Reliance on fossil fuels for energy has raised concerns about sustainability and environmental harm. Development of new sustainable fuel sources with an overall lower impact on the environment is important for modern society. In recent years, catalytic chemistry has been used in many different ways to minimize the impact of industry on the environment and to produce useful fuels for improved sustainability. CO$_2$ reduction is an important catalytic process for society and is currently a hot-topic in the scientific community. Increasing levels of CO$_2$ in the atmosphere have caused an increase in the global surface temperature. The level of atmospheric CO$_2$ has increased dramatically and no end to this pattern is foreseen. The ability to convert harmful atmospheric CO$_2$ into a useful fuel source can help substantially reduce CO$_2$, and subsequent global warming, while also providing an additional source of fuel. Current studies on the mechanism of CO$_2$ reduction all rely on a process which begins with the addition of an electron to the CO$_2$ and therefore production of the CO$_2$ anion. However, the presence of this species has not been unambiguously confirmed despite being the most important step in any of the proposed CO$_2$ reduction mechanisms.

The low-energy electron gun funded through ISEN’s generous equipment grant has allowed us to complete the resurrection of a previously operational ultrahigh vacuum chamber with liquid nitrogen sample cooling and optical access for spectroscopy. Installation of the low-energy electron gun has produced a functioning ultrahigh vacuum chamber with all capabilities necessary to probe the presence of the CO$_2$ anion. For optimal use, the electron gun was installed at a specific angle of incidence and distance to the sample surface. The installation was performed in ultrahigh vacuum conditions by ensuring a proper vacuum seal and preventing equipment contamination. Additionally, the orientation of the sample and other equipment in the chamber was also taken into consideration to prevent loss of current capabilities. After installation, the chamber was brought to an elevated temperature to remove any contaminants and establish ultrahigh vacuum conditions.

Currently, we are using the ultrahigh vacuum chamber with the electron gun to move forward with CO$_2$ anion studies. Copper-based film over nanosphere (FON) surface-enhanced Raman spectroscopy (SERS) substrates that are compatible with ultrahigh vacuum are being fabricated. Copper is being used as the substrate because it is integral to the CO$_2$ reduction process. However, copper FON substrates are not typically used and optimization of these substrates must be performed. When substrates have been optimized, CO$_2$ gas will be frozen onto the SERS substrates in the ultrahigh vacuum chamber. Performing this experiment in ultrahigh vacuum allows a pristine surface to be maintained and should also extend the lifetime of the CO$_2$ anion. Once the CO$_2$ is frozen onto the surface the low-energy electron gun will provide a flood of electrons and produce the CO$_2$ anion through electron capture. The presence of the CO$_2$ anion will be confirmed using SERS via optical access to the ultrahigh vacuum environment. We anticipate that a successful substrate will be fabricated soon and ultrahigh vacuum studies will commence towards the observation of the important intermediate, the CO$_2$ anion, in the CO$_2$ reduction process.