Raman Spectroscopy for Detection of Critical Minerals and Rare Earth Elements (REEs) : Copper (Cu)

INTRODUCTION

Copper (Cu) is a critical industrial and strategic metal essential for electrical infrastructure, renewable energy systems, electric vehicles, power transmission, and electronics. With increasing global electrification and decarbonization efforts, demand for copper continues to rise, necessitating efficient mineral exploration and accurate identification methods.

Copper occurs in nature in various mineral forms, including carbonates, silicates, sulfides, and oxides. Reliable identification of copper-bearing minerals is vital for geological mapping, resource evaluation, and beneficiation planning.

Raman Spectroscopy has emerged as an effective analytical technique for copper mineral identification due to its ability to probe molecular and lattice vibrations that are highly specific to mineral structure.

MATERIALS AND METHODS

Raman spectra were acquired using the **TechnoS IndiRAM™ CTR Raman spectrometer**, designed to provide high spectral resolution, wavelength stability, and excellent signal-to-noise performance for mineralogical analysis.

Two structurally distinct copper-bearing minerals were Analyses:
- **Dioptase –** $Cu_6Si_6O_{18} \cdot 6H_2O$ (hydrated copper cyclosilicate).
- **Malachite –** $Cu_2CO_3(OH)_2$ (basic copper carbonate)

These minerals were selected due to their contrasting silicate and carbonate frameworks.

Various Ores of Copper
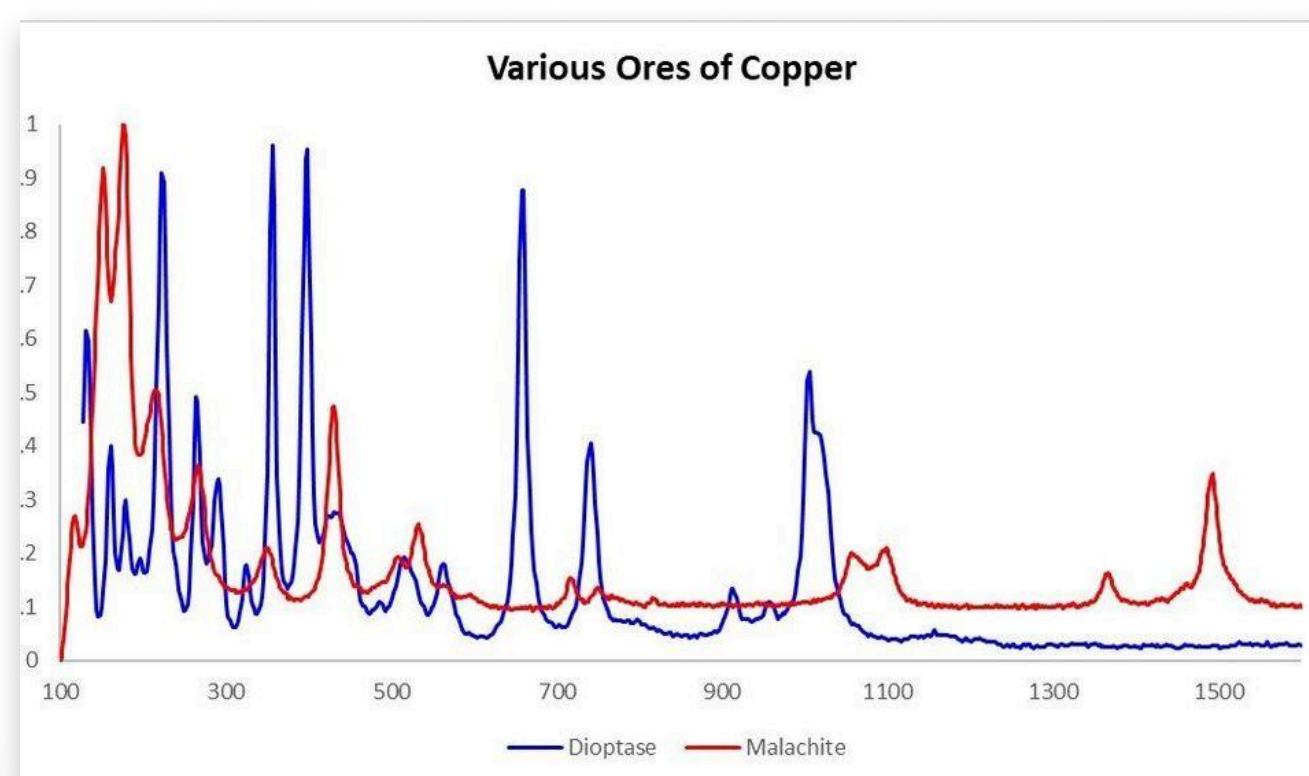
RESULTS AND DISCUSSION

Dioptase

Dioptase exhibits Raman features dominated by silicate ring vibrations:

- Cu–O lattice modes at ~137, 165, and 181 cm^{-1}
- SiO_4 bending vibrations in the 200–500 cm^{-1} range
- Internal silicate modes near 527 and 665 cm^{-1}
- Si–O symmetric stretching modes around 748, 921, 974, and 1012 cm^{-1}

These sharp and well-defined peaks reflect the ordered cyclosilicate structure of Dioptase.

Malachite

Malachite displays Raman signatures characteristic of carbonate minerals:
- Lattice vibrations at ~180, 219, 270, 355, 434, 538, and 596 cm^{-1} (with an intense Cu–O bending mode near ~434 cm^{-1})
- Carbonate group vibrations, including:
- Symmetric bending at ~721 and 755 cm^{-1}
- Asymmetric bending near 817–820 cm^{-1}
- Symmetric stretching near 1059 and 1097 cm^{-1}
- Asymmetric stretching modes around 1368–1490 cm^{-1}

The dominance of carbonate-related bands clearly differentiates Malachite from silicate-based copper minerals.

Mineral Discrimination

Despite visual similarity, Dioptase and Malachite show distinct and non-overlapping Raman fingerprints, enabling rapid and confident mineral identification without sample preparation.

CONCLUSION

Raman spectroscopy provides a fast, non-destructive, and highly specific method for identifying copper-bearing minerals. The distinct spectral signatures of Dioptase (silicate) and Malachite (carbonate) demonstrate Raman's effectiveness for copper mineral discrimination in exploration and processing environments.

Using high-resolution Raman systems and with ongoing development of **Portable Raman solutions**, TechnoS Instruments enables accurate, field-ready mineral identification to support the growing demand for critical minerals such as copper.

REFERENCE

1. Rinaudo, C., Gastaldi, D., & Croce, G. Raman characterization of lithium aluminosilicates. Journal of Raman Spectroscopy, 36, 810–816 (2005).

2. Frost, R.L., et al. Raman spectroscopy of carbonate minerals. Spectrochimica Acta Part A, 67, 604–611 (2007).

3. McMillan, P.F. Vibrational spectroscopy of silicates. Physics and Chemistry of Minerals, 16, 245–254 (1988).

4. Data taken at IIGJ-Jaipur using IndiRAM CTR-300C Raman Spectrometer system.

OUR PRODUCTS

IndiRAM™ CTR Series
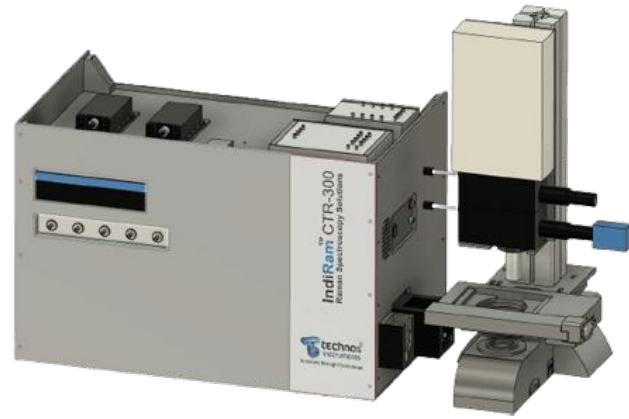
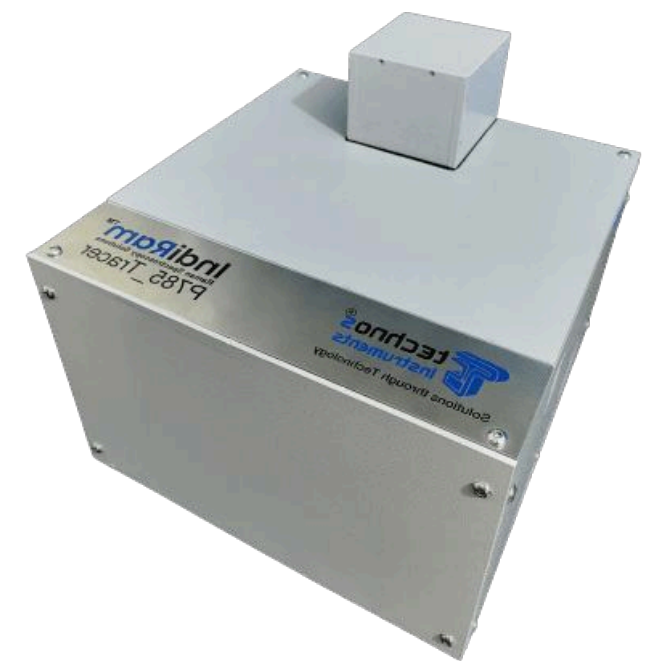**IndiRAM™ CTR for Quantum Characterizer**

IndiRAM™ CTR-Mini Series

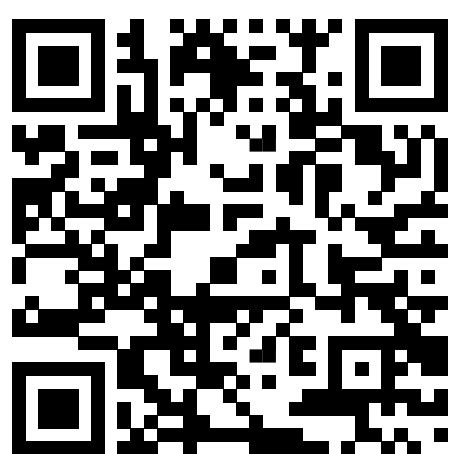**IndiRAM™ Edu**

Diamond Detection System

IndiRAM™ Handy Series

IndiRAM™ CTR P-Series

IndiRAM™ Portable System