L.3: Setting up a low-temperature Fourier transform infrared spectroscopy system

Fourier Transform Infrared (FTIR) spectroscopy is a widely used characterization tool in various fields such as material science, pharmaceuticals, biology, and geology. It has a high signal-to-noise ratio and faster data acquisition capability, which makes it suitable for characterizing semiconductor material systems whose optical/vibrational transitions lie in the infrared (IR) region. However, the FTIR signal becomes quite sensitive to thermal variations in the IR range. To obtain a high signal-to-noise ratio by minimizing thermal broadening, a low-temperature FTIR is required, especially for narrow energy bandgap material systems. Keeping this in mind, a low temperature Fourier transform infrared spectroscopy system has been setup at RRCAT. In this setup, a low-vibrational table is designed to mount the closed cycle refrigerator (CCR) with 1-dimensional/linear axis motion, as shown in Figure L.3.1. Other components, such as the CCR, turbo-molecular pump (TMP) station, temperature controller, and water chiller are suitably located to vary the sample temperature from 8 to 325 K.

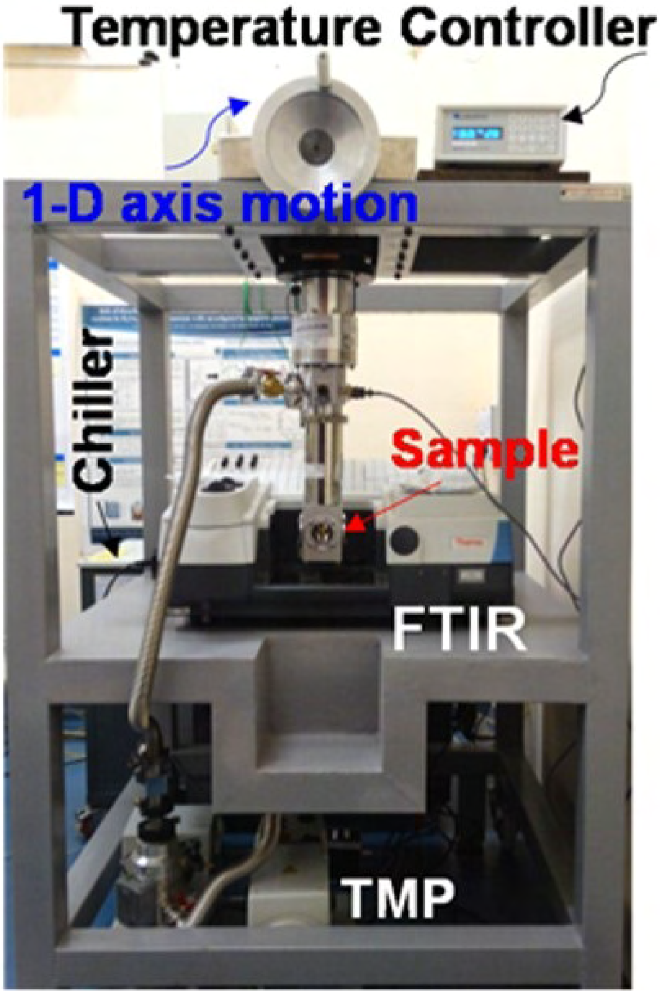

Fig. L.3.1: Photograph of the setup for low temperature FTIR measurements.

Among the group III-V semiconductors, Indium arsenide (InAs) is the most suitable material for electronic, photonic, and quantum computation applications. This is due to its small electron-effective mass (~$0.023m_0$), making it an ideal choice for high electron mobility transistor devices. Additionally, InAs is a low energy band gap direct semiconductor, which makes it the most promising material for photonic devices operating in the mid-IR region. The large electron Lande *g*-factor value ($g_e \sim -15$) makes it an ideal platform for integrating InAs on Si for long-term quantum-secured qubit-based quantum computing applications.

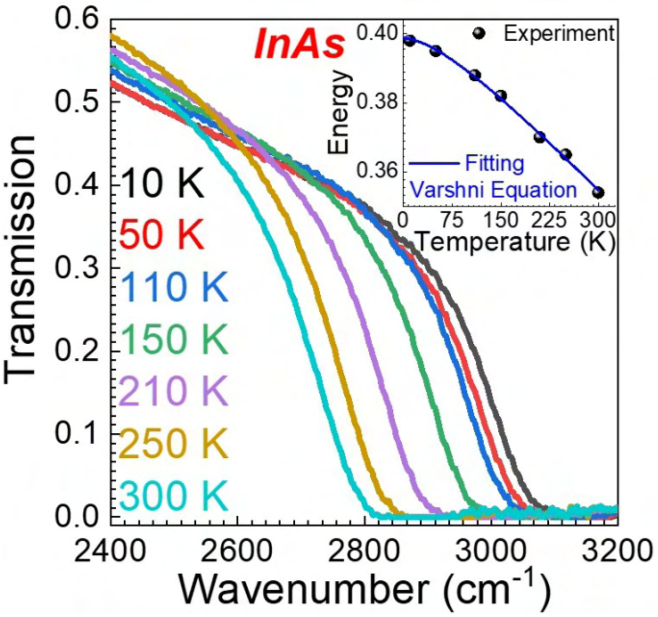

Fig. L.3.2: Temperature-dependent FTIR spectra of InAs semiconductor. The inset shows the fitting of the experimental energy bandgap data measured at different temperatures.

The band gap of InAs bulk is measured at different temperatures using the FTIR setup shown in Figure L.3.2. A sharp transition in the transmission spectra is associated with the valance band to conduction band electronic transition feature of the InAs semiconductor. The inset of the figure shows the energy band gap variation with temperature, where the Varshni equation $\left[E_g(T)=E_g(0)-\frac{\alpha T^2}{\beta+T}\right]$ is used to fit the experimental data points. The extracted values of $E_g(0)$, which is the energy band gap value of InAs at zero kelvin, is around 0.4 eV. The parameters $\alpha \sim 2\times10^{-4}$ eVK^{-1} and $\beta \sim 105$ K correspond to the entropy and Debye temperature associated with the InAs material system, respectively. The experimentally obtained values are found very close to the theoretically estimated values. Therefore, this facility can be used to characterize any semiconductor material system whose electronic/vibrational transitions occur in the IR region. Its temperature variation capability with very low vibrations at the IR region is of utmost importance. Further work is in progress to measure electronic/vibrational transitions from semiconductor quantum structures at low temperature.

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