REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
29-08-2021	Final Report	1-Sep-2019 - 31-Aug-2021

4. TITLE AND SUBTITLE
Final Report: Femtosecond Laser System for Ultrafast Spectroscopy of Quantum Materials

5a. CONTRACT NUMBER
W911NF-19-1-0480

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
106012

6. AUTHORS

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
University of Puerto Rico at Mayaguez
Call Box 9000

Mayaguez, PR 00681 -9000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
74302-EL-REP.1

12. DISTRIBUTION AVAILIBILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Sergiy Lysenko
UU	UU	UU	UU		19b. TELEPHONE NUMBER 787-832-4040

RPPR Final Report
as of 30-Aug-2021

Agency Code: 21XD

Proposal Number: 74302ELREP **Agreement Number: W911NF-19-1-0480**
INVESTIGATOR(S):

Name: Armando Rua de La Asuncion
Email: armando.rua@upr.edu
Phone Number: 7878324040
Principal: N

Name: Ph.D. Sergiy Lysenko
Email: sergyi.lysenko@upr.edu
Phone Number: 7878324040
Principal: Y

Organization: **University of Puerto Rico at Mayaguez**
Address: Call Box 9000, Mayaguez, PR 006819000
Country: USA
DUNS Number: 175303262 EIN: 660433761

Report Date: 30-Nov-2021 Date Received: 29-Aug-2021
Final Report for Period Beginning 01-Sep-2019 and Ending 31-Aug-2021
Title: Femtosecond Laser System for Ultrafast Spectroscopy of Quantum Materials
Begin Performance Period: 01-Sep-2019 **End Performance Period:** 31-Aug-2021
Report Term: 0-Other

Submitted By: Ph.D. Sergiy Lysenko Email: sergyi.lysenko@upr.edu
Phone: (787) 832-4040

STEM Degrees: **STEM Participants:**

Major Goals: This proposal focuses on the acquisition of a state-of-the-art "Spectra-Physics" femtosecond laser system in order to conduct cutting-edge spectroscopic studies of nonequilibrium dynamics in quantum materials (i. e. strongly correlated materials exhibiting cooperative phenomena) at the fundamental timescales of atomic and electronic motion, and to train STEM students in the area of ultrafast science and condensed matter physics.

The location of "Spectra-Physics" femtosecond laser system: Physics Department, University of Puerto Rico-Mayaguez (UPRM). This laser system enables conducting current research at UPRM at a contemporary level and to establish new research programs to explore time-dependent properties of electronic and structural phase transitions, exotic nonequilibrium quantum phases, magnetic phenomena and spin dynamics, statistical properties of surface dynamics and transition processes in mesoscale and nanoscale structures.

The "Spectra-Physics" laser system is a single unit of equipment to generate laser pulses of ~35 fs duration, 7 mJ/pulse energy at 1 kHz repetition rate with unmatched pulse-to-pulse stability and provides entirely computer-controlled spectral tuning within 290-2600 nm spectral range. The laser system with these parameters will provide substantially new research capabilities for our group in the area of modern ultrafast spectroscopy to observe material dynamics at sub-35 fs temporal resolution with high spectral selectivity. This enables detailed studies of coherent lattice motion, spin and electronic dynamics and coupling between these degrees of freedom. The laser system generates unprecedentedly short and high-peak intensity electromagnetic pulses, which is critical to conduct nondestructive experiments with a clear separation between electronic and phonon dynamics of solid. The "Spectra-Physics" laser system consists of four main components: Mai Tai SP ultrafast laser oscillator, Spitfire Ace regenerative amplifier, Ascend 60 diode-pumped Q-switched laser solid-state laser and TOPAS Prime automated optical parametric amplifier (OPA):

• The Mai Tai SP ultrafast laser oscillator generates ultrashort (~25 fs) laser pulses of low intensity (5.5 nJ/pulse) at the repetition rate 84 MHz. It is used for seeding sub-35 fs Spitfire Ace regenerative amplifier system. This laser provides an unprecedented level of automation and long-term environmental stability. The Mai Tai SP uses reliable ProLite diodes with a certified lifetime of ~40,000 hours.

RPPR Final Report
as of 30-Aug-2021

• The Spectra-Physics Spitfire Ace produces the main output of the "Spectra-Physics" femtosecond laser system. It operates as a laser system pumped by high-energy Q-switched pulsed solid-state laser Ascend 60. It includes a stretcher of Mai Tai SP seeding pulses and a compressor of amplified laser pulses. Spitfire Ace provides low noise, reliable day-to-day operation, and guaranteed long-term performance. The Spitfire Ace regenerative amplifier produces excellent beam quality with an average output power of more than 7 W at 1 kHz (7 mJ/pulse). The output power is sufficient to operate several optical parametric amplifiers, including computer-controlled TOPAS Prime OPA.

• TOPAS Prime OPA is the extension of the Spitfire Ace regenerative amplifier system. It is a state-of-the-art OPA for entirely computer-controlled spectral tuning of amplified femtosecond laser pulses. It will provide a parametric generation of pulses with a central wavelength tuned from the UV range (290 nm) up to infrared (2600 nm). TOPAS Prime makes a "Spectra-Physics" laser system suitable for numerous research projects which require high temporal resolution and spectral selectivity.

• Autocorrelator is a part of the setup to control the pulse compression quality. It works with Spitfire Ace regenerative amplifier, Mai Tai SP ultrafast laser oscillator, and with TOPAS Prime OPA.

Target location: University of Puerto Rico, Mayaguez, Puerto Rico, Physics Building, Laboratory of Ultrafast Laser Spectroscopy, room F-124.

Accomplishments: (see attachment)

Training Opportunities: The PI, S.Lysenko, Co-PI, Armando Rua, and graduate student Alexander Bartenev received deep training from the "Spectra-Physics" Engineer to operate the femtosecond laser system.

Results Dissemination: Nothing to Report

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Sergiy Lysenko
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

Participant Type: Co PD/PI
Participant: Armando Rua
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
National Academy Member: N

RPPR Final Report
as of 30-Aug-2021

Partners

,

I certify that the information in the report is complete and accurate:
Signature: Sergiy Lysenko
Signature Date: 8/29/21 11:14PM

Accomplishments Under Goals

The project was completed in full according to the original plan. The "Spectra-Physics" laser system was purchased and installed in the University of Puerto Rico, Mayaguez, Puerto Rico, Physics Building, Laboratory of Ultrafast Laser Spectroscopy, room F124. The laboratory has independent continuous air-conditioning and humidity control by a dehumidifier. The laser system has exactly the same components and characteristics as was originally specified in the project. This system generates laser pulses of 35 fs duration, 7 mJ/pulse energy at 1 kHz repetition rate, provides entirely computer-controlled spectral tuning within 290-2600 nm spectral range, and includes the following:

1. Femtosecond single-box Ti-sapphire ultrafast laser oscillator "Mai Ta SP"
2. Regenerative amplifier "Spitfire Ace-35-f-1-HP"
3. Diode-pumped Nd:YLF Q-switched solid-state laser "Ascend 60"
4. Automated optical parametric amplifier "HE-TOPAS-Prime"
5. Autocorrelator PulseScout2
6. Ocean Optics Micro Spectrometer Kit
7. RS4000 Series Optical Table

The Spectra-Physics service report with actual parameters of the femtosecond laser system is attached.

As soon as the COVID-19 lockdown was removed, the “Spectra-Physics” Company authorized the travel to Puerto Rico of the Service Engineer to install the new femtosecond system and sent the laser system. The femtosecond laser system arrived in the Physics Department of the University of Puerto Rico on April 29, 2021, in 8 large wooden boxes. These boxes were stored in lab F125 of the Physics Building with a controlled humidity. The "Spectra-Physics" Engineer, Mr. Christopher Jaska (Christopher.Jaska@mksinst.com) arrived in Puerto Rico on May 10, 2021, and from May 13 till May 21 he installed the system in the room F124 of the Physics Building. The PI, S.Lysenko, Co-PI, Armando Rua, graduate student Alexander Bartenev, and departmental technical personnel assisted the installation procedure. PIs and students received training from the Spectra-Physics Engineer to operate the femtosecond laser system.

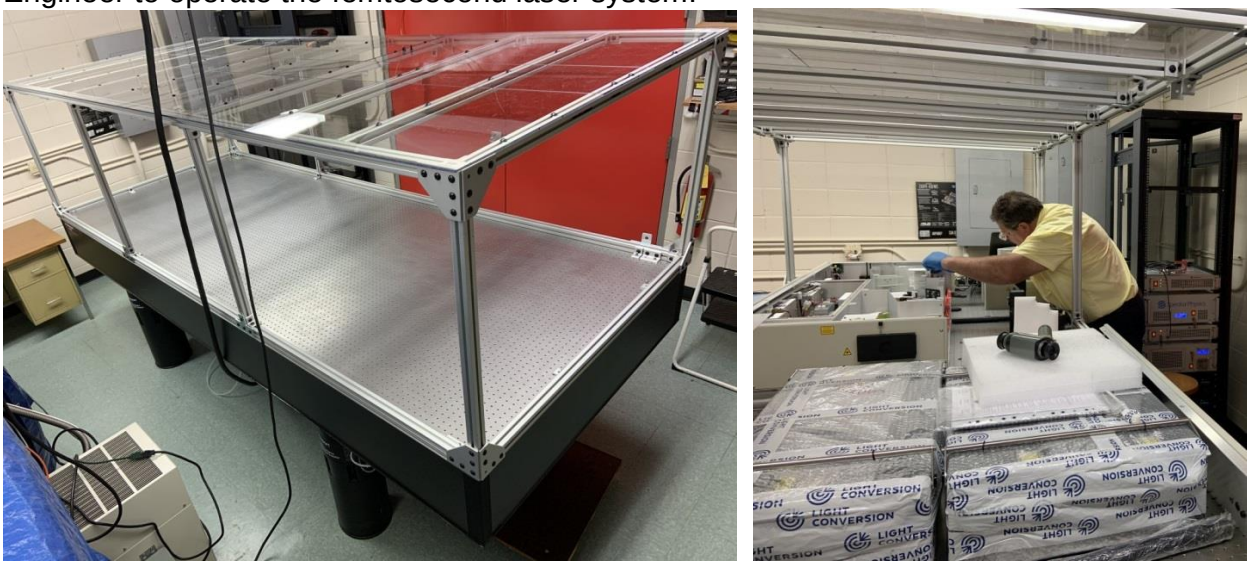

Fig.1. The RS4000 Newport optical table and the installation of the femtosecond laser system by "Spectra-Physics" Engineer.

Figure 1 shows the newly installed 5 ft x 12 ft x 12 RS4000 Newport optical table with protective frames and the installation process of the laser system by the "Spectra-Physics" Engineer. Protective frames were made by PIs for the safe and correct operation of the system. The electrical connections in the room were specially prepared to operate high current equipment. The laser system is extremely sensitive to humidity, and its design even includes a humidity control system with a continuous circulation of dry air to maintain a humidity level below 2% inside of the laser. Therefore, in addition to the air-conditioner already installed in the laboratory, we installed a new dehumidifier to control humidity level at <40% in the room. The dry environment in the lab is critical to provide the long-life operation of the equipment.

The installation was completed in full and the system is in perfect operational conditions. It is already integrated into several optical experiments and shows very high stability and flexibility as an ultrashort pulse source for different optical measurements. PIs already installed a pump-probe spectroscopy setup (optical translational stage with a retroreflector, optics, and electronics for data acquisition) on the optical table with the new system. Also, we are in the process to conjugate the new femtosecond laser system with other ultrafast 3D light scattering setup. In July-August 2021, PIs perforated the first successful measurements of the ultrafast nonequilibrium dynamics in iron-based superconducting film BaFe2As2 at T=8K. Currently, three months after the installation, the system works stable and without issues.

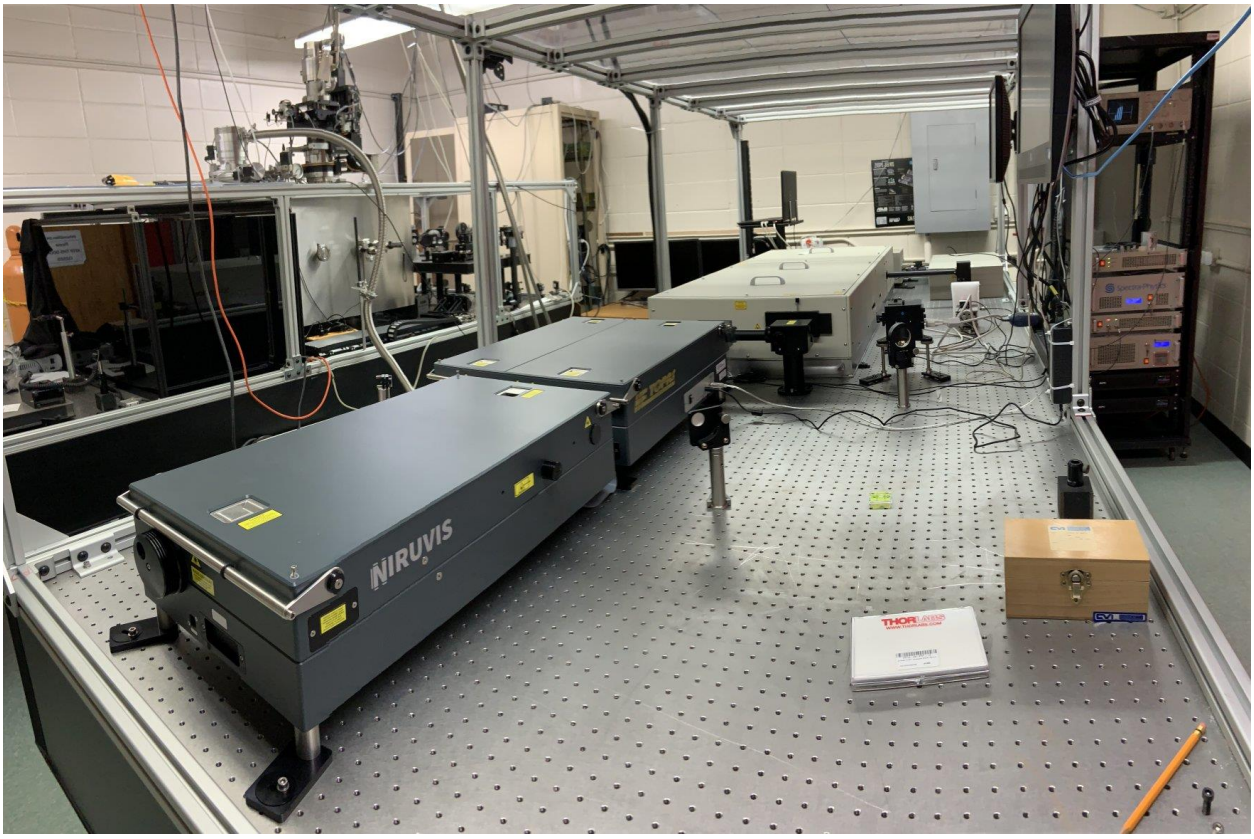

Fig.2. “Spectra-Physics” femtosecond laser system (MaiTai SP, ASCEND 60, Spitfire 35-f -1 HP ACE, Topas-U) installed in the Laboratory of Ultrafast Laser Spectroscopy, University of Puerto Rico – Mayaguez; May 2021.

The “Spectra-Physics” femtosecond laser is entirely computer-controlled system and includes the following:

1. Femtosecond single-box Ti-sapphire ultrafast laser oscillator "Mai Ta SP"

Repetition Rate: 84.42 MHz;
Bandwidth: 64 nm;
Seed pump power: 540 mW
Power out: 250 mW

The ultrafast laser oscillator includes optics and mounts for seeding the Spitfire Ace-351HP, Replace HR seed kit with 50/50 beamsplitter for access to 50% of seed beam for seeding sub-35 fs Spitfire® Ace™ regenerative amplifier system

2. Regenerative amplifier "Spitfire Ace-35-f-1-HP"

Pulse Width: 35 fs;
Pulse energy: 7.3 mJ;
Wavelength: 800 nm;
Repetition Rate: 1 kHz;
Energy Stability: 1%;
Spatial Mode: TEM00;
Beam Diameter ($1/e^2$): 10 mm (nominal);
Polarization: Linear, Horizontal.

The regenerative amplifier produces the main output of the "Spectra-Physics" femtosecond laser system

3. Diode-pumped Nd:YLF Q-switched solid-state laser "Ascend 60"

Wavelength: 527 nm;
Average Power: 31 W;
Repetition Rate: 1 kHz.

Pulsed laser Ascend 60 is to pump the Spitfire Ace-351HP regenerative amplifier. It also includes chiller "ASCND CHLLR 230-60".

4. Automated optical parametric amplifier "HE-TOPAS-Prime"

Spectral tuning range: 290-2600 nm ;
Pulse Width, FWHM: 35 fs;
Beam Diameter ($1/e^2$): <11 mm;
Pump energies:
idler: up tp 2130 mW @ 1 kHz
output signal: up to 1300 mW @ 1 kHz
Energy Stability: ≤1% rms;
Pulse-to-Pulse Stability: ≤1%.

TOPAS Prime is the extension of the Spitfire® Ace™ regenerative amplifier system to provide spectral tuning of femtosecond pulses. It includes TPH-NRD-UV1-U mixer housing for 290-1160nm tuning range and manual wavelength separators

5. Autocorrelator PulseScout2

Pulse duration input: 20-3500 fs;
Spectral range: 420-1600 nm.

Autocorrelator PulseScout2 is to measure the pulse compression quality for Spitfire® Ace™ , TOPAS and Mai Tai® SP. It includes PulseScout2 NIR PD Detector Module, and NIR PMT Detector Module, for 700-1100 nm range.

6. Ocean Optics Micro Spectrometer Kit

This kit includes: STS-NIR-L-10-400-SMA STS Microspectrometer for 600-1100nm spectral range, 10um Slit, 400 Core/1cm SMA Input, CC-3-DA Direct-attach Cosine Corrector with Spectralon diffuser.

7. RS4000 Series Optical Table

Size of the table: 5 ft x 12 ft x 12 in., 1/4-20 Holes.
The table includes SET OF FOUR S-2000A-428 legs and ACGP Air Com

The original government funding of $449,368.00 has been completely spent on the system.

FIELD SERVICE REPORT – Spitfire

General Information

Work Order	4215618	Service Date	05.10-20.21
Model	spitfire 35-f -1hpace	SN	983
Customer Institution	univ of puerto rico mayaguez		
Customer Name	sergiy lysenko Physics dept rm 124 basement violet area		sergiy.lysenko@upr.edu
Reason for call	install		
Service By	jaska		

Seed Source

Seed Laser	mai tai sp	Seed pump power (W)	0.54		
Power out (mW)	0.25	Seed WL (nm)	800	Seed BW (nm)	64
Chiller Model	Poly Sci	Chiller Temperature	21		

Pump Laser

choose 1	sn	33303	Pump power	31	current	9.1
Chiller Model	Poly Sci	Chiller Temperature	21			

Final Performance

Compressed Power	7.3	Pulsewidth	35
Compressed Wavelength	800	Compressed Bandwidth	421
Pre Pulse CR		Post Pulse CR	
Fundamental stability	1%	2 pd signal	.74

Regen performance

Seeded Power *	8.8	W	Ch 1	85.5	Ch 2	106.25	Ch 3	204.25
Q-S CD Power *	8.5	W	Ch 3 (2)		BURT	40		
Zero Delay	1900	Sync		Ch 4				
HV1 set	3.989	HV 1 read		HV1 cur	1.9			
HV2 set	3.838	HV 2 read		HV2 cur	3.3			
Rod Temp	22	TEC Temp	-5	Humidity	0.2			
Spitfire GUI	025400 1017	PN		Controller				
Empower FW ver		Amplifier FW ver						
TDG FW ver		TCU FW ver						
MaiTai Firmware								

Regen Frequency	1	KHz	ML Frequency	84.42	MHz

* measured at compressor input through any power amplifier

Power Amplifier

choose 1	sn		Pump power	31	current	9.1	
Chiller Model		Poly Sci	Chiller Temperature		21		
Power out	7.3	* measured at compressor input					

Spitfire Accessory

Model and SN	topas HE		Pump power and λ	5.5	
Output λ	sig idler	nm	Output Power	2130	mW
Output λ	sig ilder	nm	Output Power	1900	mW
Output λ	1500	nm	Output Power	1300	mW
Output λ	1300	nm	Output Power	1100	mW

COMMENTS

burned dm 2 dichroic in the topas HE. Need to send replacement. customer can replace it. It is out of the beam path and not conflicting performance.
University of Puerto Rico-Mayaguez
Department of Physics, office F-124
259 Blvd. Alfonso Valdez Cabian,
Mayagüez, PR, 00680
787 519 0225 cell
787 832 4040 x 3155, 2772

PARTS

Part Number	Description	QTY	Disposition	comment
			Material Disposition	
			Material Disposition	
			Material Disposition	
			Material Disposition	
			Material Disposition	
			Material Disposition	
			Material Disposition	
No Parts Used				

Summary

Billable Hours			
Zone charge		Per diem(s)	

Installation Complete	Laser is meeting specifications