nanoelectronic Devices" by Hutchby, et al. (Library eBook) [END]
"Solid State Physics: An Introduction" by Hofmann (Library eBook) [SSP]
"Handbook of Spin Transport and Magnetism" by Tsymbal and Zutic (Library eBook) [HSTM]
"Functional Metal Oxides" by Ogale, et al. (Library eBook) [FMO]

Schedule (subject to change)

Week	Date	Topic	Notes
0	Th 1/19	Course Introduction (Lecture)	
1	Tu 1/24		Example Presentation
1	Th 1/26	Basic Electronic Devices (Lecture)	
2	Tu 1/31	Readings Discussion	
		New materials for semiconductor electronics	
2	Th 2/2	2D Electron Systems & Carbon Based Electronics (Lecture)	
3	Tu 2/7		Presentations
3	Th 2/9	Readings Discussion	
4	Tu 2/14		Presentations
4	Th 2/16	New Single Layer 2D Electronics (Lecture)	
5	Tu 2/21		Presentations
5	Th 2/23	Readings Discussion	
6	Tu 2/28		Presentations
		Spintronics	
6	Th 3/2	Overview of spin transport & STT MRAM (Lecture)	
7	Tu 3/7		Presentations
7	Th 3/9	Readings Discussion	
8	Tu 3/14	NO CLASS	
8	Th 3/16	NO CLASS	
9	Tu 3/21		Presentations
9	Th 3/23	Pure spin currents & Topological spin transport (Lecture)	
10	Tu 3/28		Presentations
10	Th 3/30	Readings Discussion	
11	Tu 4/4		Presentations
		New functional oxides for electronics	
11	Th 4/6	Oxide materials overview & Magnetoelectrics (Lecture)	
12	Tu 4/11		Presentations
12	Th 4/13	Readings Discussion	
13	Tu 4/18		Presentations
13	Th 4/20	Ferroelectric Memory & Straintronics (Lecture)	
14	Tu 4/25	Readings Discussion	
14	Th 4/27	Final Presentations	
15	Tu 5/2	End of Class Summary (Lecture)	

Reading Schedule (subject to change)

Week	Date	Reading Assignments
0	Th 1/19	END pg. 3-15; SSP pg. 131-155
1	Tu 1/24	END pg. 279-296;
1	Th 1/26	N. Nanako, et al. "Collective bulk carrier delocalization driven by electrostatic surface charge accumulation" *Nature* **487**, 459–462 (2012)
2	Tu 1/31	Readings Discussion
		New materials for semiconductor electronics
2	Th 2/2	END pg. 298-331;
3	Tu 2/7	Y. Zhang, et al. "Experimental observation of the quantum Hall effect and Berry's phase in graphene" *Nature* **438**, 201-204 (2005)
3	Th 2/9	Readings Discussion
4	Tu 2/14	No reading list.
4	Th 2/16	D. Jariwala, et al. "Emerging Device Applications for Semiconducting Two-Dimensional Transition Metal Dichalcogenides" *ACS Nano* **8(2),** 1102–1120 (2014) K. S. Novoselov, et al. "2D materials and van der Waals heterostructures" *Science* **353(6298)** (2016)
5	Tu 2/21	L. Li, et al. "Black phosphorus field-effect transistors" *Nature Nanotechnology* **9**, 372–377 (2014)
5	Th 2/23	Readings Discussion
6	Tu 2/28	No reading list.
		Spintronics
6	Th 3/2	HSTM pg.3-15 (Chapter 1); HSTM pg. 137-152 (Chapter 7)
7	Tu 3/7	M. Gajek, et al. "Spin torque switching of 20 nm magnetic tunnel junctions with perpendicular anisotropy" *Applied Physics Letters* **100(13),** 132408 (2012)
7	Th 3/9	Readings Discussion
8	Tu 3/14	NO CLASS
8	Th 3/16	NO CLASS
9	Tu 3/21	No reading list.
9	Th 3/23	J. Sinova, et al. "Spin Hall effects" *Reviews of Modern Physics* **87**, 1213 (2015) (sections I, IV, and V only)
10	Tu 3/28	L. Liu, et al., "Spin-Torque Switching with the Giant Spin Hall Effect of Tantalum" *Science* **336(6081),** 555 (2012)
10	Th 3/30	Readings Discussion
11	Tu 4/4	No reading list.
		New functional oxides for electronics
11	Th 4/6	FMO pg. 1-18; FMO pg. 267-282
12	Tu 4/11	J. T. Heron "Deterministic switching of ferromagnetism at room temperature using an electric field" *Nature* **516**, 370–373 (2014)
12	Th 4/13	Readings Discussion
13	Tu 4/18	EMD pg. 110-120;
13	Th 4/20	M. Liu, et al. "Non-volatile ferroelastic switching of the Verwey transition and resistivity of epitaxial Fe3O4/PMN-PT (011)" *Scientific Reports* **3** (2013)
14	Tu 4/25	Reading Discussion
14	Th 4/27	No reading list.
15	Tu 5/2	No reading list.

Presentation schedule (subject to change)

Week	Date	Presentations
		New materials for semiconductor electronics
3	Tu 2/7	1. K. S. Novoselov, et al., "Electric Field Effect in Atomically Thin Carbon Films" *Science* **306(5696)**, 666-669 (2004) 2. S. J. Trans, et al., "Room-temperature transistor based on a single carbon nanotube" *Nature* **393**, 49-52 (1998)
4	Tu 2/14	1. K. I. Bolotin, et al., "Observation of the fractional quantum Hall effect in graphene" *Nature* **462**, 196-199 (2009) 2. G. J. Brady, et al., "Quasi-ballistic carbon nanotube array transistors with current density exceeding Si and GaAs" *Science Advances* **2(9)** (2016)
5	Tu 2/21	1. S. B. Desai, et al. "MoS2 transistors with 1-nanometer gate lengths" *Science* **354(6308)** 99 (2016) 2. C. Lee, et al., "Atomically thin p–n junctions with van der Waals heterointerfaces" *Nature Nanotechnology* **9**, 676–681 (2014)
6	Tu 2/28	1. Y. Yu, et al., "Gate-tunable phase transitions in thin flakes of 1T-TaS2" *Nature Nanotechnology* **10**, 270–276 (2015) 2. L. Tao, et al., "Silicene field-effect transistors operating at room temperature" *Nature Nanotechnology* **10**, 227–231 (2015)
		Spintronics
7	Tu 3/7	1. M. N. Baibich, et al., "Giant Magnetoresistance of (001)Fe/(001)Cr Magnetic Superlattices" *Physical Review Letters* **61,** 2472 (1988) 2. J. S. Moodera, et al., "Large Magnetoresistance at Room Temperature in Ferromagnetic Thin Film Tunnel Junctions" *Physical Review Letters* **74**, 3273 (1995)
9	Tu 3/21	1. S. Yuasa, et al., "Future prospects of MRAM technologies," *2013 IEEE International Electron Devices Meeting* 3.1.1-3.1.4 (2013) 2. N. Tombros, et al., "Electronic spin transport and spin precession in single graphene layers at room temperature" *Nature* **448**, 571-574 (2007)
10	Tu 3/28	1. Y. K. Kato, et al., "Observation of the Spin Hall Effect in Semiconductors" *Science* **306(5703),** 1910 (2004) 2. J. Wunderlich, et al., "Spin Hall Effect Transistor" *Science* **330(6012),** 1801 (2010)
11	Tu 4/4	1. Y. Fan, et al., "Magnetization switching through giant spin–orbit torque in a magnetically doped topological insulator heterostructure" *Nature Materials* **13**, 699–704 (2014) 2. E. Lesne, et al., "Highly efficient and tunable spin-to-charge conversion through Rashba coupling at oxide interfaces" *Nature Materials* **15**, 1261–1266 (2016)
		New functional oxides for electronics
12	Tu 4/11	1. Y. Chu, et al., "Electric-field control of local ferromagnetism using a magnetoelectric multiferroic" *Nature Materials* **7**, 478 - 482 (2008) 2. A. Ohtomo, et al., "A high-mobility electron gas at the LaAlO3/SrTiO3 heterointerface" *Nature* **427**, 423-426 (2004)
13	Tu 4/18	1. J. A. Mundy, et al., "Atomically engineered ferroic layers yield a room-temperature magnetoelectric multiferroic" *Nature* **537**, 523–527 (2016) 2. J. Zhang, et al., "A nanoscale shape memory oxide" *Nature Communications* **4**, 2768 (2013)
14	Th 4/27	Final Presentations