

1 LABORATORY FOR ADAPTIVE MATERIALS AND SMART STRUCTURES (LAMSS)

The Department of Mechanical Engineering at the University of South Carolina (USC) has initially allocated 1600 sq. ft. of floor space (a 3-room suite) in 300 Main St. Bldg and has added 800 sq. ft. in the new Horizon I Bldg for the development of a Laboratory for Adaptive Materials and Smart Structures (LAMSS). Complete information about this laboratory is available at the LAMSS website [http://www.me.sc.edu/research/lamss/](http://www.me.sc.edu/research/lamss/).

LAMSS has recently received two major equipment grants supported by Defense University Research Instrumentation Program (DURIP). The DURIP program is for the acquisition of major equipment by U.S institutions of higher education to augment current or develop new research capabilities to support research in technical areas of interest to the Department of Defense (DoD). This laboratory has been equipped with over $1,000,000 worth of state of the art specialized equipment for performing active materials and smart structures research of which $500,000 has been recently added through a DURIP grant for “Ultrasonic NDE/SHM Equipment for Advanced Materials and Structures” and another ~$200,000 DURIP grant for Integrated Opto-Electronic Equipment for Autonomous Structural Health Monitoring Research. LAMSS laboratory resources consist of:

![Figure 1](image.png)

Figure 1 Overview of multi-functional ultrasonic equipment for nondestructive characterization

1.1 NEW RESEARCH CAPABILITIES WITH ULTRASONIC NDE/SHM EQUIPMENT

The multi-functional ultrasonic equipment has been acquired and installed in the ultrasonic NDE and SHM Laboratory. The overview feather and configuration is shown in Figure 1. This ultrasonic equipment integrates several ultrasonic types and methods into a single multifunctional system with linear and nonlinear capability for investigation of advanced materials and structures. This ultrasonic capability opens wide opportunities for material characterization and the development of novel advanced ultrasonic
techniques for detecting flaws and damage in materials and structures used by the Air Force and other aerospace and defense users and manufacturers. The system has a versatile ultrasonic scanner, and a multi-functional ultrasonic hardware including general purpose immersion UT subsystem, air coupled UT subsystem, phased array UT subsystem, and nonlinear UT subsystem, etc. The system is capable of achieving real-time processing of the ultrasonic images under a multi-channel computer-controlled ultrasonic signal generation and capturing. Ultrasonic phased-arrays as well as focused and unfocused individual transducers can be accommodated to achieve pulse-echo and through-transmission inspections of advanced materials including metallic, composite, ceramics, and hybrids thereof.

![The ultrasonic gantry system before and after retrofit](image1)

**1.1.1 Gantry equipment**

The fine resolution automatic gantry system was retrofitted from a used 4-axis Testech ultrasonic immersion tank. The motion control of the inspection tank has been replaced using the Galil 4183 motion controller. Additional yoke was added to support squirter, air coupled ultrasonics, and phased array ultrasonics. A manual 2-axis (X-Y) encoding scanner was acquired from Olympus for the manual inspection of slightly curved or flat composite surfaces. The scanner is well suited for raster scanning with the following technologies: UT and phased array.

![The manual Olympus Glider scanner with Olympus Omniscan SX](image2)

**1.1.2 Conventional ultrasonic equipment**

The general purpose immersion UT subsystem contains a workstation, 35-MHz JSR DPR300 pulser-receiver, OKOS 12 bit, 250Mhz sampling AL12250 digitizer, OKOS ODIS ultrasonic imaging software, and a set of immersion transducers and accessories (focused/unfocused immersion transducers, angle beam transducers, wedge, preamplifier, etc.).
1.1.3 Phased array ultrasonic equipment

The phased array UT subsystem has Olympus Omniscan SX portable phased array UT equipment, AOS-NDT OEMPA 64/64 phased array equipment, Olympus RollerFORM hand-held roll-on conformal array transducer (wheel probe), and several Olympus standard phased array probes. The Omniscan SX ultrasound phased array instrument is designed to offer exceptional performance for both conventional UT and ultrasound phased array with multiple probe configurations in linear scan configuration. The OEMPA is a customizable, open platform, easy integrate, compact phased-array system. The RollerFORM from Olympus is acquired for the inspection of composite plate and shell specimens. (This roll-on transducer consists of water-filled acoustically-matched rubber cylinder with a 64-element linear array in its axis that is synchronized with a travel encoder to achieve fast and efficient scanning of composite structural specimens in 50-mm wide tracks). With proper automating with the gantry movements, the area C-scans can be collected at high rate.

1.1.4 Air coupled ultrasonic equipment

For air-coupled ultrasonic subsystem, we have acquired QMI Sonda 007CX that is a multi-frequency range digital airscan system that offers a new perspective in ultrasonic evaluation of novel composite materials/systems. A set of airscan transducers (50kHz, 120kHz, 225kHz, 400kHz) have been incorporated for use on developmental materials that are adverse to water immersion such as the exotic solutions proposed for thermal-protection systems (TPS) applications.
1.1.5 Nonlinear UT system

The nonlinear UT subsystem is the RITEC SNAP advanced measurement instrument with harmonic accessory package and diplexer for pulse echo work. The RITEC SNAP System is the first commercially available state-of-the-art ultrasonic instrument designed specifically to make possible the study of nonlinear properties for the nondestructive evaluation of materials. The RITEC SNAP has a high power RF tone burst outputs as high as 5 kilowatts for frequencies up to 7 MHz.

1.1.6 Acoustic emission system

The Mistras group Micro-II PCI-2 AE system (Figure 8) is a compact multi-channel AE data acquisition and digital signal processing system. Superior low noise and low threshold performance has been achieved with this revolutionary AE system design through the use of 18 bit A/D conversion, 40 MSample/second acquisition with sample averaging and automatic offset control. Additionally, a waveform data streaming capability is built in the board allowing waveforms to be continuously transferred to the hard disk. The AEWin Windows-based software allows you to acquire and replay data. AEWin also has hardware set up, powerful graphing, alarms settings, remote monitoring, printing, networking, multi-tasking and multi-threading. The NOESIS software works in conjunction with AEWin to allow real-time source location, neural network classifications for supervised pattern recognition.
The Multi-channel Acoustic Measurement System (MAS) is an energy efficient and application ready complete system for sensor networks (Figure 9). The system uses guided waves for the monitoring of large structures. Damage indicators are identified by on-line and/or off-line analysis to provide information about the condition of the structure. The system is based on digital components and customizable analog devices. The digital signal processor (DSP), standardized data transfer ports and the reconfigurable logic and software ensure individual system adaptability. The networking capability of the flexible MAS systems warrants the design of complex sensor networks to monitor a variety of system parameters. The CANWare software provides general sensor signal acquisition and basic signals processing for all MAS devices for your measurement task. An easy to use automatic setup regime lets you combine specialized setups for different sensor paths in a time-based or event based schedule.

Figure 9   IZFP-D MAS Multi-Channel System (a)MAS hardware, (b) CANWare software

1.1.7 Non-contact laser ultrasonic sensing system

For non-contact ultrasonic excitation, we have acquired a Quantel CFR400 pulsed laser for non-contact excitation using the thermal elastic effect. A Polytec PSV-400 scanning vibrometer and a single point laser vibrometer are used for non-contact ultrasonic sensing.

Figure 10   Non-contact Laser equipment
1.2 New Research Capabilities with Integrated Opto-Electronic Equipment

The optical sensing system (Figure 12) was sponsored by the ONR DRUIP. The instrumentation consists of several closely-integrated components:

a. LUNA tunable laser platform P1402 with customized FBG interrogator for high speed: (150 MHz sampling), high sensitivity (0.01 µε) ultrasonic strain measurement

b. LUNA optical distributed sensor interrogator (ODiSi B) for sensing temperature and strain on a single optical fiber on many locations simultaneously

c. Micron Optics SM690 optical sensing module (PXIe, 4-channel, 2Mhz sampling) for high speed (2 MHz sampling) strain measurement

d. Redondo Optics miniature FBG interrogators FBG-transceiver M-200 (USB powered, 40 kHz sampling) for miniature strain measurement

![LUNA optical sensing system](image1)

(a) LUNA Pheonix 1402 (b) LUNA ODiSi B

Figure 11 LUNA optical sensing system

![Micron Optics and Redondo Optics sensing system](image2)

(c) Micron Optics sm690 (d) Redondo Optics FBG M-200

Figure 12 Micron Optics and Redondo Optics sensing system
1.3 **GENERAL RESEARCH EQUIPMENT**

In addition to the equipment sponsored by the DURIP, LAMSS laboratory has resources consist of:

1. **Impedance instruments (Figure 13):**
   a. Two sets of HP 4194A impedance analyzer
   b. Agilent 4395A network/spectrum/impedance analyzer
   c. Cypher Instruments C-60 impedance module, suitable for portable field operations
   d. Omicron Lab Bode 100 vector network analyzer

2. **Ultrasonic-range power amplifiers (Figure 14):**
   a. NF Corporation HSA4014 high speed bipolar amplifier (output: 150 Vpp, 4 A rms, 11.3 App, DC – 1 MHz)
   b. Ciprian Model US-TXP-3 high voltage linear power amplifier (output: 800 Vpp, 4A peak, 10 kHz - 10 MHz)
   c. Krohn-Hite 7600 wideband power amplifier (200 Vpp, DC to 1 MHz)

3. **Nation Instrument sensing and actuation platforms (Figure 15):**
   a. NI PXIe-1082 chassis
   b. NI PXIe-8135 controller
   c. PCI-6115, PCI-6023 DAQ
   d. SCXI -1321 strain gage module

4. **Scanning Acoustic Microscope (SAM) (Figure 16):**
   a. customized SAM 300 manufactured by PVA TePla, Germany

5. **Structural health monitoring system (Figure 17):**
   a. Metis Design MD7 digital SHM system for guided-wave phased-arrays monitoring

6. **Acoustic emission system (Figure 9):**
   a. Mistras PAC AE Micro II Chassis with PCI-2: 4-channel, 18-bit, 1kHz - 3MHz
   b. Fraunhofer IKTS-MD ultrasonic measurement system is a multi-channel, energy efficient, application ready system for sensor networks

7. **Other Ultrasonic NDE system:**
   a. Parametrics 5900PR 200MHz computer controlled pulser/receiver for normal ultrasonic NDT testing

8. **A complement of standard laboratory equipment including:**
   a. Signal generators (Agilent 33120A; Agilent 33522B)
   b. Digital oscilloscopes (Tektronix TDS5034B, 350 MHz, 5 GS/s; Tektronix DPO5034, 350 MHz, 5 GS/s; Tektronix TDS210, etc.)
   c. Universal counter (EZ FC-7150u)
   d. Power supplies (BK Precision 1751 DC power supply, HP 3617A DC power supply, Trek 50/750 high voltage power supply, etc.)
   e. Laboratory PC’s equipped with GPIB and DAQ cards and LabView and MATLAB software

9. **Sensors:**
   a. Piezoelectric wafer active sensors (PWAS) of various sizes, adhesives, connectors, and environmental protection materials for structural installation
   b. Optical distributed strain and temperature sensors (LUNA)
   c. Optical FBG sensors
   d. Conventional ultrasonic transducers (Olympus)
   e. Ultrasonic phased array transducers (Olympus)
   f. Conventional AE transducers (PAC R15a, R15AST, wideband WSA)
   g. Strain gages, load cell, and thermocouples, etc.
Figure 13  Impedance analyzers

(a) HP 4194A impedance analyzer  (b) Agilent 4395A analyzer
(c) Cypher Instruments C-60  (d) Omicron Lab Bode 100

Figure 14  Ultrasonic-range power amplifiers

(a) NF Corporation HSA4014  (b) Ciprian US_TXP-3  
(c) Krohn-Hite 7600
(a) PXI-e system 
(b) PCI-6115 DAQ

Figure 15 National instrument sensing and actuation platforms

Figure 16 Scanning acoustic microscope 300 by PVA TePla, Germany

Figure 17 Metis Design MD7 system
2 SPECIMENS AND TEST APPARATUS

During the previous research and projects, lots of specimens and test apparatus were designed and used to assist research and verify theoretical deductions. Some of specimens and experimental setups are described next:

PWAS Lamb-wave propagation experiments

Figure 18 shows a typical setup for performing wave propagation studies with PWAS-generated Lamb waves. A 1.6 mm thick, 2024-aluminum alloy plate (914mm x 504mm x 1.6 mm) was instrumented with an array of eleven 7-mm x 7-mm PWAS. The PWAS were connected with thin insulated wires to a 16-channels signal bus that ended into two 8-pin connectors. An HP33120A arbitrary signal generator was used to generate a 300 kHz tone-burst excitation with a 10 Hz repetition rate. Both constant-amplitude and smoothed tone-burst signals were used. The signal was sent a transmitter PWAS and received at the other 10 receiver PWAS. A Tektronix TDS210 two-channel digital oscilloscope, synchronized with the signal generator, was used to collect the response signals from the PWAS. The two oscilloscope channels were digitally switched among the remaining 10 active sensors using a digitally controlled switching unit. A data acquisition program using LabView software controlled the switching unit and recorded the data from the digital oscilloscope. A Motorola MC68HC11 microcontroller was tested as an embedded stand-alone unit.

Figure 18  Experimental setup for PWAS Lamb-wave propagation experiments in LAMSS: (a) photograph of the overall setup (b) detail of the microcontroller switching unit
High-power PWAS Lamb-wave propagation experiments

Figure 19 shows a typical setup for performing high voltage wave propagation studies with PWAS generated Lamb waves. A NF Corporation broadband amplifier (Model HSA4014) can output up to 300Vpp, DC to 10MHz frequency was used to amplify the excitation signal. This setup is used with thick specimen, or high attenuation composites specimens.

Figure 19  Experimental setup for high voltage PWAS Lamb-wave propagation experiments in LAMSS
Electromechanical impedance spectroscopy (EMIS) experiments

The electromechanical impedance measuring with the HP4194A Impedance Analyzer is shown in Figure 20. An aging aircraft panel instrumented with an array of piezoelectric wafer active sensors (PWAS) is shown connected to the impedance analyzer.

Figure 20  Typical experimental setup using the HP4194A Impedance Analyzer to measure the electromechanical (E/M) impedance in LAMSS
PWAS phased array experiments with the embedded ultrasonic structural radar (EUSR)

The embedded ultrasonic structural radar (EUSR) using PWAS phased arrays is shown in Figure 21. PWAS array elements were excited in a round robin fashion and the reflections from structural features were collected by the phased array. Once the interrogation is finished, all the sensor data from the array are compiled with data processing software developed in LAMSS, and a reconstructed image of the reflected signal unveils structural anomalies. The software was named embedded ultrasonic structural radar (EUSR). The EUSR software integrated guided wave propagation theory, phased array algorithm, data management scheme and visual data presentation tools, is a convenient yet powerful software for phased array studies conducted in LAMSS.

Figure 21  Experimental setup for the embedded ultrasonic structural radar using PWAS phased arrays: (a) experimental setup (b) reconstructed array data image
Realistic specimen testing experiments

Figure 22 shows a specimen testing at UDRI testing facility in Dayton, OH as part of the project “Development of a Multi-Sensor Structural Health Monitoring System Using Embedded Piezoelectric Sensors” took place in the 2003-2005 timeframe and consisted of collaboration between two universities (University of South Carolina and North Carolina A&T State University) and a company (Triad Semiconductors, Inc.) under AFRL NDE branch sponsorship. The project objective was to develop an SHM system that would combine the active sensing technology developed by USC with the acoustic emission passive sensing technology developed by NC A&T into a working system to be tested at AFRL. The project started with initial sensor developments done independently at each university using coupon specimens and culminated with a common test done on a piece of an aging aircraft structure at UDRI testing facility in Dayton, OH (Figure 22a). In the project, each university developed the sensors and the specific methodology, whereas Triad Semiconductors developed the electronic hardware that would integrate the two sensing methods.

Figure 22 Multi-sensor structural health monitoring testing of actual aircraft component at UDRI lab: (a) Al Wicks (Triad Inc.), Victor Giurgiutiu (U of SC), Lt. Freemantle (AFRL), Mannur Sundaresan (NC A&T); (b) detail of sensors installation
Fatigue damage detection experiments

Figure 23 shows a test used to detect damage due to cyclic fatigue loading. Composite coupons were instrumented with PWAS and conventional foil strain gauges. The strain gauge data was used as a reference to record the loading history. Baseline data was collected on pristine specimens. The specimens were into extension loading group and compression loading group to evaluate the sensitivity of PWAS to different fatigue damage types. With pitch-catch, pulse echo, and E/M impedance methods, data were collected.

Figure 23 Cyclic loading test on composite coupon specimens
Realistic composite specimens

Figure 24 presents a composite aircraft panel from the Boeing Aircraft Co, in St. Louis, MO branch (formerly, McDonnell Douglas) from the canceled A12 program. The panel was constructed from carbon-fiber epoxy composite material. It has Part # 7630186A231552-2 and Serial 81540236. As shown in Figure 24, the panel has high curvature, typical of a fuselage region. The panel also has ‘hat’ stiffeners placed along the generator of the outer skin. Approximate dimensions of the panel are 940 mm × 500 mm with a skin thickness of 3 mm. The stiffeners have tapered construction of 70-mm through 50-mm width and 66-mm height. The stiffeners wall thickness is 3 mm. Three types of subsurface damage are considered possible in this type of composite aircraft panel: (a) impact damage in the panel skin; (b) flexure/compression delamination damage in the stiffeners; (c) disbonding at the adhesive attachment between panel skin and stiffeners. These damage types could happen due to low velocity impact and/or operation loads. All these damage types are critical to the strength and durability of the panel. The panel was instrumented with PWAS transducers operating in (i) pitch-catch; (ii) pulse-echo; and (iii) E/M impedance modes.

Figure 24 Integrated composite panel from the canceled A-12 program was used for predictive simulation of impact-damage detection
Fatigue crack growth detection with PWAS phased arrays and the EUSR algorithm

Figure 25 shows an experiment demonstrates PWAS phased array for fatigue crack growth in metallic plates under cyclic loading. PWAS phased array was instrumented on the specimen. A pre-crack was manufactured at designed location as an EDM slit. The phased array excitation and reception signals were collected and compared with the analytical predictions. Various boundary and clamping conditions were tested to represent different cases in real application. Data analysis software EUSR (Figure 25c) was developed in LAMSS to interpret the phased array data.

Figure 25 PWAS phased array instrumented on fatigue specimen was used to monitor fatigue crack growth. (a) schematic of fatigue specimen; (b) specimen under cyclic loading, clay was used to damp reflection from clamps; (c) phased array data analysis software EUSR showing crack detected
3 MECHANICAL ENGINEERING DEPARTMENT TESTING EQUIPMENT

The multi-million dollar material characterization equipment of the Center for Mechanics and Materials and NDE in the Department of Mechanical Engineering (Figure 26 to Figure 31) will also be made available for the proposed research. Major equipment includes

- Three MTS hydraulic tension testing systems with specialized software for fatigue testing
- One Instron hydraulic testing system with Centorr vacuum furnace
- Two single-axis MTS vibration table
- Dynamic test equipment capable of impact loading of materials at speeds up to 180 mph
- Thermotron environmental chamber capable of temperature, humidity, boil, freeze/thaw
- Weatherometer chamber for intense ultraviolet and humidity aging exposure
- High speed cameras:
  - Phantom v7.3 capable of capturing 800 x 600 pixels at 6,688 frames-per-second (fps) and up to 500,000 fps with the “turbo mode” (two cameras)
  - DRS Imacon 200 capable of capturing up to 16 frames at 5 nano-seconds each with an equivalent rate of 200,000,000 fps (two cameras)
- High-rate loading test equipment includes a pendulum (3.5 m/sec or 5.2 m/sec, 163 Joules or 358 Joules, Charpy and Izod), a gas gun (gun barrel -3m long and 38mm inner dia. up to 45 m/sec; up to 8kJ), a split Hopkinson pressure bar (SHPB) for tension and compression, and an model 8140 drop-weight tower (up to 6.7 m/sec; up to 18kJ).

Figure 26 MTS tensile test machines (a) MTS 810 capable of static and cyclic loadings up to 500kN (b) Instron 8501 capable of up to 10 Hz cyclic loading for fatigue testing (c) MTS equipped with ATS3710 oven can perform tensile test at temperature between -300F and 800F

The fabrication and research resources of the Department of Mechanical Engineering of the University of South Carolina will be available as support services for the proposed project. These resources include a large machine shop, an electronics, instrumentation and microprocessor facility, optical image correlation laboratory, thermo-graphic camera system, etc. These resources will be available to the project to the full extent necessary, in coordination with the scheduling of other on-going projects. Further information about the machine shop is available at http://www.me.sc.edu/machine_shop.html.
Figure 27  MTS vibration test machine and drive up to 200Hz in University of South Carolina

Figure 28  shock test systems (a) MTS drop tower 8ft drop tower (up to 600 lbs specimen) (b) Instron 8140 drop-weight tower (up to 6.7 m/sec; up to 18kJ).
Figure 29 Environmental testing equipments in University of South Carolina (a) Thermotron SE-300; (b) Atlas Weather-ometer; and (c) Humboldt EC3400 rapid freeze-thaw cabinet

Figure 30 Blue M 6680 Ultra-temp industrial oven in University of South Carolina

Figure 31 High-speed cameras in the Department of Mechanical Engineering at University of South Carolina: (a) Phantom v7.3; (b) DRS Imacon 200
The Structural Testing Laboratory is a 7400 square-foot two-story high bay (Figure 32) containing a 1400 square foot reaction floor and a 300 square foot by 16 foot deep geotechnical test pit surrounded by an additional 400 square foot reaction floor. The entire Laboratory area is served by a 3000 psi hardline connected to a 180 gpm MTS hydraulic pump. The Laboratory is equipped with 55 and 110 kip servo-hydraulic actuators suitable for static, dynamic and fatigue testing. There are two independent control systems for the MTS actuators permitting two tests to be conducted simultaneously. Two portable 10,000 psi hydraulic systems equipped with double-acting hollow-core rams having a maximum capacity of 400 kips are also available for static testing. A 4 foot x 12 foot x 16 foot tall modular “Lego”-style test frame is located on the reaction floor and may be tailored to suit a wide variety of test configurations. A modular 64 channel high-speed data acquisition system which may be configured as up to four separate 16 channel systems is available. The structural group has access to state-of-the-art tools for Non-Destructive Evaluation, two additional 55 kip MTS hydraulic test systems for material testing, a MTS Drop Tower for dynamic testing, an MTS Vibration Testing system, and a fully equipped Materials Laboratory. The Materials Testing Laboratory occupies over 2900 square feet. Equipment includes a 135 kip Instron Servo-hydraulic closed-loop Material Test System, a 60 kip Tinius Olsen Material Testing System, 500 kip and 250 kip concrete cylinder compression testing machines, digital ovens, digital scales, etc.
5 OTHER RESOURCES IN USC

The Electron Microscopy Center (EMC) of the College of Science and Mathematics is the centralized analytical microscopy and imaging facility for the entire University of South Carolina system. The EMC website is: http://emc.sc.edu/. The EMC is available to both university personnel and the industrial community. The EMC houses cutting edge microscopy equipment and is supported by staff experts. The EMC also serves as an educational center with programs geared towards all ages.

The nano-mechanical characterization equipment includes a Hysitron nanoindenter, a DI 3100 atomic force microscope, an MTS nano-tensile tester, and a CETR nano/micro-tribometer.

![Image](a) ![Image](b) ![Image](c)

Figure 33 Class-1000 clean room in USC nanocenter: (a) Scanning electron microscope (b) Fume hoods (c) From left to right, heated ribbon bonder, wire bonder, and high purity gold thermal evaporator.

A class 1000 clean room for sample fabrication which includes a JEOL JSM-840A scanning electron microscope (SEM) capable of defining mask features down to 30 nm for nano-lithography, wire and ribbon bonding machines to make electrical connection to the mesoscopic devices, high purity gold thermal evaporation system, optical microscopes, and a general purpose deposition system for sputtering, thermal and e-gun evaporation, and ion milling.

The EMC instrumentation consists of:

- **ESEM FEI Quanta 200** - The Quanta 200 is a conventional SEM with optimum performance for both imaging and microanalysis of conductive and/or coated specimens. With versatile yet easy to operate software control, the instrument is an excellent tool for both the experienced and first-time user. The electron optical column with its conical final lens and fixed final lens aperture is optimized for high-
resolution imaging, X-ray microanalysis and low magnification performance. The fixed final lens aperture, column design and the computer controlled alignment guarantee alignment free selection of kV and spot size, even up to high beam currents. User friendliness is a special benefit. The integration of advanced electron optics and extensive system automation with a unique, high-level user shell has produced a precision instrument with exceptional levels of performance, flexibility and usability.

Figure 34  USC Electron Microscopy Center (EMC) instrumentation (a) FEI Quanta 200 ESEM (b) Cameca SX50 EMPA (c) Hitachi H-8000 TEM (d)JEOL JEM 2100F

- **SEM Hitachi 2500 Delta** -- The scanning electron microscope is an integrated model Hitachi 2500 Delta equipped with a quadruplex electron backscatter detector, IXRF digital imaging and microanalysis processing system, a Kevex X-ray detector with light element capabilities and an electron beam lithography system (NPGS). The SEM is a high performance instrument with a resolution of 3.5 nm with a range of magnification from 17X to 200,000X. Through utilization of the Digital acquisition software provided by IXRF, images can be taken, processed, and printed on to our photographic quality dye sublimation printer. TEM Hitachi H-8000 - The Hitachi H-8000 is a transmission electron microscope capable of accelerating voltages from 75-200kv. It can provide a magnification from three thousand to one million with resolution of 0.14 nm. The Hitachi is primarily used for materials research and is an analytical microscope that is equipped with a side entry goniometer, STEM, X-ray microanalysis that is integrated with an IXRF system, and digital AMT CCD Camera. TEM Jeol 100 CX II - The Jeol 100 CX II is a transmission electron microscope
capable of accelerating voltages from 20-100kv. It can provide magnification from 100x to 600000x and a resolution of 0.2nm. The instrument is user friendly and rarely needs alignment. The Jeol is primarily used in analysis of biological specimens. The Jeol is equipped with a side entry goniometer and in the future a CCD camera and digital interface will be incorporated into the hardware of the microscope.

- **EMPA Cameca SX50** - The electron microprobe analysis facility is a non-destructive method ideal for materials characterization, such as quantitative chemical analysis, X-ray mapping, and imaging. This technique is used to obtain chemical data and images that show the distribution and variation of a material's constituents. The technique combines high sensitivity (~0.01 wt % detection limit), high speed (seconds to minutes per analysis), high precision and accuracy (1-2 % errors), and high spatial resolution (0.001mm analysis area). Integrated optical microscope imaging allows visual selection of specific sample features to measure. Solid materials such as alloys, semiconductors, ceramics, borosilicate glasses, rocks, or minerals can be analyzed for major, minor, and trace elements.

- **Confocal Microscope Bio-Rad MRC 1024** - The multi-photon laser scanning confocal microscope system is probably the most important development in fluorescence microscopy since the introduction of confocal imaging in the mid-1980’s. It provides researchers with unique possibilities when imaging deep into live tissues and carrying out experiments over extended periods of time. Bio-Rad pioneered the commercial application of multi-photon techniques. The first commercial multi-photon system was delivered in 1996.

### 6 COMPUTER

Computer facilities with standard software programs are widely available at various locations in all the departments participating in this proposal. Each participating department has a large number of PC’s equipped with state of the art software for research applications placed in the laboratories, graduate student offices, and faculty offices. In addition, we have dedicated computer labs with banks of PC’s that are on upgraded periodically under a lease contract with the PC manufacturer. A computer communication local area network (LAN) with wireless capabilities is installed in all the buildings. Faculty and students have instant access to the network from class rooms, laboratories, and offices. This allows them to fully utilize the modern computer facilities available throughout the universities. For intensive computation, online accesses to the extensive computational facilities of several National Labs exist.

### 7 OFFICE

The key investigators are provided with faculty offices, while the graduate students are provided with office space in dedicated room suits and in the labs. These resources include secretarial and photocopying support, courier services, etc. Also available are extensive library facilities.