Significant Differences between H.T.-Elec. Conductivity of Fe-bearing Synthetic and 'Natural' Olivine Rocks

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INTRODUCTION AND AIM

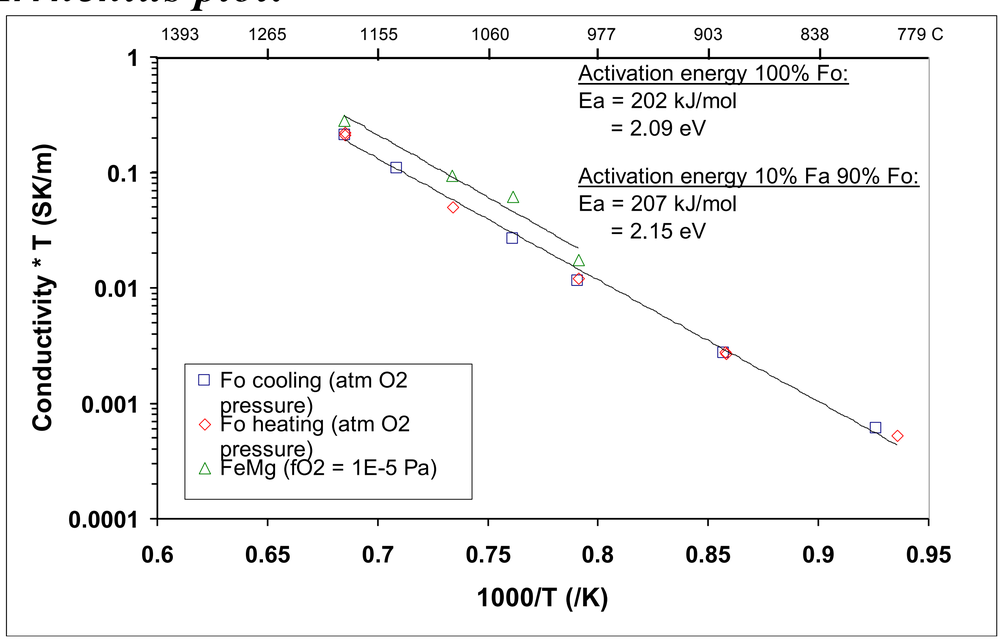
The electrical properties of olivine $(Mg\text{-}Fe)_2SiO_4$, the most abundant mineral in Earth's mantle, are beneficial to scientists studying deformation processes involving diffuse mass transfer, and deep geo-thermometry inferred from magneto-telluric methods. Sol-gel synthesis of pure, fine grained, olivine material, as pure forsterite (Fo) and as Fo_{90} with a 10% fayalite (Fa) composition allows us to further investigate the effects of controlled oxygen fugacity (using a CO/CO_2 gas mix) on conductivity. Use of impedance spectroscopy (IS), with an alternating current, also allows us to distinguish frequency dependent conductivities that are most likely coupled to the grain interior, grain boundary and any electrode effect (ion to electron charge transfer). Controlled temperature and oxygen fugacity experiments enable us to identify the charge carriers and to find the corresponding activation energy.

APPARATUS AND EXPERIMENTS

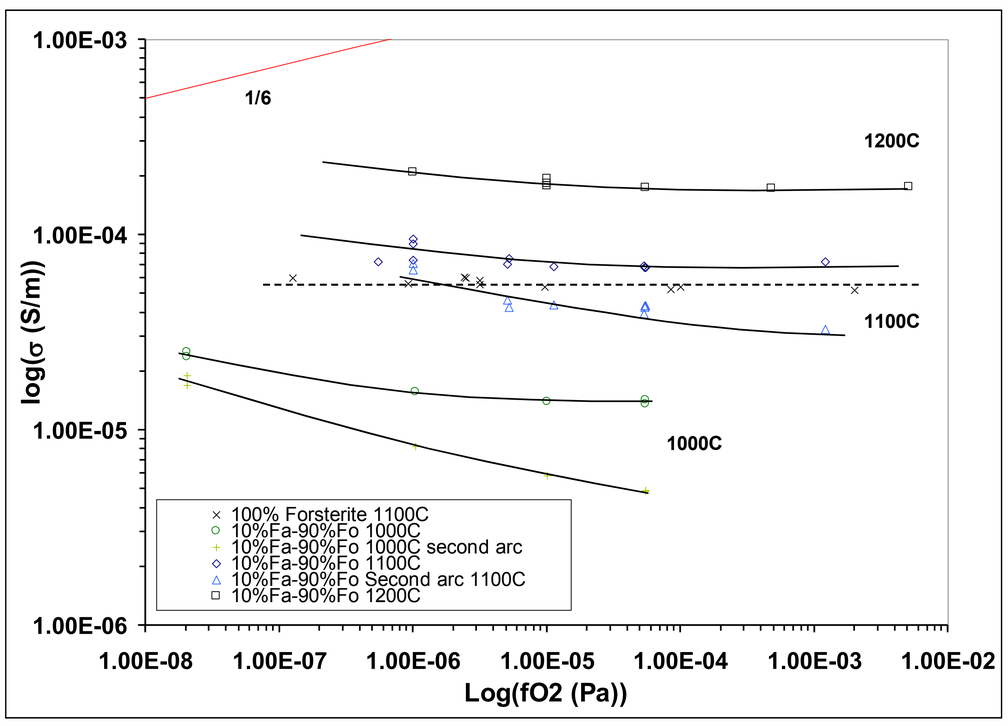
Apparatus used:	Solartron 1260A impedance analyser coupled with a 1296A dielectric interface. Platinum electrodes on sample disc in tube-furnace at 1 atm pressure.
Control of:	Temperature, oxygen fugacity, Si activity because of known/controlled sample compositions.
Monitoring of:	Temperature or oxygen fugacity and electrical impedance (reactance and resistance of sample)
Materials:	Synthetic samples of pure Mg forsterite and forsterite with 10% fayalite. Grain size: 1 micron
Experiments:	Constant oxygen fugacity / constant temperature experiments for each sample.

RESULTS - I

Arrhenius plot:

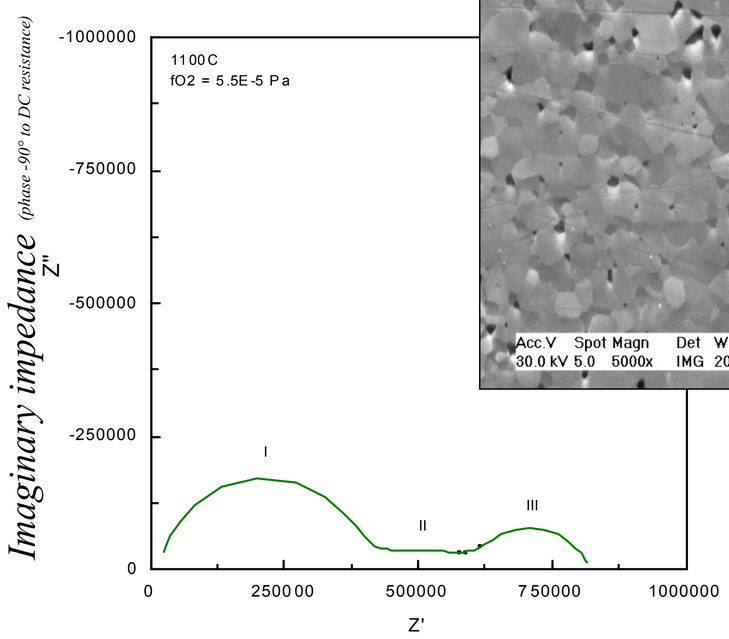


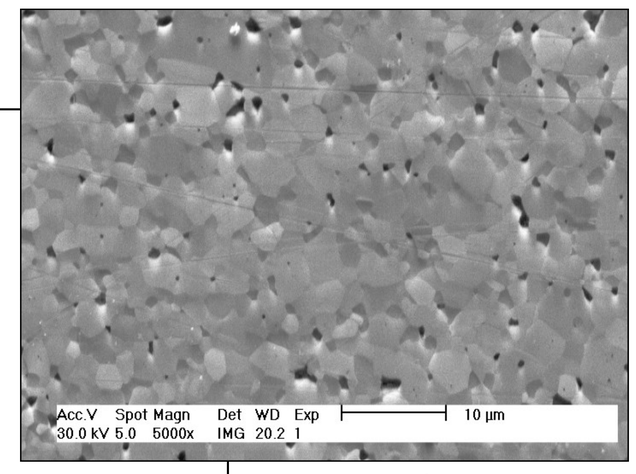
Oxygen fugacity (fO_2) plot:
(entire range is within the olivine stability field)



RESULTS - II

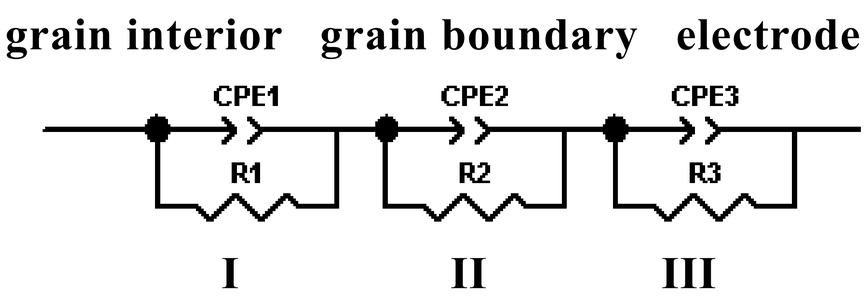
Impedance plot with model fit for 10% Fa - 90% Fo:





Fo microstructure

EQUIVALENT CIRCUITS MODEL



CPE: Constant Phase Element (like a capacitor)
R: Resistor

INTERPRETATION

- Iron free or iron bearing synthetic olivine both yield the same slope and activation energy. This means the charge carriers are the same and probably Mg or Fe interstitials/vacancies and/or electrons.
- fO_2 plot shows no or negative fO_2 dependence, as opposed to the +1/6 slope obtained for 'natural' olivine, Fo_{90}. This indicates no electron-hole formation on Fe^{2+} (forming Fe^{3+}), which some authors invoke to explain the +1/6 slope dependence.
- Three impedance arcs show three conduction processes. With increasing fO_2, grain boundary resistance increases. Could be explained by oxygen interstitial blocking at grain boundaries.

CONCLUSIONS / FURTHER RESEARCH

- 'Natural' olivine exhibits different behaviour to synthetic iron-bearing olivine. Numerous chemical reactions involving fluids may take place before olivine gets to the Earth's surface, changing its composition. The effects of the altered composition of 'natural' olivine can be seen by this +1/6 slope. Laboratory experiments require control of all variables save one to fully understand the process of interest that is going on. Hence the choice of using synthetically grown olivine.
- Further experimentation on synthetic olivine will involve:
  1. Grain size variation in order to better understand the second arc
  2. Oxidation of iron-bearing synthetic olivine to distinguish the true role of electron charge carriers.
  3. Grain-scale 4-point impedance measurements, to separate intra- and inter-crystalline effects, seen in the bulk impedance spectra.