Q-FACTOR AND FREQUENCY SHIFT OF RESONATING SILICON DIAPHRAGMS IN AIR

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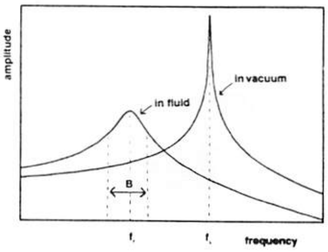
INTRODUCTION

Diaphragms vibrating in a fluid show a shift of the resonance frequency due to an increase of the inertia (caused by fluid motion). Besides this, they dissipate energy in the fluid, resulting in a broadening of the resonance peak. The dependence of the relative frequency shift (*rfs*) and the *Q*-factor (i.e. energy dissipation) on the air pressure and the geometry is investigated. The research is concentrated on the first two modes of vibration of square silicon diaphragms. The aim of the research is to obtain rules which can be used when designing resonant diaphragm sensors.

THEORY



$$rfs = \frac{f_r - f_v}{f_v}$$

$$Q = \frac{f_r}{B}$$

The theory is based on Lamb's work (1920's). Acoustic processes are assumed to be dominating. Viscous processes are neglected. Results (for small values of *rfs*):

first mode: $rfs = -1.75\times10^{-9}\,\frac{ap}{hp_0}$ $\quad Q = \frac{5.12\times10^{6}}{R}\,\frac{p_0}{p}$

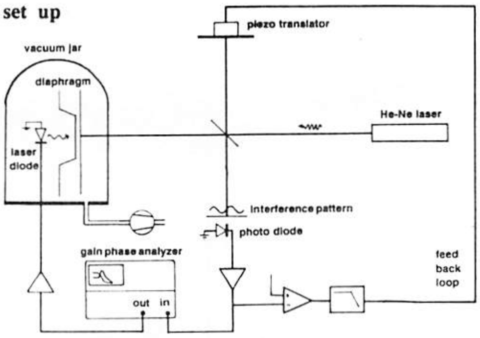
second mode: $rfs = -7.82\times10^{-10}\,\frac{ap}{hp_0}$ $\quad Q = \frac{4.10\times10^{2}}{R^3}\,\frac{a^2 p_0}{h^2 p}$

a, h side, thickness of the diaphragm
p, p_0 air pressure, 1 Pa
R: ratio of observed frequency and expected frequency for a stress free diaphragm

At low pressures, acoustic damping is dominated by structural damping: Q becomes independent of the pressure.

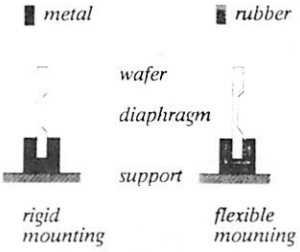
EXPERIMENTS

set up



opto-thermal excitation
detection by Michelson interferometer

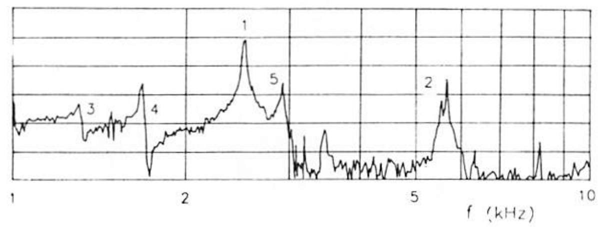
samples



a = 4 .. 16 mm
h = 3 .. 40 µm.

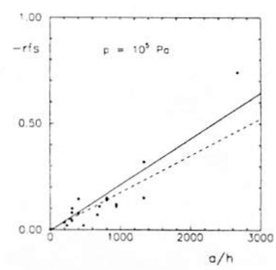
RESULTS

spectrum

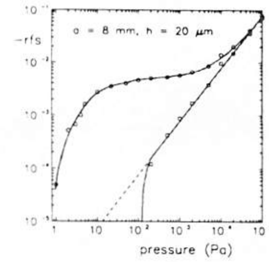


1: first mode resonance; 2: second mode resonances; 3,4: mechanical cross-talk and 5: origin unknown

relative frequency shift

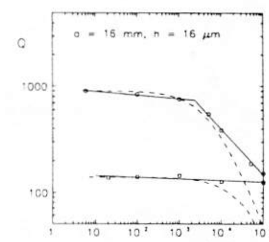


- - *theory*
— *experiment*



- - *theory*
— *experiment*
o f_v = 4102.0 Hz *(measured value)*
□ f_v = 4082.1 Hz *(matched value)*

Q-factor



- - *theory*
— *experiment*
o *rigid mounting*
□ *flexible mounting*

Similar results were obtained for the second mode.

CONCLUSIONS

Both *rfs* and *Q* show poor agreement with the theory. Probably, the acoustic effects are overshadowed by viscous processes, which are nor yet included in the model.

Considerable coupling between the diaphragm and the wafer was observed. This results in a low structural *Q*-factor and mechanical cross-talk between different diaphragms on the same wafer. When designing sensors with resonant diaphragms, the mass of the diaphragm should be chosen very small with respect to its surroundings (wafer and support). Only in that case a reasonable performance of sensors with resonant diaphragms can be expected.