FUSING LUNAR MATERIALS WITH MICROWAVE ENERGY. PART I: STUDIES OF DOPING MEDIA;

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Ultra-high-frequency (UHF) microwaves of 2.45 GHz are effective for melting ilmenite-doped terrestrial materials[1]. Microwaves of this energy couple effectively with defects, impurities, and H-O bonds, but their ability to couple with ilmenite is not well characterized. To better understand the coupling process, we conducted a series of experiments using both an ilmenite-doped terrestrial basalt and titania-doped hematite.

The ilmenite-rich terrestrial rock used as a doping material was Ward's Natural Science "Norwegian ilmenite," consisting of $\sim$75% ilmenite, 20% plagioclase, and minor amounts of other minerals. This predominantly ilmenite-plagioclase mixture was selected to approximate an ilmenite-enriched lunar feedstock. Terrestrial basalt samples that would not melt in pure crushed form (-70 mesh) did melt when in a mixture containing 10% of the ilmenite-rich rock, and attained 1300°C within 40 minutes of exposure to 700 watts of 2.45 GHz microwave energy. This treatment was sufficient to melt the sample but not to exceed liquidus temperature; olivine phenocrysts from the crushed basalt did not melt and accumulated at the base of the alumina crucible (Figure 1). Of particular importance is the observation that optimum coupling at a temperature of 1300°C occurred only briefly, and temperature quickly dropped thereafter to a "plateau" of about 1100°C even though full power was maintained (Figure 2). This phenomenon indicates that phases "transparent" to mirowave energy (i.e., high-resistivity crystals that are distinctly non-coupling) have begun to form. Petrographic examination of the air-quenched experimental charge indicates extensive chain-type olivine growths that are optically continuous with the settled olivine phenocrysts, and we suspect that these chain-type olivines account for most if not all of the transparency to microwave energy under prolonged microwave energy input.

Although the mechanism for microwave coupling with ilmenite is not presently understood, the effects of defect coupling can be observed in mixtures of titania with α Fe_2O_3 (hematite). Pure Fe_2O_3 did not couple with microwave radiation, but by adding just 0.1 atom % TiO_2, the sample reached red heat in 20 minutes. It was observed that the time to red heat decreases with increased TiO_2 content (Table 1).

The coupling of TiO_2-doped hematite with microwave radiation is due to the defect (vacancy) structure that results from introducing TiO_2 into α Fe_2O_3 [2]. If Ti^{4+} is added to hematite, an increased fraction of Fe^{3+} is reduced to the Fe^{2+} state. The conductivity of hematite is substantially increased by TiO_2-doping (Figure 3), and it begins to behave as an n-type semiconductor. The number of newly created Fe^{2+} ions is equal to the amount of Ti^{4+} introduced, so the increase in conductivity is determined by the concentration of TiO_2.

N-type semiconductor electron mobility accounts for the microwave coupling of TiO_2-doped hematite, but why does ilmenite couple? From calculations based on band gap [3], ilmenite may behave as a defect semiconductor. It is possible that the electron instability associated with this semiconductor behavior accounts for ilmenite's ability to couple with microwave energy.

Electrical studies of ilmenite are underway to test this hypothesis as part of a project to characterize the photoelectric behavior of ilmenite.

References: [1] Meek, T. T., D. T. Vaniman, F. H. Cocks, and R. A. Wright, "Microwave Processing of Lunar Materials: Potential Applications." In Lunar Bases and Space Activities in the 21st Century, NASA (in press).
[2] Lark-Horovitz, K. (1949), "Conductivity in Semiconductors," Electrical Engineering 68, 1047-1056.
[3] Loferski, J. (1956), "Theoretical Considerations Governing the Choice of the Optimum Semiconductor for Photovoltaic Solar Energy Conversion," Jour. Appl. Phys. 27, 777-784.

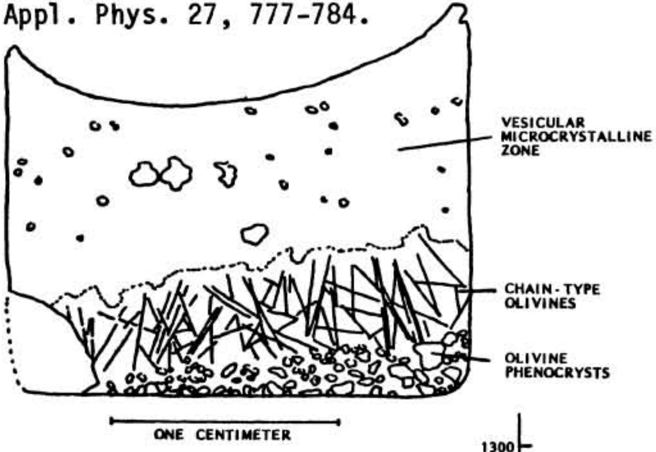

Figure 1: Thin section of experimental charge of terrestrial basalt and ilmenite-rich rock [1]. Sample partially melted at 2.45 GHz, but olivine phenocrysts settled out. Chain-type olivines grew up from phenocrysts.

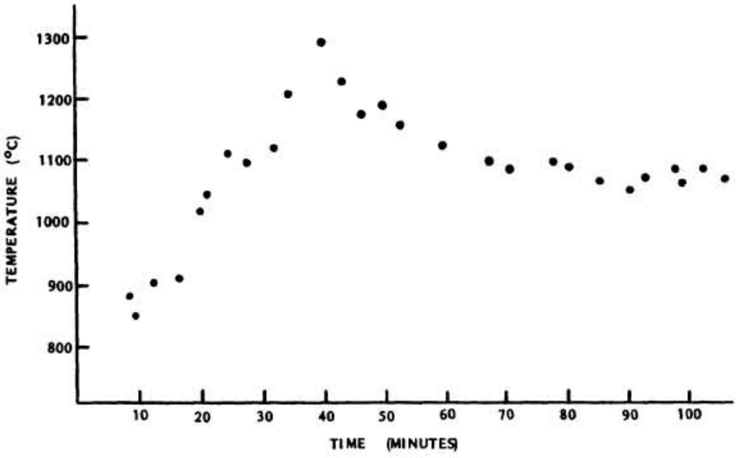

Figure 2: Temperature-time plot for the experiment shown in Figure 1.

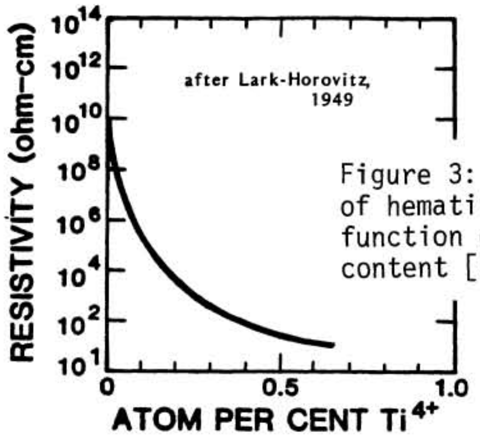

Figure 3: Conductivity of hematite as a function of TiO_2 content [2].

Atom % TiO_2	Time to Red Heat(min.)
0.0	no coupling
0.9	8
0.3	17
0.1	20

Table I