

Spectroscopic Characterization of Olivine [(Fe, Mg)₂SiO₄] in Mahadevpur H4/5 ordinary chondrite

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Abstract

This study demonstrates for the first time, the spectroscopic characterization of Mahadevpur H4/5 chondrite that fell at Mahadevpur near Namsai town (Lat.27°40' N, Long. 95°47' E, Auranachal Pradesh, India) on 21 February 2007. The olivine group [(Mg, Fe)₂SiO₄] in Mahadevpur is characterized by the Fourier transform infrared (FT-IR), X-ray fluorescence (XRF) and Laser-Raman spectroscopic (RS) method. A comparison of results with Dergaon H5 chondrite is presented. Particular emphasis is given to the 10μm (1000cm⁻¹) and 20μm (500 cm⁻¹) region of infrared and Raman bands, which is originated from tetrahedral vibrations of silicates. [The Journal of American Science 2009; 5(4): 71-78]. (ISSN: 1545-1003)

Key words: Mahadevpur meteorite; olivine; spectroscopic characterization

1. Introduction

Meteorites are fragments of rocks which originated from outer planetary bodies and fell on the surface of the earth. Meteorites can be divided into two major types, primitive and differentiated. Differentiated meteorites are igneous rocks that were crystallized from magmas generated at the interiors of their parent bodies. The primitive ones have not experienced the melting in their parent bodies, thus their bulk compositions, except for volatiles, are considered to represent those of the solar nebula where and when the meteorites formed. Since the majority of primitive meteorites have chondrules, they are commonly called chondrites. Chondritic meteorites are the oldest and most primitive rocks in the solar system. The primary divisions of chondrite classification are the carbonaceous, ordinary, and enstatite classes (Parthasarathy and Sarma, 2004). The chondrites are the most numerous meteorite group, accounting for 87% of all meteorites observed to fall. The largest group of chondritic meteorites is known as the ordinary chondrites, account for 80% of all known meteorites (Philip et al 2000).

Three subgroups of ordinary chondrites are identified, H group (high iron), L group (low iron), and LL group (low total iron, low metal). Chondrites contain small round masses of olivine or pyroxene. The silicates in meteorites predominantly consist of olivine and pyroxenes or non-crystalline silicates of intermediate compositions (Freund and Freund 2006).

On 21 February 2007, a meteorite fell Mahadevpur near Namsai town (Lat.27°40'N, Long. 95°47'E, Auranachal Pradesh, India) at 09:10 hrs Indian standard time (GMT+5:30hrs) (Weisberg et al 2008). The Mahadevpur meteorite is the fourth documented meteorite from the north-eastern region of India. The last one was reported to fell on 2 March, 2001, at Dergaon and is classified as H5 chondrite (Grossman et al 2001). The other two are 'Assam' (1846) of type L5 and 'Goalpara' (1868) of type ureilite. The Mahadevpur meteorite has been documented as type H4/5 ordinary chondrite (Weisberg et al 2008). The present study represents the nature of olivine [(Mg,Fe)₂SiO₄] in Mahadevpur meteorite by comparing with Dergaon H5 chondrite.

The olivine of Dergaon meteorite has reported by Gohainbarua (2003); Bhattacharyya (2004) (Gohainbarua et al 2003; Bhattacharyya et al 2004). The comparative study of Mahadevpur is performed using X-ray fluorescence (XRF), Fourier transform infrared (FTIR) and Laser-Raman spectroscopy (RS). Particular interest is directed toward the 10 μ m (1000cm⁻¹) and 20 μ m (500cm⁻¹) region which exhibits the characteristics of olivine group.

2. Materials and Methods

A part of the meteorite samples (Figure 1) was crushed into fine powder by using agate mortar for analysis. The X-ray fluorescence (XRF) data on the Dergaon and Mahadevpur meteorite were collected by using powdered homogenous sample in pellet form. For XRF studies a Philip Magix XRF spectrometer PRO model PW 2440 has been used in wavelength dispersive mode. Typical uncertainty involved is +/- 0.02 wt %. The thin sections of the sample have been characterized by electron microprobe analyzer. The experimental details were similar to that described elsewhere

(Bhandari et al. 2005; Dhingra et al. 2004). We tried to minimize the grinding time to avoid the deformation of the crystal structure, the ion exchange and the water absorption from atmosphere. The powdered sample was homogenized in spectrophotometric grade KBr (1:20) in an agate mortar and was pressed 3mm pellets with a hand press. The infrared spectra was acquired using Perkin-Elmer system 2000 FTIR spectrophotometer with helium-neon laser as the source reference, at a resolution of 4 cm⁻¹. The spectra were taken in transmission mode in the region 400-4000 cm⁻¹. The room temperature was 27°C during the experiment.

Raman spectrum is recorded using a Perkin-Elmer System 2000 FT-Raman spectrometer. For Raman microscopy a 50x objective was used and the spectra were excited by the 633 nm line of a He-Ne laser operating at 8 mW at the sample. The excitation laser for the FT-Raman spectra was a Nd:YAG laser of 1064nm wavelength, which could be operated at powers up to 500mW, but 150-250 mW for the high-pressure phases to avoid overheating the samples. Depending on fluorescence of the sample and acquisition times were between 120 and 180s. Slit widths were near 2 cm⁻¹.

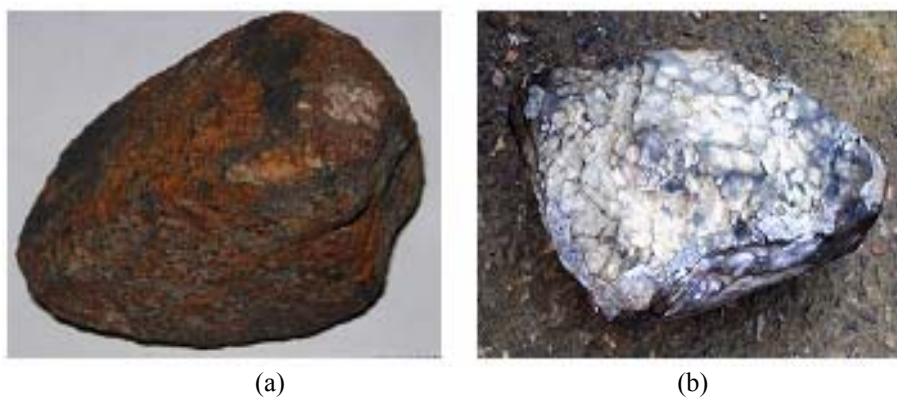


Figure 1: The photograph of the studied meteorite samples. (a) Dergaon H5 chondrite (b) Mahadevpur H4/5 chondrite.

3. Results

The elemental composition of Dergaon and Mahadevpur chondrite by X-ray fluorescence (XRF) using the Dhajala (H3) meteorite as a standard. The classification, petrological and chemical characteristics of the Dergaon has been reported by Shukla et al 2005 (Shukla et al 2005). The elemental composition of

Mahadevpur is compared with standard literature of Mason (1962) and Dergaon H5 chondrite which is listed in Table1. The elements of Mahadevpur are well agreement with the Mason (1962) and Dergaon results. The elemental ratio is compared with results of Aderson (2007) and Dergaon (Table 2). Olivine is the most abundant mineral in chondrites, followed by hypersthene, feldspar, nickel-iron, troilite and diopside

with minor apatite, chromite and ilmenite. The composition of the olivine varies widely, from 0 to 30 wt% Fe₂SiO₄ (Fa) (Mason 1962; Anderson 2007). Generally chondrites are distinguished by Mg/Si ratios. The Mg/Si ratio of Mahadevpur is indicative to the

type-H (Table 2). The olivine compositions of the two meteorites are presented in Table 3. The mineralogical phases of olivine in Mahadevpur meteorite is: olivine (Fo_{80.8} Fa_{19.3}), orthopyroxene (En₈₁ Fs₁₇ Wo₁), and clinopyroxene (En₅₈ Fs₈ Wo₃₅).

Table 1: Major elements observed in Dergaon and Mahadevpur meteorite. The elements of the studied meteorites are compared with the data obtain by Mason (1962) for H chondrite.

Sample	Element (wt%)											
	Si	Mg	Ca	Al	Fe	Ni	Co	Cr	K	P	Na	Ti
H chondrite *	17.08	14.10	1.26	1.22	27.81	1.64	0.09	0.29	0.08	0.15	0.64	0.06
Dergaon	17.30	14.26	1.19	1.20	27.73	1.75	--	0.03	0.067	0.15	0.670	0.04
Mahadevpur	16.90	14.10	1.19	1.32	28.40	1.67	0.07	0.20	0.075	0.12	0.052	0.04

Table 2: Comparison of elemental ratio of Dergaon, and Mahadevpur with the data of Aderson (2007) for a standard H chondrite.

Sample	Elemental ratio (wt%)			
	Al/Si	Mg/Si	Ca/Al	Cr/Mg
H chondrite (standard) *	0.063	0.800	1.110	0.025
Dergaon	0.069	0.824	0.992	0.002
Mahadevpur	0.078	0.834	0.084	0.014

Table 3: Olivine composition of Dergaon and Mahadevpur meteorite.

Oxides (wt%)	Dergaon-1	Dergaon-2	Dergaon-3	Mahadevpur-1	Mahadevpur-2	Mahadevpur-3
SiO ₂	39.030	38.900	39.297	37.500	36.300	36.230
Cr ₂ O ₃	0.047	0.047	--	0.026	0.026	0.026
FeO	18.400	18.734	18.999	18.650	18.650	18.470
MnO	0.455	0.475	0.465	0.100	--	--
MgO	41.372	41.512	41.774	43.600	44.320	44.800
NiO	--	--	0.063	0.070	0.010	--
CaO	0.294	--	0.261	--	0.150	--
Total	99.568	99.668	100.859	99.946	99.456	99.526

The silicates in primitive meteorites carry important information about cosmic silicates and their modification in the solar system. Strong emission and absorption features found around 9.7µm and 18 µm, produced by Si-O stretching and O-Si-O bending modes, respectively. The 18 µm band is additionally broadened due to the coupling of the bending mode to the metal-oxygen stretching vibration located in this spectral region.

The position of the Si-O stretching vibration depends on the level of SiO₄ polymerization. Generally, the spectrum can be divided into three main spectral regions. The bands between 1100 and 800 cm⁻¹ correspond to different asymmetric and symmetric stretching vibrations of the SiO₄ tetrahedra. The various features between 700 and 470 cm⁻¹ are caused by bending vibrations of the SiO₄ tetrahedra.

The far-infrared bands in the low-frequency region beyond 470 cm⁻¹ can be attributed to translational motions of the metal cations within the oxygen cage and complex translations involving metal and Si atoms.

The comparison of olivine group (Gadsden 1975) with Dergaon and Mahadevpur meteorite is presented in the Table 2. Generally free SiO₄ ion has exhibit four fundamental vibrational modes: a symmetric stretch (ν₁); a symmetric bend (ν₂); an asymmetric stretch (ν₃) and an asymmetric bend (ν₄). The infrared spectra of Dergaon and Mahadevpur meteorite in the 10μm and 20μm region are shown in the Figure 2. The strong bands in the 10μm (800-1150cm⁻¹) region is identified as Si-O stretching and the bands present in the 20μm (400-700cm⁻¹) region is assigned as Si-O-Si bending vibrations. The decreasing intensities in the Si-O stretching and Si-O-Si bending region are observed at 1053, 1012, 935, 920, and 504 cm⁻¹ and 1059, 1002, 944, 927, and 506 cm⁻¹ for Dergaon and Mahadevpur meteorite respectively, which are identical to the bands of fayalite (Fe₂SiO₄), the bands found at 407, 467, 506, 601, 839, 988 and 1002 cm⁻¹ in Mahadevpur infrared spectra and 467, 504, and 1012 cm⁻¹ in Dergaon infrared spectra are identical to the bands of forsterite (Mg₂SiO₄) and the infrared bands 410, 506, 537, 694, 725, 927, 973, 1059, 1121 cm⁻¹ and 504, 537, 724, 920, 976, 1012, 1053, 1122 cm⁻¹ observed at Mahadevpur and Dergaon infrared spectra respectively are identical to the bands of enstatite (Mg₂SiO₃) (Gadsden1975). The band found at 506.0 cm⁻¹ can be interpreted as Si-O and Mg-O vibrational modes in enstatite (MgSiO₃) with slight shifts in the matrix (Nakamoto 1978). The petrologic type-5 chondrites have two strong peaks at 973 cm⁻¹ and 535 cm⁻¹ which may be related to Fe-O and Mg-O stretching modes (Nyquist et al 1971). The existence of these two peaks is found in Mahadevpur infrared spectra in weak and medium intensities.

The Figure 2 displaying clear Raman lines attribute to olivine in the meteorites. Generally olivine has 81 numbers of optic modes, out of which 36 numbers are Raman-active (Chopelas 1991; Hofmeister 1987). The Raman spectra (Figure 2) are divided into three regions as: below 400 cm⁻¹; 400– 800 cm⁻¹ (20μm); and 800– 1100 cm⁻¹(10μm). It may be noted that 20μm Raman bands are relatively weak as compare to their infrared counterparts. The peaks between 800 and 1100 cm⁻¹ are attributed to SiO₄ internal stretching vibrational modes; the dominant feature in this region is a doublet with

peaks near 818 and 852 cm⁻¹. The relative heights of these peaks are a function of crystal orientation (Ishii 1978). These peaks result from coupled symmetric (ν₁) and asymmetric (ν₃) vibrations of SiO₄ tetrahedra (Piriou and McMillan 1983; Chopelas 1991; Hofmeister 1987; Paques-Ledent and Tarte 1973; Lam et al 1990). The peaks in the 400–800 cm⁻¹ region are the SiO₄ internal bending vibrational mode.

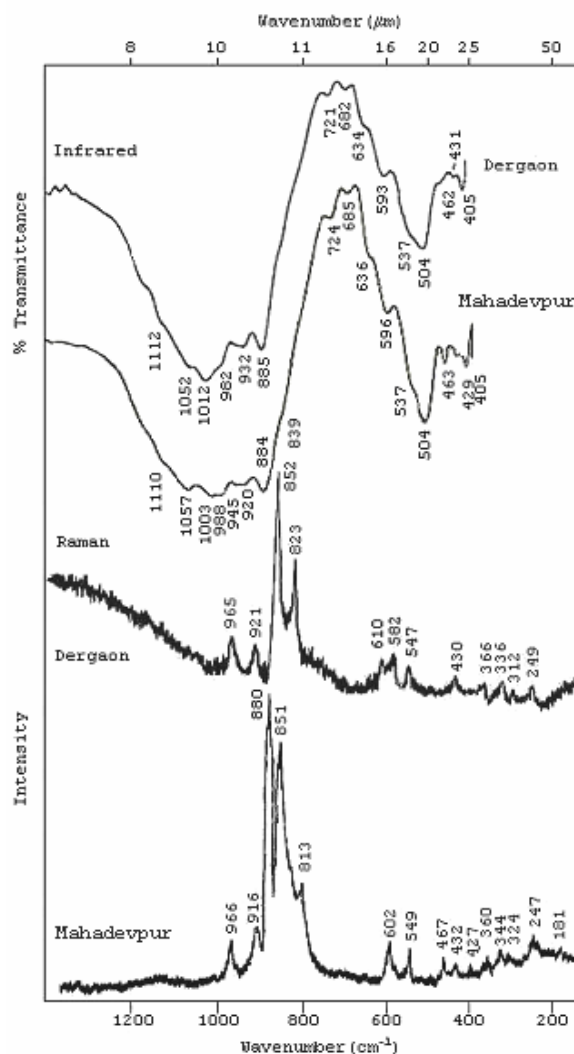


Figure 2: Infrared and Raman spectra of Dergaon and Mahadevpur meteorite in 10μm (800-1150cm⁻¹), 20μm (400-700cm⁻¹) and below 400 cm⁻¹ region.

The peaks below 400 cm^{-1} are mostly contributed by lattice modes: rotations and translations of SiO_4 units and translations of octahedral cations in the crystal lattice (Chopelas 1991). These are weaker peaks, not often resolved in multi-phase spectra so only the doublet in the 800–1100 cm^{-1} region is used in the calibration. In the studied meteorite samples, weak olivine bands are observed at 916-921 and 965-966 cm^{-1} . The other bands at 249, 312-324, 336-344, 366 and 602-610, cm^{-1} correspond to pyroxene.

In the infrared spectrum the Si-O asymmetric stretching vibration (TO2-T2O5) is observed in between the peaks 1112-1003 cm^{-1} . In between the peak position 920-988 cm^{-1} and 885-884 cm^{-1} the meteorites exhibits Si-O asymmetric vibration (TO3) and (T2O7--TO4) respectively. In the bending vibration region, the

symmetrical bending vibration of O-Si(Al)-O is observed at the peak position 685-682 cm^{-1} . Another peak is observed at 463-462 cm^{-1} which is due to Si-O-Si bending vibration. In the Raman spectrum strong Si-O symmetric stretching bands appear at 813-823 and at 852-852 cm^{-1} , and a medium-intensity antisymmetric Si-O stretching band appears at 965-966 cm^{-1} due to forsterite (Fo). The peaks of the 813-852 cm^{-1} doublet is assigned to a mixed contribution of the symmetric (ν_1) and asymmetric (ν_3) stretching modes of Si-O_{nb} bonds (Non-Bridge Oxygen, NBO) in SiO_4 tetrahedra (Lam et al 1990). This peak position may shift upwards as the values of F_o increase (Chopelas1991). The value $F_o = \text{Mg}/(\text{Mg}+\text{Fe})$ of an olivine can be determined from the XRF results. The peak 811-823 cm^{-1} has a higher contribution of ν_3 (asymmetric mode) than the 852 cm^{-1} peak. This mode is more easily affected by variations

Table 4: Comparative spectral position of IR and RS in 10 μm and 20 μm region indicates fayalite, forsterite and enstatite in Dergaon and Mahadevpur meteorite. The infrared data of Gadsden (1975) and Raman data of Griffith (1975), White (1975) is taken as standard for fayalite, forsterite and enstatite spectral position analysis.

Fayalite (Fe_2SiO_4)		Forsterite (Mg_2SiO_4)		Enstatite (Mg_2SiO_3)		Dergaon		Mahadevpur	
IR (cm^{-1})	Raman (cm^{-1})	IR (cm^{-1})	Raman (cm^{-1})	IR (cm^{-1})	Raman (cm^{-1})	IR (cm^{-1})	Raman (cm^{-1})	IR (cm^{-1})	Raman (cm^{-1})
--	--	--	--	1128-04	--	1112	--	1110	--
1060	--	--	--	1070-56	--	1052	--	1057	--
--	--	1000-990	--	1020-10	--	1012	--	1003	--
--	--	--	964	--	--	--	--	--	--
965-55	--	965-58	--	980-70	--	982	963	988	966
950-47	--	--	--	942-28	938	932	--	945	--
920-15	--	--	919	908-02	--	--	919	920	916
880-73	--	890	--	877-52	--	885	--	884	880
--	838	840	855	--	863	--	852	839	852
828	815	--	824	--	758	--	818	--	813
--	--	--	--	728-19	715	721	--	724	--
--	--	--	--	695-93	681	682	--	685	--
--	608	620-02	608	--	650	634	610	636	602
--	--	--	589	--	--	593	582	596	--
566-58	550	545	--	--	545	--	--	--	--
--	--	524	544	535	523	537	547	537	549
510-02	--	512-01	--	505	--	504	--	504	--
482-80	--	473-63	--	460	--	462	--	463	467
--	--	430-28	434	--	--	431	430	429	432
--	--	409-05	--	410	--	409	--	405	427
--	--	--	--	397	--	366	--	360	--
380	--	374	--	375	--	336	--	344	--
--	--	317	--	340	--	312	--	324	--
--	--	--	234	249	--	247	--	--	--
--	--	--	--	--	--	--	181	--	--

in the Si-O_{nb} force constant, and is also affected by the breakdown of SiO₄ during polymerization (Lam et al 1990). The medium intensity peak in the region 547-610 cm⁻¹ occurs due to the bridging oxygen (BO). The medium intensity peak at 916-921 cm⁻¹ is indicative of the polymerization. The relative peak height is a function of crystal orientation (Ishii 1978). Therefore, the systematic variations of the high-frequency Si-O bands are attributed to decreased distortion of SiO₄ tetrahedra.

4. Discussions

This is the first spectroscopic characterization of Mahadevpur H4/5 chondrite. The olivine group is identified from the compositional analysis, and is identical to the infrared and Raman results. The olivine composition of both meteorites is almost similar to each other. The strong IR and Raman absorption bands are due to olivine. It may be noted that in 20µm region Raman bands are relatively weak as compare to their infrared counterparts which is due to pyroxene.

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