

AN OVERVIEW OF THE APPLICATIONS OF MIR AND THz SPECTROSCOPY IN ASTROCHEMISTRY STUDIES*

C. Suwannajak^{†1}, W. Jaikla¹, M. Jitvisate⁵, U. Keyen¹, A. Leckngam¹, P. Nimmanpipug³,
S. Pakluea², T. Phimsen⁴, S. Rimjaem^{2,6}, N. Tanakul¹, P. Wongkummoon²,

¹National Astronomical Research Institute of Thailand, Chiang Mai, Thailand

²Plasma and Beam Physics Research Facility, Department of Physics and Materials Science,
Faculty of Science, Chiang Mai University, Chiang Mai, Thailand

³Department of Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai, Thailand

⁴Synchrotron Light Research Institute, Nakhon Ratchasima, Thailand

⁵School of Physics, Suranaree University of Technology, Nakhon Ratchasima, Thailand

⁶also at Thailand Center of Excellence in Physics,

Ministry of Higher Education, Science, Research and Innovation, Bangkok, Thailand

Abstract

Interstellar complex molecules can be found in molecular clouds throughout our galaxy. Some of these molecules are thought to be precursors of bio-molecules. Therefore, understanding the formation processes of those interstellar complex molecules is crucial to understanding the origin of the building blocks of life. There are currently more than a hundred known complex molecules discovered in interstellar clouds. However, the formation processes of those molecules are not yet well understood since they occur in very extreme conditions and very short time scale. Ultrafast spectroscopy can be applied to study those processes that occur in the time scales of femtoseconds or picoseconds. In this work, we present an overview of the applications of MIR and THz pump-probe experiments in astrochemistry studies. An experimental setup to simulate space conditions that mimic the environments where the interstellar complex molecules are formed is currently being developed at the PBP-CMU Electron Linac Laboratory. Then, we present our development plan of the experimental station and its current status.

INTRODUCTION

Stars, planets, and everything around us are all originated from the interstellar medium, which is the matter in the space between stars. The interstellar medium can be found in the form of molecular clouds, which contain simple molecules such as H₂ and CO in gas phase and micron-size solid dust grains. When those molecular clouds collapse due to their own gravity to form stars and planets, relatively more complex molecules can be formed. Certain species of the complex molecules are thought to be the precursors of bio-molecules such as sugars and amino acids. These molecules can be later transported to planets through asteroid and meteoroid bombardments during the process of planet formation and thus, provide the planets with the building blocks of life.

During the collapse of a molecular cloud, the density of the cloud increases. This allows gas molecules to stick onto a solid dust grain, forming ice layers, which further allow the formation of relatively more complex molecules to occur on the ice surface under extremely cold temperature. The process usually be referred to as grain surface chemistry. It is currently accepted that complex molecules found in interstellar clouds are formed through this process. In addition, the increased density of the cloud also shield the grains from external stellar radiation, preventing the newly formed molecules from being photo-dissociated. When the temperature of the cloud increase due to the newly formed star inside the cloud, the molecules can be desorbed into gas phase. This allow them to be observed from the earth through their rotational spectra.

Currently, there are more than a hundred known species of complex molecules identified in molecular clouds [1]. Organic molecules such as ribose and related sugars were also found in a meteorite [2]. However, the formation pathways of those molecules and the conditions that those complex molecules prefer are not yet well understood. Here we present the development of Thailand's first astrochemistry laboratory to study the processes of complex molecule formation under extreme interstellar conditions. The work includes the current progress, the development plan, and the experiments and applications.

DESIGN OF THE EXPERIMENTAL CHAMBER

With the goal to study the processes of complex molecule formation under interstellar cloud conditions, an experimental chamber needs to be constructed to simulate such extreme conditions. This includes an ultrahigh vacuum with pressure as low as 10⁻¹⁰ mbar and a temperature of about 77 K or below similar to those of the molecular clouds. In addition, a vacuum UV source is also needed to irradiate the sample inside the chamber to trigger chemical processes similar to the cosmic ray-induced UV inside the interstellar clouds [3].

Figure 1 shows the design of the experimental chamber and its side-view schematic. The chamber will be con-

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[†] chutipong@narit.or.th

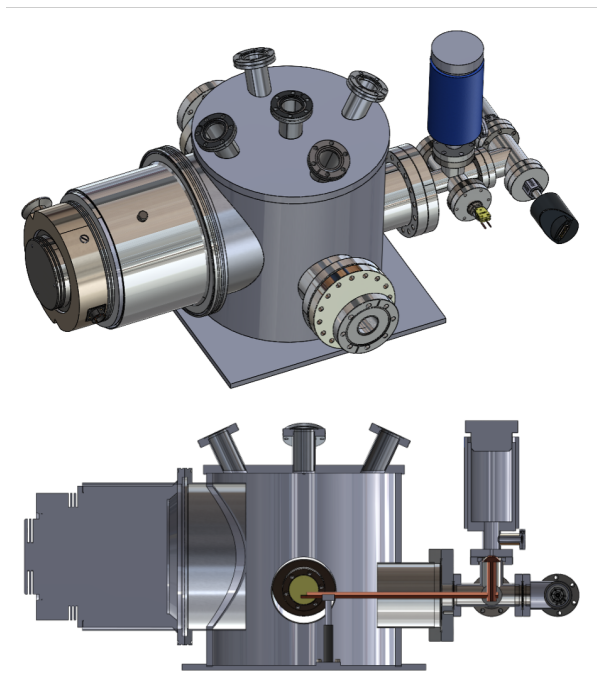


Figure 1: The design of the experimental chamber.

constructed with stainless steel with various ports for the experimental components. Connected to the chamber on the left side of the figure is a turbomolecular pump, capable of pumping the pressure inside the chamber to 10^{-10} mbar. On the opposite side of the turbomolecular pump, a liquid nitrogen dewar, a sample holder, a conduction bridge, and pressure gauges are connected through the same port. The dewar is connected to the sample holder bridge to maintain the low temperature at the sample holder during experiments. Five ports are put on top of the chamber for connecting with gas injection units and a VUV source. Finally, two optical ports with ZnSe windows are connected to the sides of the chamber for FTIR transportation into the chamber and from the chamber to an MCT detector.

EXPERIMENTS AND DEVELOPMENT PLAN

To conduct an experiment, the interested molecules will be deposited onto the cold surface of the sample holder inside the chamber through gas injection units. The sample can be irradiated with VUV for photochemical reactions. The chemical species and structures of the products will be analyzed using Bruker FTIR spectrometer and MCT detector at the PBP-CMU Electron Linac Laboratory (PCELL). Figure 2 shows the schematic of the experimental setup which includes the chamber, the FTIR spectrometer, and the MCT detector. The FTIR beam will be transported from the spectrometer into the chamber via IR optical matching box connected to the ZnSe window. Then, the signal from the chamber will be transported to the MCT detector on the opposite side. We note that the MCT detector will be inside

an IR optical cavity. The box is removed from this figure only for illustration purposes.

Currently, we are at the stage of constructing the experimental chamber. This includes the vacuum, sample holder, and cooling components. The gas injection unit is being designed to allow the deposition of interested molecules in the gas phase onto the cold surface under ultrahigh vacuum conditions. Then, the IR matching boxes will be installed to connect the chamber to the FTIR spectrometer and the MCT detector. Simple reactions of formaldehyde (H_2CO) and ammonia (NH_3) will be conducted as our starting experiment [4]. The experiments probe the thermal reactivity of H_2CO and NH_3 , which are abundant in interstellar clouds, to form aminomethanol ($\text{NH}_2\text{CH}_2\text{OH}$). The product from the reactions will be probed with MIR spectroscopy via their MIR fingerprints. This setup is similar to [4–7], which are astrochemistry laboratories to study the complex molecules in molecular cloud conditions. Although, each of these laboratories has unique variations of the setup for conditions such as varying VUV intensity, multi-stage gas, and atomic sources. In addition, the crystalline structure of the ice layers can be studied with THz spectroscopy in a setup similar to [8].

With the advantages of pump-probe spectroscopy and high-intensity IR beam from a free-electron laser (FEL) source, the intermolecular interactions and formation mechanisms, which occur in the time scales of picoseconds, can be studied [9, 10]. The FEL and pump-probe spectroscopy setup is also being developed at PCELL. The setup will be similar to that of the FELIX laboratory [11], which is unique due to its capability for studying ultrafast chemical reactions under interstellar conditions. The inclusion of FEL and ultrafast spectroscopy will make our laboratory very unique for its capabilities.

SUMMARY

An experimental laboratory to simulate molecular cloud conditions is being developed to study the formation and interaction mechanisms of interstellar complex molecules. This work presented the design of the experimental chamber and the setup for MIR and THz spectroscopy. We also discussed the development plan of the laboratory including the inclusion of ultrafast spectroscopy in the setup, which will make our laboratory very unique for its capabilities.

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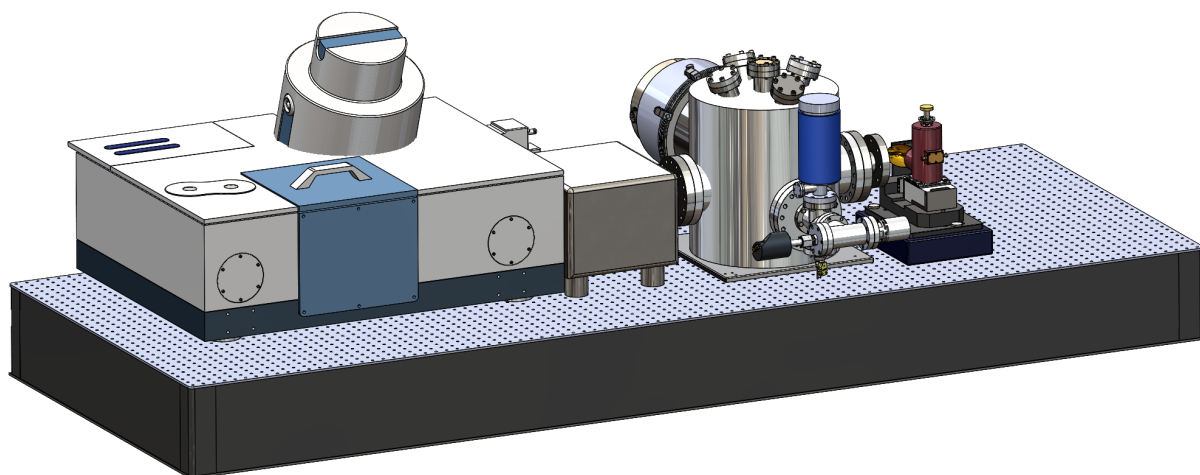


Figure 2: The experimental setup with the experimental chamber, FTIR spectrometer, and MCT detector.

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