Preface

When a material is submitted to a stress below the elastic limit, it extends elastically, the strain being proportional to stress and disappearing upon stress removal. This behaviour was first proposed by Hooke in the seventeenth century and is now well known as Hooke's law.
However, Coulomb at the end of the eighteenth century and then Weber at the beginning of the nineteenth century noticed that deformation is not instantaneous when the stress is applied, but depends on time, even when non-irreversible strain occurs.
So time-dependent deformation (called anelastic deformation) appears (the strain lags behind the stress) and when the applied stress is removed, the strain will gradually disappear.
This behaviour occurs in all materials, but in general the strain which depends on time is not very significant, so that, to a first approximation, the material can be considered to be elastic. However, depending upon temperature, stress, time..., some materials can present a significant anelastic strain.
The capacity of materials to damp out vibrations is a function of the lag between stress and strain and is related to the anelastic strain: it is called damping capacity or internal friction.
The damping capacity of materials can vary significantly from one to another and is a function of the microstructure, stress, temperature or frequency.
The anelastic strain can result from the motion of structural defects such as point defects, dislocations, grain boundaries, and the sliding of polymer chains... and conversely, the internal friction can be used to study such motions. This technique was first exploited in the 1940's:

- in Europe, by Snoek who studied the so-called Snoek relaxation in α iron containing small amounts of nitrogen or carbon and by Köster who observed an increase followed by a subsequent decrease in the internal friction and modulus defect in metals after plastic deformation, and who studied the magnetomechanical hysteretic damping in iron-nickel alloys.
- in the USA, by Zener who first studied energy dissipation by thermal currents, internal friction due to macroeddy relaxations in ferromagnetic materials and then the internal friction in substitutional solid solutions, the so-called Zener relaxation. At the same time, Read, a student of Quimby, found evidence that the damping in pure metals was essentially due to dislocations.

These studies constitute a truly pioneering contribution to the field of internal friction, which led Zener, in 1948, to present the state-of-the-art in his remarkable monograph "Elasticity and Anelasticity of Metals".
After Zener's book, the literature concerning the damping behaviour of materials experienced significant growth as it became evident that internal friction was a powerful technique for studying the physical behaviour of materials.
Concerning dislocation relaxations, Bordoni observed (1949) an internal friction peak in fcc metals, which was attributable to dislocations alone and was quickly associated with the generation of double kinks, first by Mason (1955) and then by Seeger (1956).
The Bordoni relaxation, first studied in fcc metals, was then also observed in bcc and hcp metals and in other crystals.
A cold-work peak was first observed in bcc metals by Snoek (1941) and then by Kê (1948) and Köster and his co-workers (1954) : the Snoek-Köster relaxation involves interactions of point defects and dislocations.
Granato and Lücke, in 1956, developed the vibrating string model, which includes both amplitude-independent and amplitude-dependent internal friction. The amplitude-independent internal friction has been linked to dislocation resonance whereas the amplitude-dependent damping results from dislocation breakaway from pinning points.
The Granato-Lücke theory has been applied to a remarkably wide range of dislocation effects.

Only a few refinements concerning thermal effects have been required since the original model.
Finally, other peaks, which appear in the range between room temperature and the Bordoni peak, were first observed by Hasiguti and his co-workers in 1962. These peaks were related to the interaction of dislocations with point defects.
In the 1940's, Zener suggested that an internal friction peak due to viscous sliding of grain boundaries would appear as a function of temperature. Such a peak was observed by Kê in 1947 in polycrystalline aluminium by means of a torsion pendulum.
By 1958, a review of the available knowledge was presented by Mason in his book "Physical Acoustics and the Properties of Solids". Since that time, the progress made concerning anelastic relaxation has been presented in the "Physical Acoustics" series edited by Mason since 1964, and at the international conferences on "Internal Friction and Ultrasonic Attenuation in Solids" held in the U.S.A., Europe, Japan, China and Argentina since 1956.

Since the 1950's and -1960's, the literature concerning internal friction and ultrasonic attenuation in solids has been greatly enriched in many domains: point defects, dislocations, grain boundaries, phase transformations, lattice vibrations, magnetoelastic relaxations, electronic relaxation.
In step with this, experimental methods have been developed in many laboratories. Various methods can be distinguished: resonance, sub-resonance, mechanical after-effect, pulse-echo.
The resonance techniques can be subdivided into low-frequency (between 0.01 and 20Hz, the domain of the torsion pendulum) and medium-frequency (between 100 Hz and 100 kHz, the domain of resonant systems such as vibrating reeds, flexural bars, longitudinal waves).
The pulse-echo techniques are restricted to high frequencies ($\geq$ 1 MHz) and are generally used for dislocation, electron, phonon and phase transition studies. The after-effect methods are restricted to long relaxation times ($\geq$ 10s).
So, at the end of the 1960's, there was a need for an up-to-date monograph on internal friction in crystalline solids, in which the basic principles, the various fields of application and the available experimental techniques would be covered.
This need was answered by three books between 1969 and 1972. In the first one, Ultrasonic Methods in Solid State Physics by Truell, Elbaum and Chick (1969), the authors discussed the applications of high frequency wave propagation methods in the field of intrinsic properties and defects in solids.
In the others, Anelastic Relaxation in Crystalline Solids by Nowick and Berry (1972), and Internal Friction of Structural Defects in Crystalline Solids by De Batist (1972), the authors presented up-to-date monographs on internal friction in crystals, which are very useful to new researchers in this field.

Concerning polymers, intensive studies of viscoelasticity began in the 1940's and there was a significant growth in the literature after 1950. The knowledge available at the end of the 1960's was covered by several authors and Ferry's book (1970) "Viscoelastic Properties of Polymers" can be cited here. Polymers in the transition region exhibit some of the highest losses observed in solids.
From the 1970's, studies of internal friction in other materials, such as rocks, ceramics, glasses, concrete, ice, asphalt, ferroelectrics, biological materials and composites...began to appear and refinements of the techniques described in the three preceding books were proposed by many authors and laboratories around the world.
This immense progress in understanding internal friction and ultrasonic attenuation in solids was reported at national or international conferences, but no state-of-the-art source is currently available, except in the case of polymers.
For example, books dealing with the viscoelastic properties of polymers were published by Aklonis and MacKnight in 1983 (Introduction to Polymer Viscoelasticity), then by McCrum, Read and Williams in 1991 (Anelastic and Dielectric Effects in Polymeric Solids) and, most recently, by Lakes (1998) (Viscoelastic Solids).

It is now the time to publish an up-to-date book on the basic phenomena involved in the dissipation of mechanical energy in solids and their applications in materials science.

The objective of the present textbook, which resulted from the summer school on "Mechanical Spectroscopy Q^{-1} 2001", is to satisfy this need. The following topics are treated here:

- Introduction to mechanical spectroscopy
- Point defect relaxations
- Dislocation relaxation
- Grain boundary relaxations
- Phase transformations
- Interfaces
- Non crystalline materials
- Applications
- Techniques

The introduction to mechanical spectroscopy is based upon a complete description of the elastic, viscoelastic and viscoplastic behaviours of solids. The response of a solid to an applied stress of low level is analysed from several viewpoints: phenomenology, rheology and thermodynamics. The basic equations, which are derived from these analyses, are given in chapter 1.
Anelastic relaxations due to structural defects are treated according to the defect's dimensionality: point defects (Ch. 2), one-dimensional defects, such as dislocations (Ch. 3) and two-dimensional defects, such as grain boundaries (Ch. 4) or the surfaces of domains (Ch. 6). In each chapter, one finds first a description of the defects and of their dynamical properties. The typical relaxation mechanisms of the given structural defect are then described.
Mechanical losses due to phase transitions are presented in chapter 5. Non-crystalline materials, especially polymers, are treated in chapter 7.
Applications of the technique to various domains of materials science, such as thin-layers, surface properties, stress relaxation in composites, fatigue, development of high damping-capacity materials, are presented in chapter 8. Chapter 9 describes both classical and new techniques for measuring internal friction or ultrasonic attenuation in solids.

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