Ferroelectret-film accelerometers with high sensitivities

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Introduction

Ferroelectrets [1] are piezoelectric films of charged cellular or porous polymers and have larger d_{33}-coefficients than lead zirconate titanate (PZT). Compared to PZT and other piezoelectric materials, ferroelectrets are flexible, lightweight, and cheap. These properties allow the construction of light, flat, and sensitive accelerometers of various shapes. Accelerometers are mainly used to measure acceleration, vibration and structure-borne sound [2]. They are increasingly present in many portable electronic devices and in the controllers for video game consoles.

Several designs of accelerometers based on ferroelectrets are possible. Two of them are shown in Figure 1. In the present work, accelerometers, similar to the one in the bottom part of the Figure, were built with polypropylene (PP) ferroelectrets ($d_{33} \approx 500$ pC/N quasistatically measured [3]) in single- and in multi-layer arrangements, with seismic masses from 3 to 25 g and with two springs, which allowed the application of static pressures in the range 0 to 50 kPa. Film area, number of ferroelectret film layers, seismic mass and static pressure determine sensitivity and resonance frequency of the accelerometer and these parameters were varied for the construction of different accelerometers and their characterization. The measurements will be presented and briefly discussed in the following.

Measurements were performed using an electrodynamic vibration exciter (B&K 4809), a power amplifier (B&K 2713), charge amplifiers (B&K 2635), accelerometers (B&K 4332 and 4344) and an audio analyzer (R&S UPD).

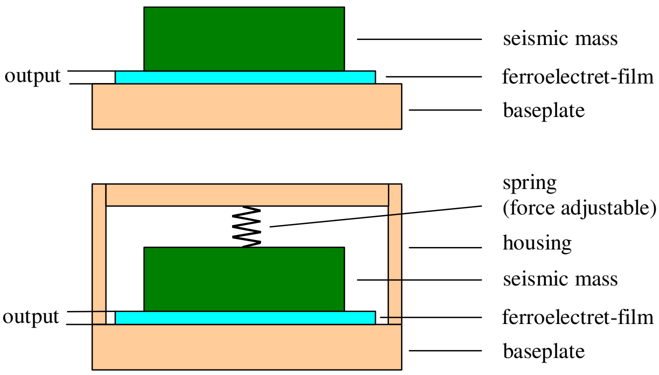

Figure 1: Two designs of ferroelectret accelerometers: In the upper part of the figure, seismic mass and ferroelectret are glued on a baseplate or directly on the vibrating object. In the bottom part of the figure seismic mass and ferroelectret are mounted inside a metal housing, which permits the application of a static force to the seismic mass by means of a spring and shields the ferroelectret acoustically and electrically.

Sensitivity measurements

Dependence on seismic mass

In Figure 2, sensitivity measurements of an accelerometer loaded with different masses are shown. For all masses, a slight decrease of the sensitivity with increasing frequency and a resonance peak was found.

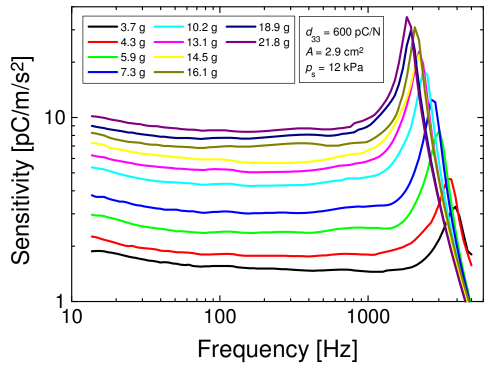

Figure 2: Sensitivity of an accelerometer with different seismic masses. For all measurements the same ferroelectret-film was used and the same static pressure was applied.

The decrease of sensitivity is due to the decrease of the d_{33}-coefficient of the ferroelectret [3,4], while the resonance peak can be explained if the film (with its Young's modulus Y) and the seismic mass of the accelerometer are modeled as a spring-mass-system.

This is illustrated in Figure 3: Sensitivities (@100 Hz) and the resonance frequencies of the measurements in Figure 2 are shown as symbols and the two solid lines are results obtained for a spring-mass-system. Both, the straight line and the inverse root function expected for such a system are in good agreement with the measured data points.

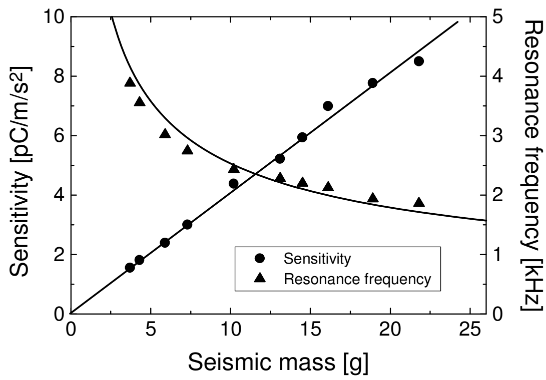

Figure 3: Sensitivity (@100 Hz) and resonance frequency of the accelerometers from Figure 2.

Dependence on static pressure

While the dependence of sensitivity and resonance frequency on the seismic mass is obvious and easy to explain, their dependence on the static pressure is more complicated. This can be seen in the Figures 4 and 5: In Figure 4 sensitivity measurements for different static pressures are shown. The sensitivity at 200 Hz and the resonance frequency as a function of the applied static pressure, obtained from Figure 4, are presented in Figure 5.

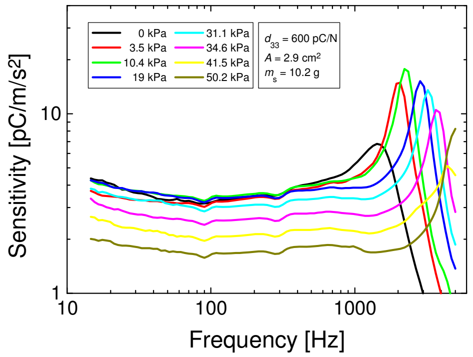

Figure. 4: Sensitivity of an accelerometer with a seismic mass of 10.2 g. The static pressure on the seismic mass was changed in the range from 0 to 50 kPa. For all measurements the same ferroelectret-film was used.

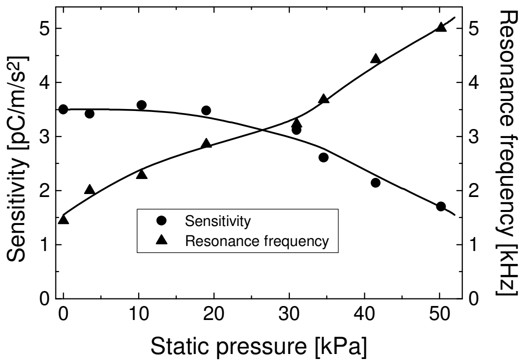

Figure. 5: Sensitivity (@200 Hz) and resonance frequency of the accelerometers from Figure 4.

While the resonance frequencies increase with increasing static pressure, the sensitivities are constant up to a pressure of about 20 kPa and then decrease with increasing pressure. This behavior can be understood, if the relatively rough surface of the ferroelectret-films and their non-linear Young's modulus are taken into account: With increasing static pressure, first the effective contact area of the films increases and then, at about 30 kPa, Young's modulus Y starts to increase as well.

Multilayer accelerometers

Folding the ferroelectret-films leads to multilayer transducers with larger total film areas (and therefore larger generated charge) since the inertial forces of the seismic mass act on each layer. Results for multilayer accelerometers are shown in the Figures 6 and 7. As for single layer accelerometers, increasing the sensitivity by increasing the seismic mass results in a decreasing resonance frequency. However, with multilayer accelerometers, the same sensitivity/resonance frequency pairs can be achieved with smaller seismic masses, resulting in lighter accelerometers.

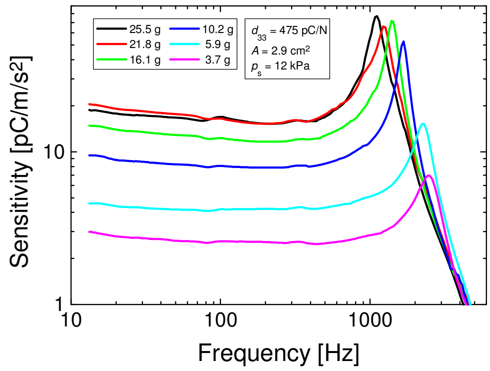

Figure 6: Sensitivity of a two-layer accelerometer with different seismic masses. For all measurements the same two layers of a ferroelectret-film (d_{33}=475 pC/N) were used and a static pressure of 12 kPa was applied.

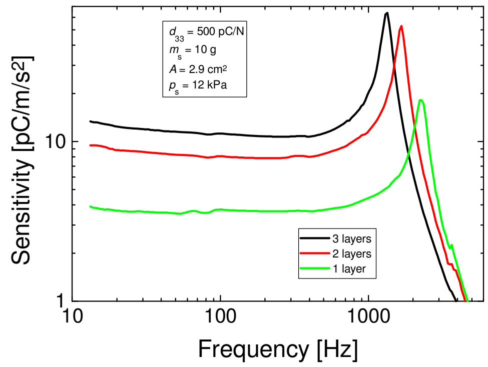

Figure 7: Sensitivities of accelerometers with one, two, and three layers of ferroelectret-film (d_{33}=500 pC/N). In all three accelerometers a seismic mass of 10 g and a static pressure of 12 kPa were used.

Summary

Accelerometers based on ferroelectrets are lightweight and inexpensive. Their sensitivity and resonance frequency can be adjusted by the d_{33}-coefficient and Young's modulus of the film and by the seismic mass, the static pressure on the film, and the number of films. Presently, sensitivities of more than 20 pC·s^2/m are available. The accelerometers can be used at extremely low frequencies, since the conductivity of the ferroelectret-films is very low. Furthermore, all measured data are in good agreement with model calculations.

Acknowledgement

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