Dielectric Relaxation Phenomenon in Ferroelectric Structures

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Dielectric Relaxation

$$J_{\mathrm{tot}} = J_{\mathrm{c}} + J_{\mathrm{d}} = \sigma E - i\omega\varepsilon' E = -i\omega\hat{\varepsilon} E$$

where

- σ is the conductivity of the medium;
- ε' is the real part of the permittivity.
- $\hat{\varepsilon}$ is the complex permittivity

The complex dielectric permittivity (ε) can be expressed as:

$$\varepsilon(\omega) = \varepsilon'(\omega) - i\varepsilon''(\omega)$$

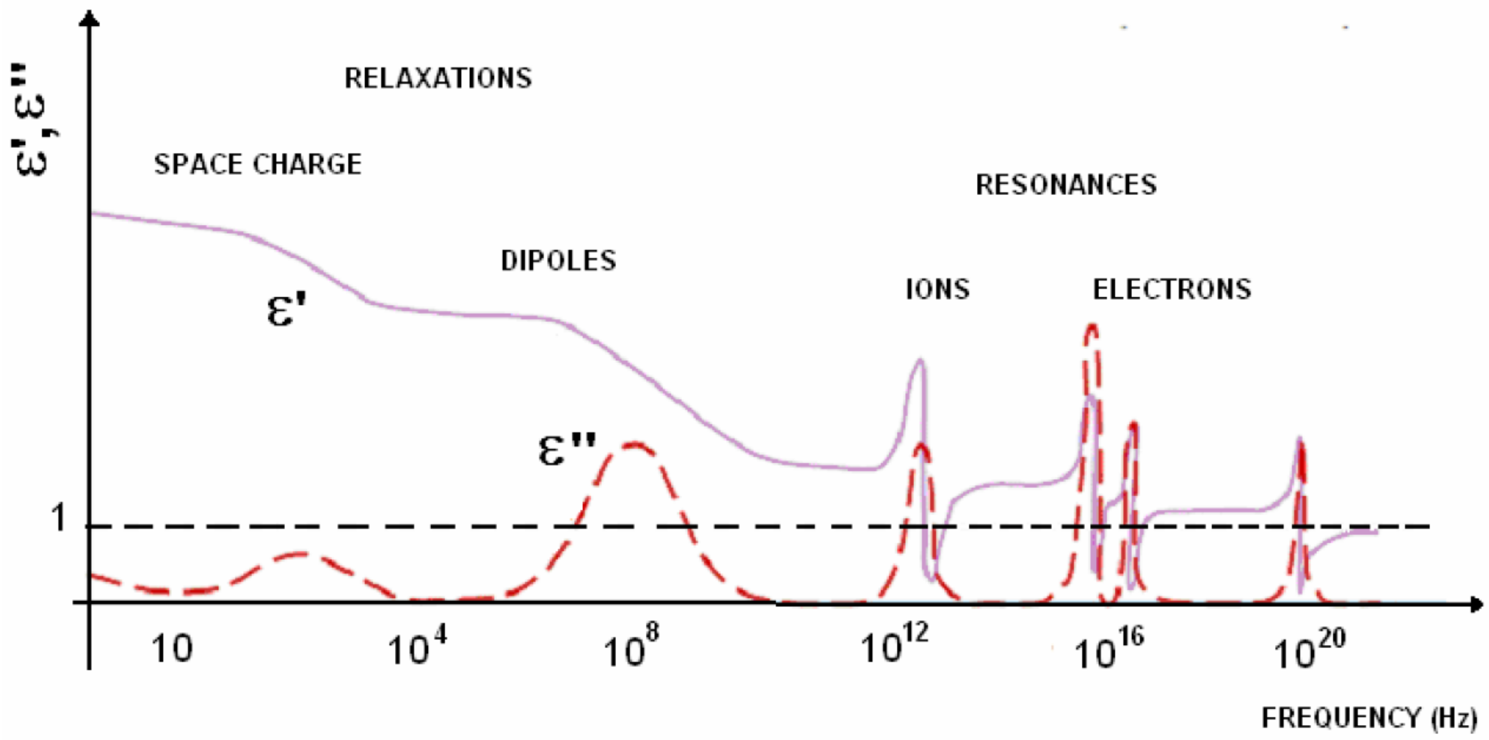

Fig. 1. General representation of relaxation and resonance types

Dielectric dispersion is the dependence of the permittivity of a dielectric material on the frequency of an applied electric field.

Different types of polarization cause several dispersion regions

Dielectric Relaxation

Dielectric relaxation refers to the relaxation response of a dielectric medium to an external, oscillating electric field.

The **Debye's model** (Debye, 1929), which considers not-interacting dipoles, proposes the following expression for the complex dielectric permittivity:

$$\hat{\varepsilon}(\omega) = \varepsilon_\infty + \frac{\Delta\varepsilon}{1 + i\omega\tau} \qquad \varepsilon' = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + \omega^2\tau^2} \qquad \varepsilon'' = \frac{(\varepsilon_s - \varepsilon_\infty)\omega\tau}{1 + \omega^2\tau^2}$$

where ε_∞ is the permittivity at the high frequency limit

$\Delta\varepsilon = \varepsilon_S - \varepsilon_\infty$

ε_S : the static, low frequency permittivity

τ : the characteristic relaxation time of the medium.

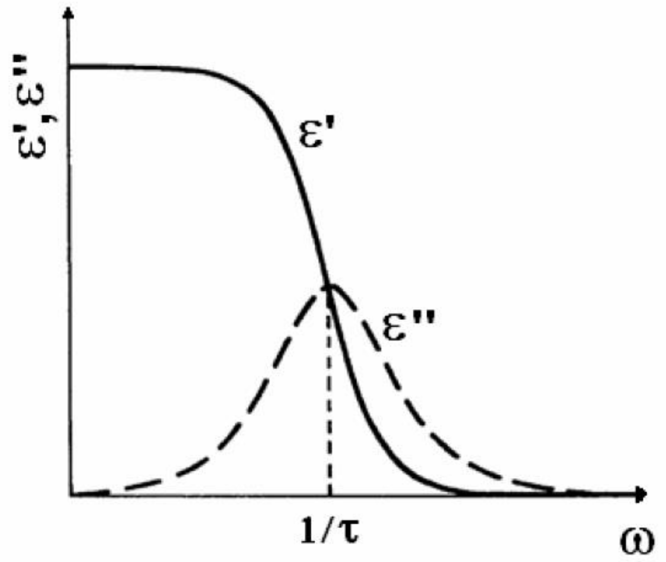

Fig. 2. Frequency dependence for the real and imaginary components of the dielectric permittivity from the Debye's model

Experiments

Al/ 5um Polycrystalline ferroelectric $Sn_2P_2S_6$ /Al

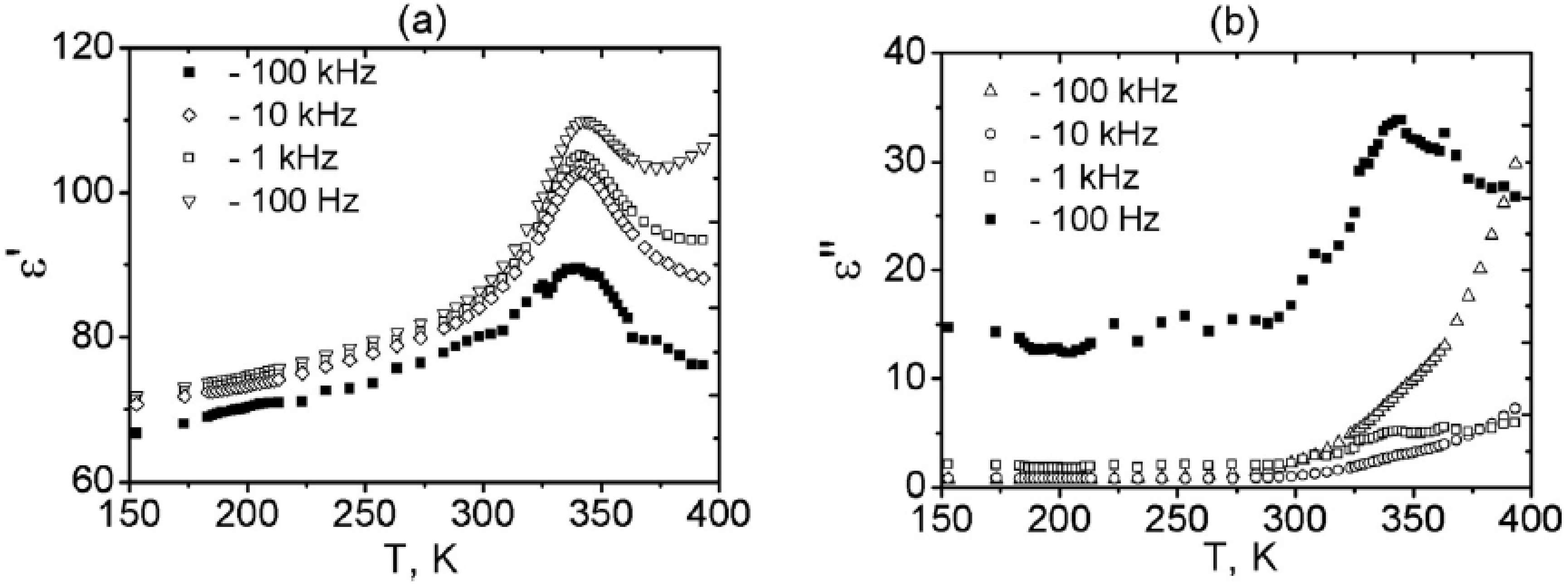

Fig. 2. Real (a) and imaginary (b) parts of the complex dielectric permittivity of the $Sn_2P_2S_6$ films as functions of the temperature.

This dielectric peak of ε′ corresponds to the ferroelectric-to-paraelectric phase transition of the $Sn_2P_2S_6$ crystal at 339 K

Experiments

Al/ 5um Polycrystalline ferroelectric $Sn_2P_2S_6$ /Al

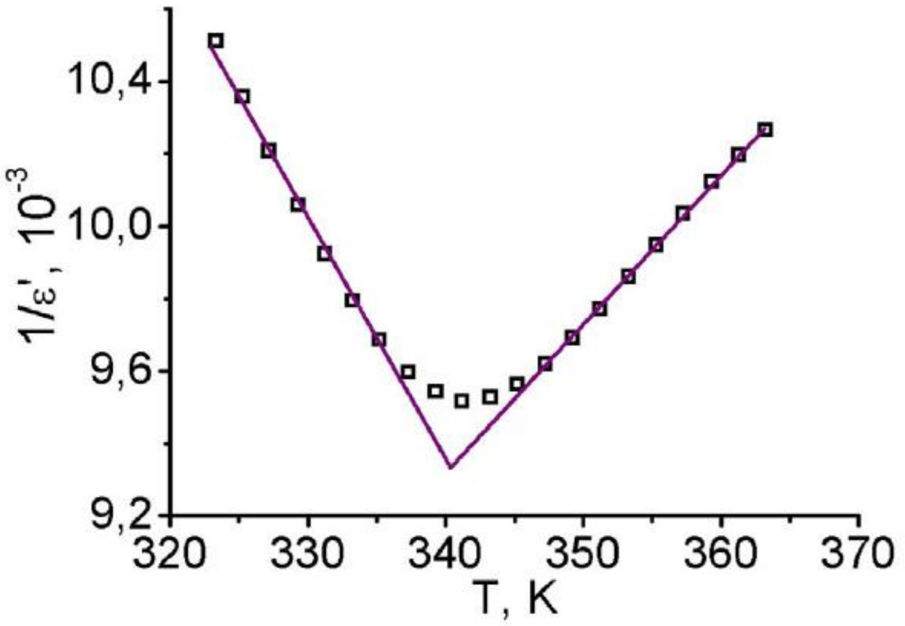

Fig. 3. Temperature dependence of the reciprocal dielectric constant for $Sn_2P_2S_6$ films at a frequency of 1 kHz.

The dielectric constant obeys the Curie-Weiss law both above the phase transition temperature. For $T > T_c$, this law is given by

$$\varepsilon' = \frac{C_{C-W}}{T - T_C},$$

Two possible reasons for the deviation of the $1/\varepsilon'$ from linearity

1. An order-parameter fluctuation contribution near the phase transition and influence of crystal lattice defects
2. Appearance of small polar regions near defects at temperatures above T_C

Experiments

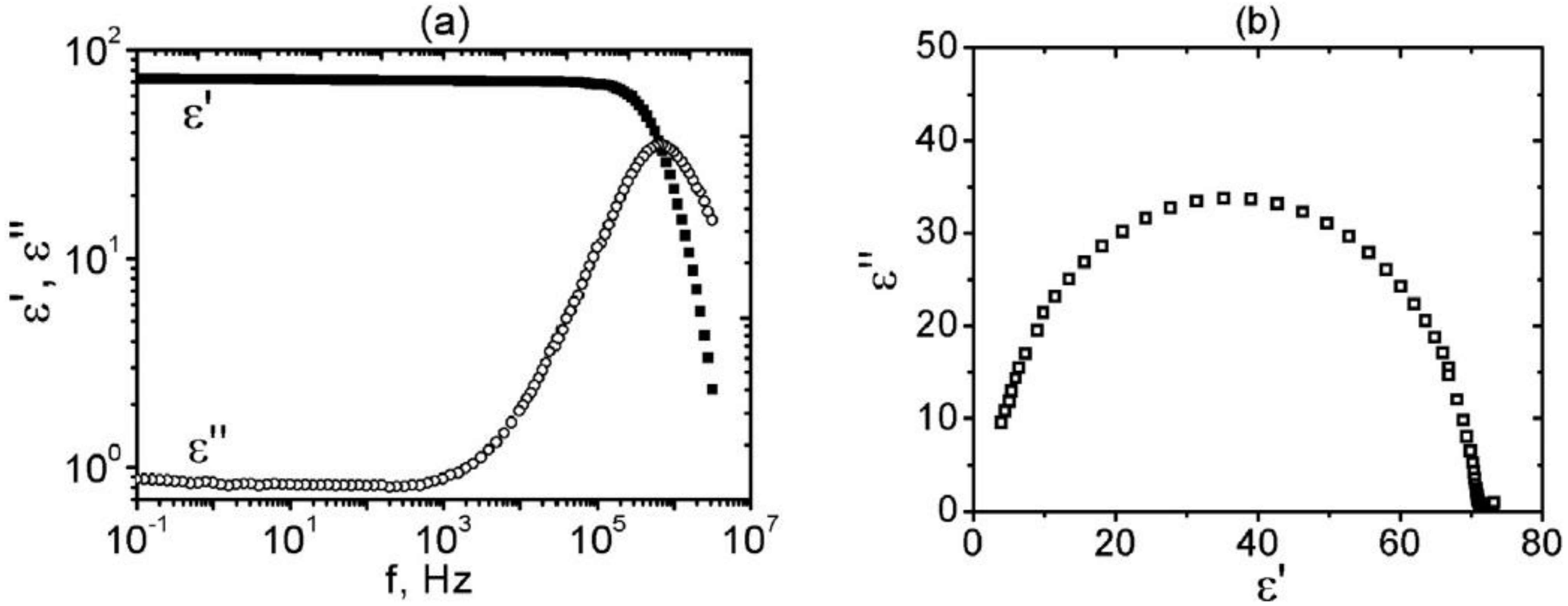

Fig. 4. Frequency dependence of the dielectric permittivity components (a) and Cole-Cole diagram (b) observed for the $Sn_2P_2S_6$ film at 153 K.

Two possible mechanisms for Debye-like relaxation:

1. a “giant dispersion” can be attributed to ferroelectric domains
2. the existence of Schottky barriers between the ferroelectric film and Al electrode

Experiments

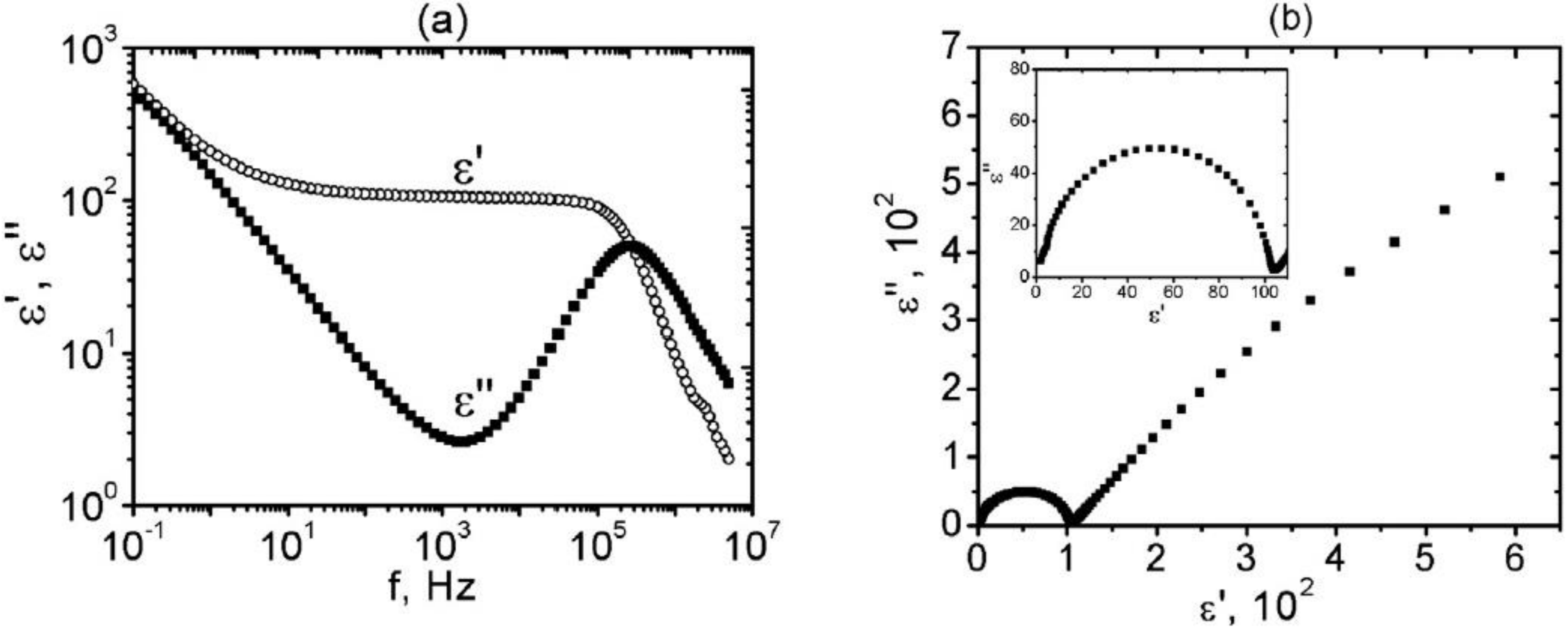

Fig. 5. (a) Frequency dependence of the dielectric permittivity components and (b) Cole-Cole diagram observed for the $Sn_2P_2S_6$ film at 340 K.

The Debye-like relaxation is maintained in the high frequency region at 400 K, so it is not connected to the ferroelectric state. But semiconductor properties of the material are maintained above Tc, so the most probable mechanism is Schottky barrier

The negative slope of ε″ (ω) in the low-frequency region can be explained by increasing the dc conductivity at growing temperature.

Thanks and questions?