DIELECTRIC PARAMETERS MEASUREMENT OF ROCK AND ORE SAMPLES

Sixin Liu and Junjun Wu

College of Geo-exploration Science & Technology, Jilin University, Changchun, China, 130026

1. INTRODUCTION

The dielectric parameters measurement is very important for not only practical applications such as geophysical prospecting, remote sensing, and material study, but also in theory. Borehole radar detection is a geophysical tool based on dielectric difference of subsurface materials. In order to investigate the feasibility of borehole radar to detect the metal ore-body, we measure the dielectric parameters of metal ore and host rock.

Borehole radar, operated at tens to hundreds of MHz, detects the reflection and refraction of electromagnetic wave in the formation. Dielectric constant determines the wave velocity and reflection coefficient on a subsurface interface. We collected nickel-cupper ore samples of different grade and its host rock samples including mixed granite, mictite, lightly alterative hornblende pyroxenite in a metal mine in China. These samples are manufactured into smooth sheets, and measured by our open-ended coaxial probe.

2. METHODOLOGY

There are many methods for dielectric measurement, such as capacitance method, coaxial transmission/reflection method, etc [1, 2]. The former is mainly for DC measurement, and the later is difficult for samples making. Therefore, we choose open-ended coaxial method as shown in Fig. 1, for which the sample making is relatively easy. The probe is an open-ended coaxial line with flange touching the sample as close as possible, and the sample is backed by a metal ground. The probe is connected to a vector analyzer which can measure the reflection coefficient which is reflected to the material dielectric parameters. The electromagnetic modeling is used to calculate the reflection coefficient. An optimization procedure is used to adjust the dielectric parameter to match the calculated coefficient and the measured one until the error is small enough. Quasi-static electromagnetic modeling [3] is used to calculate the reflection coefficient here.

We assume there is only main TEM mode inside the coaxial probe, omitting harmonic term $e^{j\omega t}$, the electric and the magnetic fields inside the probe can be expressed as:

$$E_{ri} = \frac{A}{r}[\exp(-jk_i z) + \Gamma \exp(jk_i z)], \tag{1}$$

$$H_{\varphi i} = \frac{A}{\eta_r}[\exp(-jk_i z) - \Gamma \exp(jk_i z)], \tag{2}$$

Where $k_1 = \omega\sqrt{\mu_0\varepsilon_0\mu_1\varepsilon_1}$, $\eta_1 = \sqrt{\mu_0\mu_1/(\varepsilon_0\varepsilon_1)}$, Γ is the reflection coefficient, A is the amplitude of the electric field on the probe end surface.

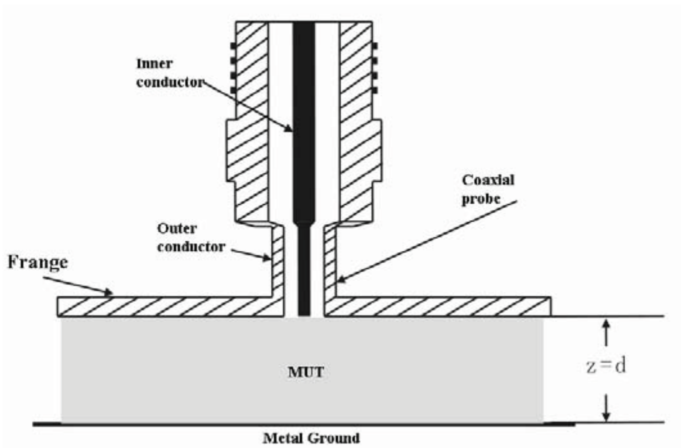

Fig. 1 Open-ended coaxial probe

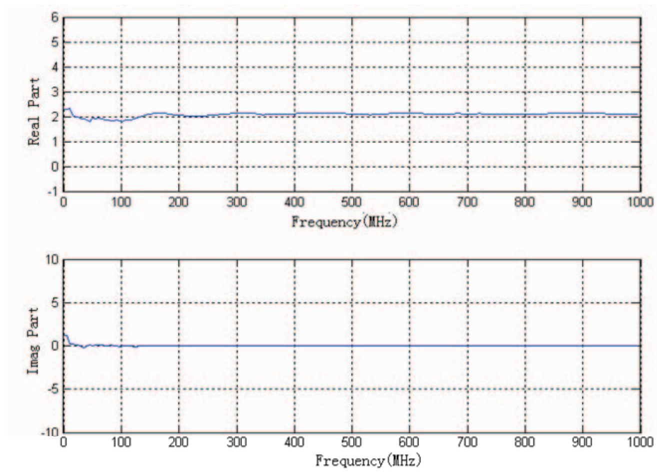

Fig. 2 Measured dielectric constant for TPFE

The electromagnetic fields inside the material under test can be expressed as an integral formula of all plane waves including high modes in the spectrum domain.

$$E_{rs} = \int_0^\infty B(k_c)[\exp(-\gamma_z) + \Gamma_b(k_c)\exp(\gamma_z)]J_1(k_c r)k_c dk_c, \tag{3}$$

$$H_{rs} = \int_0^\infty B(k_c)Y(k_c)[\exp(-\gamma_z) - \Gamma_b(k_c)\exp(\gamma_z)]J_1(k_c r)k_c dk_c, \tag{4}$$

where $\gamma = \sqrt{k_c^2 - k_s^2}$ and $\mathrm{Re}(\gamma) \ge 0$, $k_s = \omega \cdot \sqrt{\mu_0\varepsilon_0\mu_s\varepsilon_s}$, $Y(k_c) = j\omega\varepsilon_0\varepsilon_s/\gamma$, $\Gamma_b(k_c) = -\exp(-2\gamma d)$, $J_1(x)$ is the first kind Bessel function of first order, $B(k_c)$ is the field amplitudes in the spectrum domain, k_c is the continuous eigenvalue.

According to the boundary condition at $z = 0$, where transverse components of the electric and magnetic field are continuous,

$$\int_0^\infty B(k_c)\left[1+\Gamma_b(k_c)\right]J_1(k_c r)k_c dk_c = \begin{cases} \dfrac{A(1+\Gamma)}{r} & a \le r \le b \\ 0 & r \le a, r \ge b \end{cases} \tag{5}$$

$$\int_0^\infty B(k_c)Y(k_c)\left[1-\Gamma_b(k_c)\right]J_1(k_c r)k_c dk_c = \frac{A(1-\Gamma)}{\eta_i r} \qquad a \le r \le b \tag{6}$$

Multiply $J_1\left(k_c'r\right)r$ on both side of (5), and take an integral $\int_0^\infty dr$:

$$\int_0^\infty \int_0^\infty B\left(k_c\right)\left[1+\Gamma_b\left(k_c\right)\right]J_1\left(k_c r\right)k_c dk_c \bullet J_1\left(k_c' r\right) r dr = \int_a^b \frac{A\left(1+\Gamma\right)}{r} \bullet J_1\left(k_c' r\right) r dr \tag{7}$$

After transforms and expansion, we get

$$\frac{1-\Gamma}{1+\Gamma} = \frac{\eta_1}{\ln(b/a)} \int_0^\infty \frac{\left[J_0\left(k_c a\right)-J_0\left(k_c b\right)\right]^2 \left[1+2\exp\left(-\sqrt{k_c^2-\omega^2\varepsilon_0\varepsilon_s\mu_0\mu_s}\bullet d\right)\right]\varepsilon_s i\omega\varepsilon_0}{\left[1-2\exp\left(-\sqrt{k_c^2-\omega^2\varepsilon_0\varepsilon_s\mu_0\mu_s}\bullet d\right)\right]k_c\sqrt{k_c^2-\omega^2\varepsilon_0\varepsilon_s\mu_0\mu_s}} dk_c \,. \tag{8}$$

Since other parameters are known, (8) is a nonlinear equation between ε_s and Γ. We can find the dielectric constant from this nonlinear equation.

We test the probe with TPFE which is a stable material [3] with dielectric constant of 2.1+j0.0004. The measured data is shown in Fig. 2. The maximum relative error is within 5%. The average relative error is within 2.2764% in the frequency between 1and 1000MHz.

3. MEASURED DATA AND ANALYSIS

We collected 64 samples in this nickel-cupper mine, including 25 mixed granite samples, 9 mictite samples, 13 lightly alterative hornblende pyroxenite sample, 8 middle grade nickel-cupper ore samples, and 9 high grade Nickel-cupper ore samples. The processed mixed granite sheet samples photo is shown in Fig. 3 together with measured results of 25 samples. It is found that the values are variable in a certain range; we take the average values for this rock.

The average values for these ore and rocks are illustrated in Fig. 4. We found high grade ore has highest values, then the values range from high to low are the light alterative bornblende pyroxenite, middle grade ore, mictite, mixed granite. Actually, the light alterative bornblende pyroxenite and the mictite are something between host rock and ore; they resulted from metamorphism and other geological process. Their dielectric characteristics are similar to the ore. The mixed granite is the only host rock which has distinguished lower values. These measured data show optimistic aspect for borehole detection for metal ore-body.

4. CONCLUSIONS

Open-end coaxial line method is used to measure the dielectric constant of metal ore and other surrounding rocks. The sheet samples are easy to manufacture in this method. We used quasi-static method to model the electromagnetic response for the probe. The method is validated by TPFE material measured. The high grade nickel-cupper ore shows higher values than other. The host rock mixed granite show lowest values. The difference between ore and host rock show that the physical difference exists and it is advantageous to for geophysical detection.

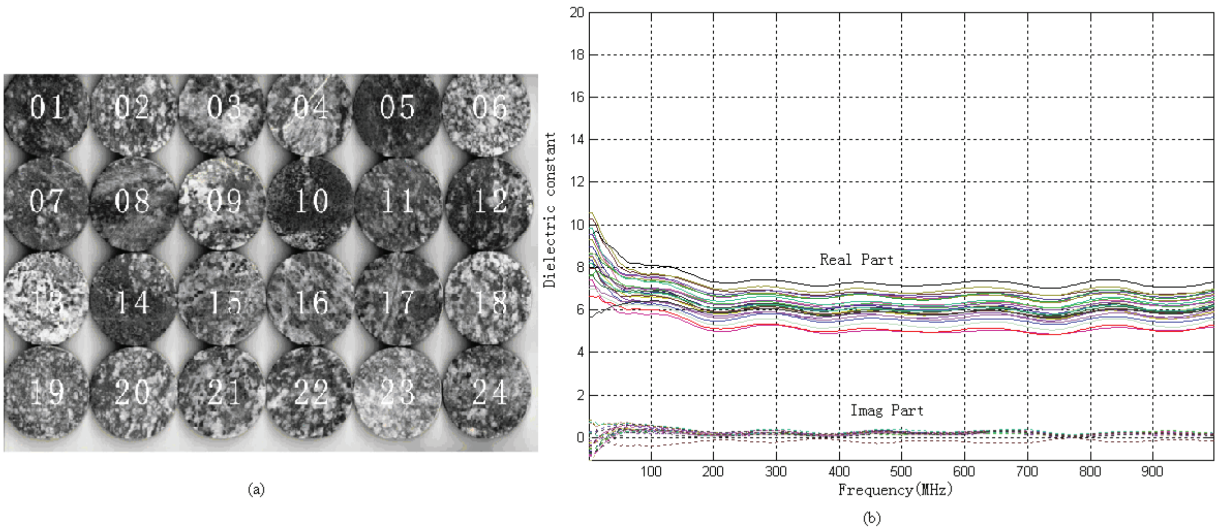

Fig. 3 Mixed granite photo (a) and measured results (b)

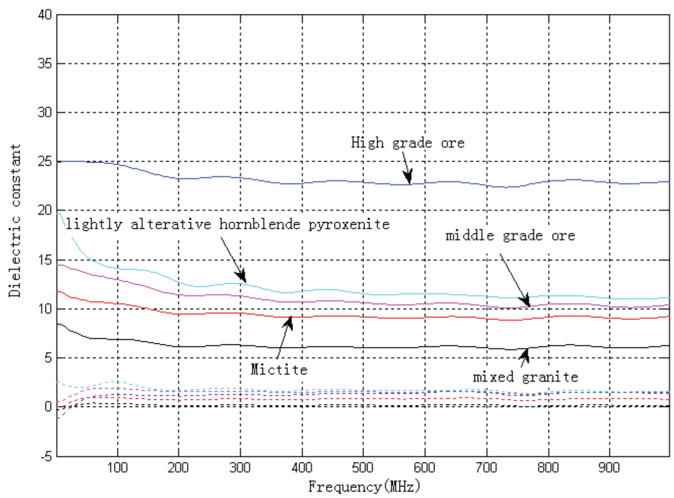

Fig. 4 Measured results of ores and rocks

5. ACKNOWLEDGEMENT

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6. REFERENCES

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