UNIVERSITY OF MANITOBA

13-6

CANADA FOUNDATION FOR INNOVATION
Innovation Fund

Notice of Intent

1. Completed NOIs must be submitted by the Associate Dean (Research)/Research Liaison Officer of the "Lead" Unit to the Office of Research Services to: Birtukan.Gebretsadik@umanitoba.ca by May 15, 2018.

Proposed name of project: Materials in new light: Terahertz technologies and applications	**Estimated Total Project Costs: 1.5M**
Designated Project Leader/Faculty/Dept: **A. Major/ Engineering/ ECE** **CV:** x	
List Principal Users/Faculty/Dept:	
1. C. Shafai/ Engineering/ ECE CV: x	
2. B. Kordi/ Engineering/ ECE CV: x	
3. J. Paliwal/ Agriculture/ Biosystems CV: x	
4. F. Koksel/ Agriculture/ Food CV: x	
5. D. Isleifson/ Environment/ Env & Geo CV: x	
6. L. Shafai/ Engineering/ ECE CV: x	
'Lead' Unit ADR/RLO: Engineering	
Name: Cyrus Shafai	

Briefly describe (max 1 page, 12 pt. font size, 2 cm margins):

- The proposed research and how it is world-class, innovative and demonstrates clear benefits to Canada.
- The infrastructure and how it will enhance the University's existing research capacity.
- The excellence of the team, including expertise and existing collaborations necessary to conduct the proposed research.
- Plans to secure matching funds and the potential funding sources for the operation and maintenance of the infrastructure.

Materials in new light: Terahertz technologies and applications

Overview

The proposed research aims to develop and apply a number of innovative techniques based on terahertz (THz, 10^{12} Hz) radiation. This non-ionizing type of electromagnetic radiation has several unique properties which make it ideally suited for communications, non-destructive testing, chemical analysis and three-dimensional imaging of various materials such as agricultural products and chemicals, pharmaceuticals, plastic materials, food, etc. Terahertz technologies and applications are still in their infancy because efficient sources of such waves only recently became available. At the same time new materials and devices to manipulate properties of THz waves are needed. With this in mind the main idea of this CFI proposal is to acquire state-of-the-art equipment for generation of THz radiation and for material deposition and processing to enable (1) testing of cutting-edge approaches for next generation of telecom devices and development of new innovative tools for (2) remote environmental sensing (including Arctic), (3) non-destructive testing and (4) high resolution imaging of electrical, biological and chemical materials. The envisioned research closely aligns with strategic research themes of the University of Manitoba.

1. The proposed research, its novelty and benefits to Canada

Constant demand in high-quality video streaming and conferencing, mobile apps, 3D displays and other real-time applications requires continuous growth in wireless data traffic which cannot be accommodated by current microwave technology. This issue can be resolved by using a higher frequency waves, i.e. in the THz range. Until recently, this frequency region has been referred to as the *Terahertz Gap*, as the generation and modulation of coherent electromagnetic signals in this frequency range ceases to be possible with conventional electronic devices used to generate microwaves. Some elements are now appearing, but still critically lacking are conductors suitable for the efficient transmission of terahertz signals, i.e. the backbone of any communication system. Recent research of Profs C. Shafai and L. Shafai has recently resulted in the first demonstration of low loss conductors by means of a composite laminated conductor, formed by nano-layerings of metal and dielectric materials. This new multi-layer conductor structure has been described by industrial colleagues as the new disruptive technology since it will effectively result in the *superconductivity effect* for THz waves. This breakthrough will enable the development of ultra-low loss conductors, which will pave the way for various THz communication circuit elements, waveguides, sources, and receivers. This will lead to new innovations in THz communication systems and significant new industrial opportunities. Research will include thin film formation and study of electronic properties of metal-dielectric layerings, development of THz circuitry, and development of and integration within THz sources and receivers.

Another unique feature of THz radiation is that many common materials (including paper, wood, cloth, ceramics, plastics, fat, various powders, and dried food) are semi-transparent in this spectral range and have distinct absorption peaks. Therefore, careful inspection of THz absorption spectra allows many substances to be analyzed and selectively identified. The fact that terahertz radiation can easily penetrate through plastics and cardboard opens up numerous applications in manufacturing, quality control and process monitoring where the packaged objects can be inspected for either size, structure or chemical composition. The plan is to pursue several application areas: quality control of grain, food processing, composite materials, and chemical sensing of oil. Development of a portable THz system capable of real-time chemical analysis will be particularly important to the Canadian grain industry worth $6B. With about 70% of the produced grains being exported to global markets, quality control of grain during handling and storage systems is a major concern. Additional attractive direction is grain spoilage detection. Spoilage usually results in higher water content. Strong absorption of THz radiation by water will act as a contrast imaging mechanism and allow for remote detection of grain areas with increased water content. The imaging will be done by the THz spectrometer which has an imaging option (both in transmission and reflection) with sub-mm resolution. This work will be done by PI in collaboration with Prof. Paliwal, an expert on grain storage and quality control. The same imaging principle will be used to monitor moisture content in food processing in collaboration with Prof. Koksel. THz imaging capabilities will be also exploited for quality control of composite aerospace and electronic materials. Since plastics are mainly transparent at THz frequencies, any defects will result in modification of signal transmission/reflection. Thus THz imaging will enable non-destructive analysis of ply-orientation, reinforcement-ply-count, ply thickness, and detection of various imperfections such as porosity, delamination and cracks. High power THz radiation will be particularly useful for imaging of thick materials and large areas at long distances. This program will be done in collaboration with local (Boeing, MB) or national (Stelia-Aerospace, NS) industrial partners who are willing to collaborate and are active players in this multi-million dollar market niche. On the other hand, ageing of electrical insulating materials (plastics, paper, oil products) will be investigated in collaboration with Prof Kordi and backed up by Manitoba Hydro which has a strong interest in this area. Moreover, direct measurements and modeling of dielectric properties of the oil and oil products that are enabled by THz spectroscopy will be linked to the dielectric properties of the sea ice/oil mixtures and used for remote oil sensing in Arctic by Prof. Isleifson. From this research, novel results on the dielectric properties of sea water/oil emulsions and oil infiltrated sea ice will be established and used in satellite sensing and imaging of oil spills. All of this is enormously important in predicting and minimizing environmental impact in Arctic due to changing climate and economic conditions, thus contributing to the development of sustainable practices and policies.

2. The infrastructure and existing research capabilities

This research program is based on the use THz radiation and/or innovative materials. The proposed research requires both low (telecom & bio-imaging) and high (~100 times higher, remote sensing) power THz radiation with imaging capabilities. The needed equipment therefore includes a (low power) THz imaging spectrometer and a high power laser source (with relevant accessories) that will be used to develop a high power THz source for remote sensing and inspection of materials. The estimated cost is $900k. The materials part will need precision deposition, processing and characterization equipment (thin-film deposition, sputtering, etching, ink-jet printing) with an estimated cost of $600k. To the best of our knowledge, the proposed equipment is not available at the University of Manitoba. The material and THz equipment will capitalize on the previous CFI awards by Major, Kordi, and Shafai (microwave spectrometer, optical microscopy, material processing) and will form an excellent platform for potential collaboration with the newly announced NRC center on Smart and Additive Manufacturing that is coming to Winnipeg.

3. The team and existing collaborations

Each team member is an expert in the areas relevant to this proposal: Major (optical and laser technologies), C. and L. Shafai (micro- and nano-electronics and materials), Paliwal (grain storage and inspection), Kordi (insulating materials), Isleifson (remote sensing), Koksel (food inspection). The unique properties of THz radiation provide a natural synergy for the proposed innovative and interdisciplinary research. The team has strong ties to local and national industry partners that are interested in the described research areas.

4. Plans to secure matching funds

Based on our current and previous interaction with industrial suppliers we are confident that they will contribute 20% of total project cost as in-kind CFI discount.