

Dynamic Test Method Based on Strong Electromagnetic Pulse for Electromagnetic Shielding Materials with Field-Induced Insulator-Conductor Phase Transition

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Abstract. In order to measure the pulse shielding performance of materials with the characteristic of field-induced insulator-conductor phase transition when materials are used for electromagnetic shielding, a dynamic test method was proposed based on a coaxial fixture. Experiment system was built by square pulse source, coaxial cable, coaxial fixture, attenuator, and oscilloscope and insulating components. S11 parameter of the test system was obtained, which suggested that the working frequency ranges from 300 KHz to 7.36 GHz. Insulating performance is good enough to avoid discharge between conductors when material samples is exposed in the strong electromagnetic pulse field up to 831 kV/m. This method is suitable for materials with annular shape, certain thickness and the characteristic of field-induced insulator-conductor phase transition to get their shielding performances of strong electromagnetic pulse.

1. Introduction

Several types of materials such as some nonlinear conductive particle-filled polymer composites and voltage-sensitive metal oxide films were found to be characteristic of field-induced insulator-conductor phase transition or high-to-low resistivity transformation, which was also called non-linear conductive switching effect in some other literatures. So these materials have expansive application potentiality in the field of electromagnetic shielding, integrated circuit [1], non-volatile resistive switching memories [2], and sensors and so on, becoming a hot issue of researches.

For examples, as early start in 1980s, S. H. Kwan and F. G. Shin investigated the electrical conduction of composites made from unsaturated polyester with silver powder and silver-coated glass spheres [3], which had found the resistance of composites changed sharply under certain voltage. Many homologous works [4-8] have been done till now such as that A. N. Aleshin. Manufactured nanocomposite thin films based on graphene (graphene oxide) nanoparticles and poly (9-vinylcarbazole), which occurred obvious high-to-low resistance switching under 0.2~0.4V voltage [9]. Researches on ZnO and VO₂ or their adulterant are more extensive. The paper [10] gave a review of VO₂ applications in field effect switches, optical detectors, nonlinear circuit components and solid-state sensors, also discussed the mechanisms of metal-insulator transitions. Similar investigation on ZnO and its adulterant can be seen from lots of papers such as [11-14].

However, most of these researches focus on the preparation and mechanism analysis of materials. Because the thickness of these composites and metal oxide films is limited in nanoscale or micrometer scale, a very little voltage can form strong electric field strength. So when materials tested, simple sandwich structure as electrode/material/electrode was adopted. Such as in [11], E.J.Yoo and J.H.Kim showed the volt-ampere characteristics of materials using the test system consisted of atomic force microscope (AFM), Cr pole and current amplifier to form a Cr/ZnO/Cr structure. This kind of method



can be deemed as static method, which generates high voltage electrostatic field applied on materials between two electrodes. Some researchers used four-probe measurement [15], which also belongs to static method. Two outside probes measure the current meanwhile two inside probes measure the voltage on the surface of materials, finally give the resistance or the volt-ampere characteristics.

Electromagnetic shielding materials with field-induced insulator-conductor phase transition turn into conductors immediately to reflect or shield the pulse when the external electromagnetic field exceeds a threshold value. At most of the time, they keep the phase of insulator to ensure the transmission or communication of useful signals. As we can see, the static method listed above is not suitable to measure the pulse shielding performance of materials when materials are used for electromagnetic shielding. So in this paper, a dynamic test method was proposed based on coaxial fixture and square-wave source equipment. Observing the change of output waveform of system, the process of insulator-conductor phase transition can be measured.

2. Dynamic Test Method and Experiment System

The dynamic test method puts the circular shape of material into the joint of coaxial fixture and then transmits transverse electromagnetic wave (TEM) simulated as actual far field plane wave onto materials. The measured shielding effectiveness and output waveforms would change greatly as the materials' phase changed from conductor to insulator or vice versa. As the rising edge of pulse source is sharp, wide frequency band is necessary to ensure the test precision. It is as smaller as possible for the diameter ratio of internal and external conduct of coaxial fixture to give strong enough electromagnetic field. Meanwhile, insulating design need to be considered in case of breakdown between coaxial conductors when the peak value of electromagnetic field is too high.

2.1. Design of Coaxial Fixture

The design of coaxial fixture is shown as in figure 1, which was composed of outside conductor (marked by 1 in figure 1) and inside conductor (marked by 2 in figures 1). The outside and inside conductors both concluded four components connected with each other through thread. Materials with annular shape (diameter less than 43mm) and certain thickness (1 mm~ 5 mm) should be placed in the middle of fixture. The insulating supports (marked by 3 in figure 1) were made by Teflon to isolate the conductors and had been grooved annularly to compensate discontinuous capacitance. The air inlet and outlet (marked by 4 in figure 1) were designed to inject and outflow the insulating gas. And the zones marked by 5 were all chamfered to avoid discharge at sharp points when strong electromagnetic pulse field was input in the coaxial fixture. According to equations (1) and (2) [16], the radius ratio of outside and inside conductors of coaxial is 13mm to 5.65mm, which has made the characteristic resistance as 50Ω matched and the theoretical working frequency range as DC to 10.23GHz.

$$f_c = \frac{2c_0}{\pi(R_1 + R_2)} \quad (1)$$

$$Z_0 = \frac{60}{\sqrt{\epsilon_r}} \ln \left(\frac{R_2}{R_1} \right) \quad (2)$$

where: f_c is the cut-off frequency, c_0 is the velocity of light, R_1 and R_2 indicate respectively the radii of inside and outside conductor, Z_0 means the characteristic resistance of coaxial and ϵ_r is the relative dielectric constant.

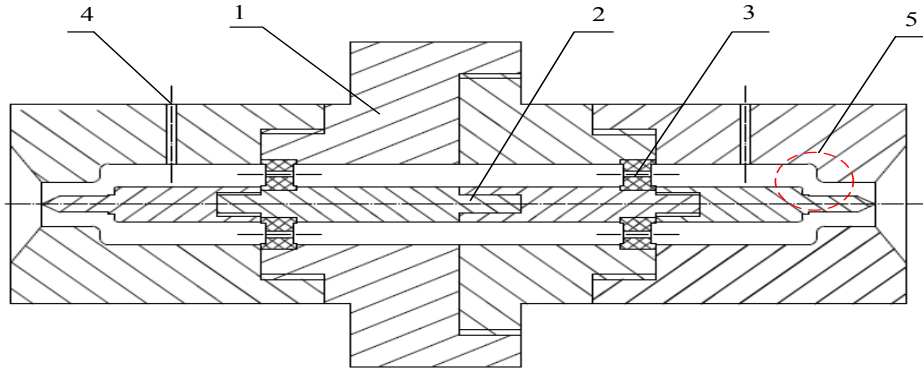


Figure 1. Design diagram of coaxial fixture

2.2. Building of Experiment System

As shown in figure 2, the experiment system was composed of square pulse source, coaxial cable, coaxial fixture, and attenuator (60dB), oscilloscope and insulating components. As pulse source, NOISEKEN INS-4040 was adopted, which can generate square wave pulse with pulse width changing from 10 ns, 50 ns, up to 1 μ s stepped by 50 ns and the peak value of strength up to 4kV. If other waveforms needed, corresponding pulse source could be used to replace the square pulse one. According to equation 3 [17], we can get that the maximum pulse field is 831 kV/m in the coaxial fixture. Material samples were put in the joint of fixture. Insulating gas (SF_6) was injected in the fixture to avoid discharge between conductors if strong electromagnetic pulse is put in.

$$E_{\max} = \frac{V_0}{R_1 \ln\left(\frac{R_2}{R_1}\right)} \quad (3)$$

where: V_0 is the input voltage of coaxial and also is output peak value of square pulse source, E_{\max} is the maximum pulse field in the coaxial fixture.



Figure 2. Photo of experiment system

3. Results and Analysis of Test Experiment

In order to avoid wave distortion, S11 parameters of system need meet requirements. So S11 curves are obtained through vector network analyser (VNA) in the frequency range of 300 kHz to 1.5GHz and 10MHz to 10.23 GHz respectively, as shown in figure 3 and 4. We can see that S11 of this coaxial fixture is less than -10 dB and the standing-wave ratio (SWR) is less than 2 in the frequency range of 300 kHz to 7.36 GHz, which is enough to ensure the well transmission performance of the fast rise-

time pulse in this paper. It was proved from the output waveforms of system with no material tested shown as in figure 5. The error between input and output waveforms came from the original pulse source and was acceptable.

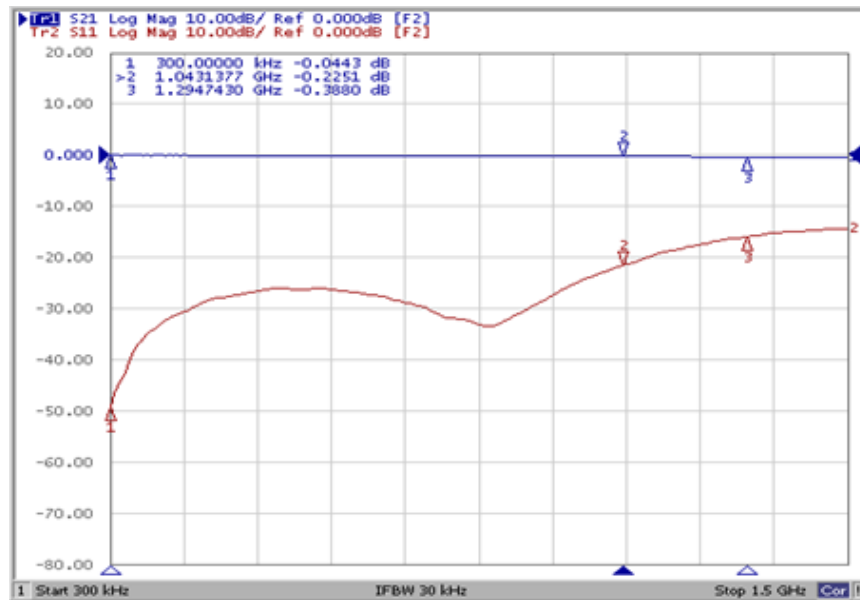


Figure 3. S11 of coaxial fixture (partially shown in 300 KHz ~1.5 GHz)

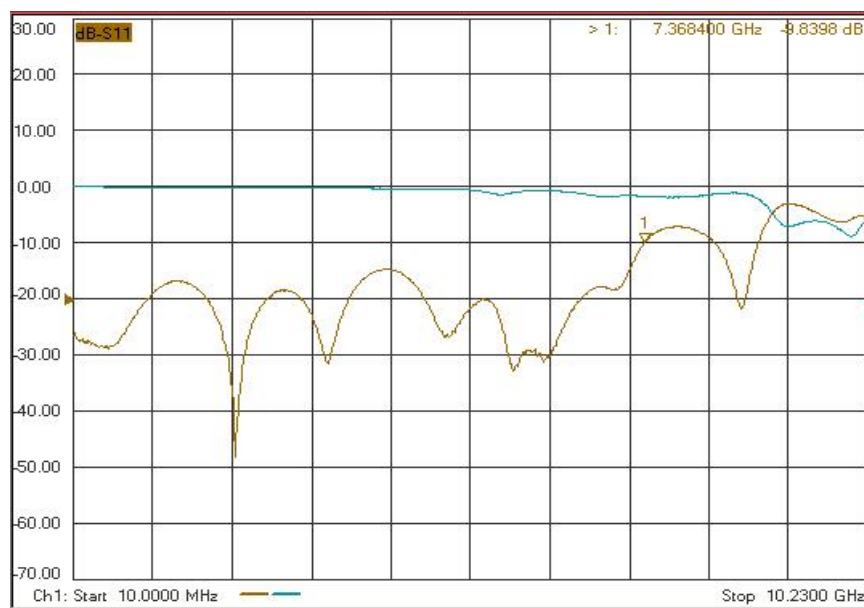


Figure 4. S11 of coaxial fixture (partially shown in 10 MHz ~10.23 GHz)

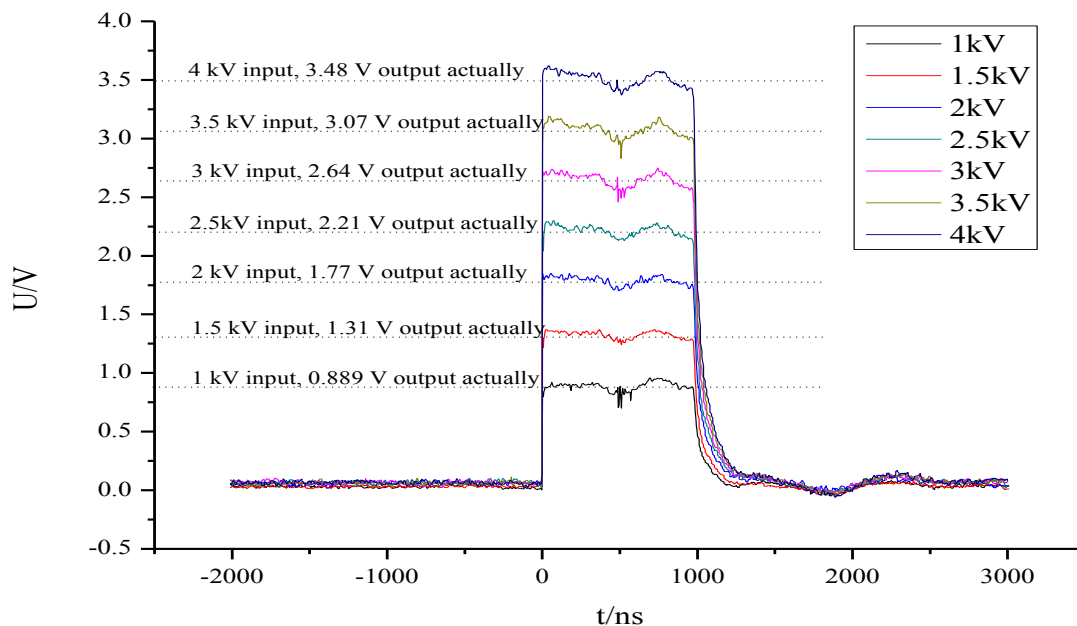


Figure 5. Output waveforms of system

To prove the validity of test method, we chose two annular shape materials for test. One is metal sheet, and the other is plastic sheet. When metal sheet was placed in the coaxial fixture, the output waveform displayed by oscilloscope had the value of zero. For contracting, when the plastic sheet was tested, the output waveforms were almost same with that in figure 5, which proved that this method could give an index to the insulator-conductor phase transition.

4. Conclusion

In conclusion, a dynamic test method based on coaxial fixture was proposed. The coaxial fixture was well designed to make the working frequency range from 300 KHz to 7.36 GHz and ensure the good insulating performance to avoid discharge between conductors when material samples were exposed in the strong electromagnetic pulse field up to 831 kV/m. It would be suitable for materials with annular shape and certain thickness to use this dynamic method when their electromagnetic pulse shielding performances need to be test.

5. References

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