Influence of gold electrodes on the properties of shear horizontal acoustic plate mode viscosity sensor in BT-cut quartz

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Until now the influence of gold electrodes on the properties of shear horizontal acoustic plate modes (SHAPMs) in BT-cut quartz (-50.5°YX90°) was never before calculated or measured. Calculation presented in this study show that the amplitude of mechanical motion at the quartz plate surface decreases with an increase of the thickness of the gold layer. When the thickness of the gold layer is increased only on one side of the quartz plate, the amplitude decreases on the same side, whereas it remaines unchanged on the opposite side. For one of the SHAPMs, the amplitude of mechanical motion become about twice as big when the gold layer thickness increased from about 0.1 μm to 1 μm. This effect was confirmed by the measurements of the changes of the delay line insertion loss against viscosity of glycerine and water solutions.

Key words: shear horizontal acoustic plate modes, BT-cut quartz, gold electrodes, delay line, insertion loss, viscosity sensor

Wpływ złotych elektrod na właściwości czujnika z poprzecznym horyzontalnym akustycznym modem płytowym w kwarcu o orientacji BT

Po raz pierwszy wykonano obliczenia i pomiary wpływu złotych elektrod na właściwości czujnika lepkości z poprzecznym horyzontalnym akustycznym modem płytowym (PHAMP) w kwarcu o orientacji BT (-50.5°YX90°). Stwierdzono, że amplituda drgań mechanicznych na powierzchni płytki kwarcowej maleje wraz ze wzrostem grubości warstwy złota. Gdy grubość warstwy złota wzrasta po jednej stronie płytki kwarcowej, to zmniejszanie ma miejsce po tej samej stronie, podczas gdy pozostaje niezmienione po stronie przeciwnej. Dla jednego z PHAMP, amplituda drgań mechanicznych zmalała dwa razy gdy grubość warstwy złota wzrosła od 0,1 μm do 1 μm. Efekt ten został potwierdzony przez pomiar zmian tłumienności linii opóźniającej w funkcji lepkości roztworów gliceryny i wody.

Słowa kluczowe: poprzeczne horyzontalne akustyczne mody płytowe, kwarc o orientacji BT, złote elektrody, linia opóźniająca, tłumienność wtrącenia, czujnik lepkości

1. Introduction

Shear horizontal acoustic plate modes (SHAPMs) in BT-cut quartz (-50.5°YX90°) are attractive for application in viscosity sensors [1]. However, previous calculations of the SHAPMs properties were done on the undestanding that the thickness of electrodes deposited on both sides of the BT-cut quartz plate is infinitesimally small. Because the finite thickness of the electrodes is used in practical applications, it is important that the influence of the thickness on the SHAPMs properties become calculated and measured. Compared to aluminium, gold is more convenient for the fabrication of larger thicknesses of layers and is much more resistant to mechanical and chemical undesirable effects in liquid sensors. This paper presents calculations and measurements results of the influence of finite thickness of gold electrodes on the properties of SHAPM viscosity sensor in BT-cut quartz.

2. Calculation method and results

Compared to the case of infinitesimally thin metal layers [1], new algorithm and computer program were developed to solve the problem of SHAPMs in the case of finite thickness of isotropic metal layers deposited on both sides of a piezoelectric plate (Fig. 1). Here, X, Y', Z' and x_1, x_2, x_3 are the crystallographic and wave coordinate systems, respectively. In this case, equations of motion were solved in the piezoelectric plate and in both isotropic metal layers of different thicknesses. By applying mechanical and electrical boundary conditions as used in the case of Love wave [2], properties of SHAPMs in BT-cut quartz were calculated for $h/\lambda = 14$, where h is the quartz plate thickness and λ is the acoustic wavelength [1].

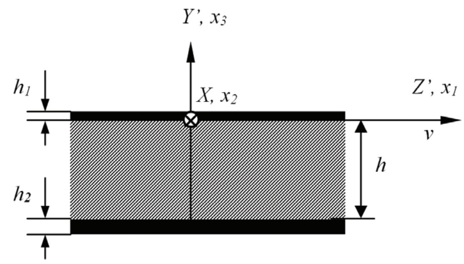

Fig. 1. BT-cut quartz plate with gold electrodes and coordinate systems.
Rys. 1. Płytka kwarcu o orientacji BT ze złotymi elektrodami i układy współrzędnych.

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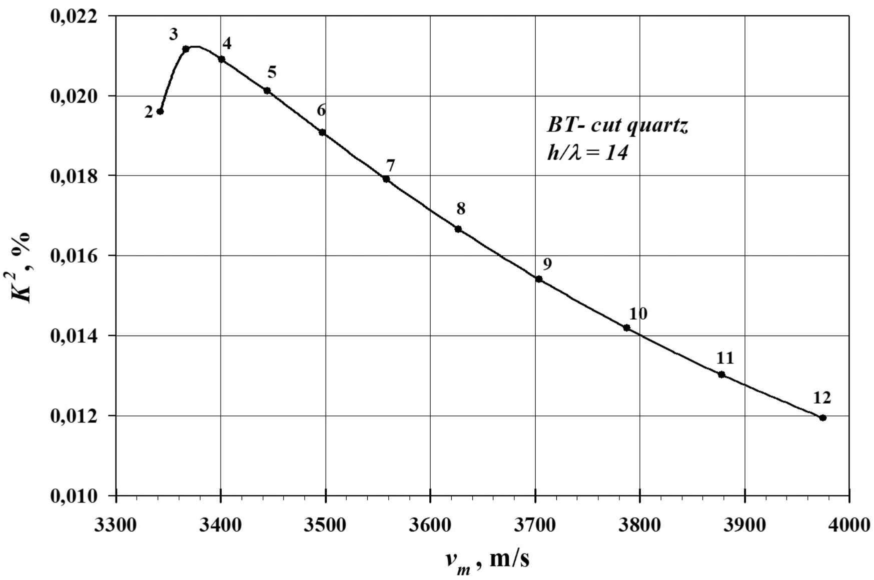

Fig. 2. Electromechanical coupling coefficient against SHAPMs velocity for $h_1 = h_2 = 0.1$ µm.
Rys. 2. Współczynnik sprzężenia elektromechaniczneg PHAMP w funkcji prędkości dla $h_1 = h_2 = 0,1$ µm.

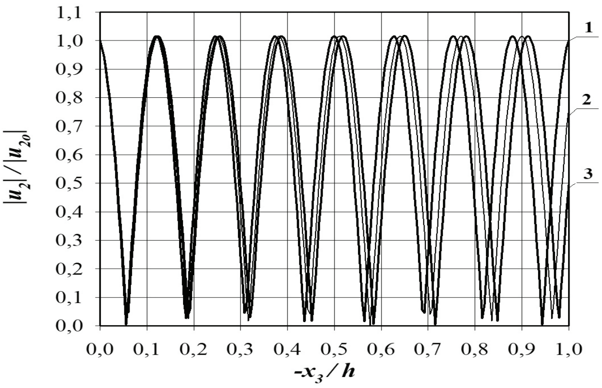

Fig. 3. Distributions of relative u_2 mechanical component amplitudes of the 8th mode for different values of h_2: 1- $h_2 = 0.1$ µm; 2- $h_2 = 0.5$ µm; 3- $h_2 = 1$ µm.
Rys. 3. Rozkłady względnych amplitud mechanicznych u_2 dla modu ósmego przy różnych wartościach h_2: 1- $h_2 = 0,1$ µm; 2- $h_2 = 0,5$ µm; 3- $h_2 = 1$ µm.

The results of calculations of the electromechanical coupling coefficient K^2 against velocity v_m of the metallised plate are shown in Fig. 2. Compared to the case with infinitesimally thin electrodes [1], there are significant differences of K^2 for the first several modes, whereas above this area, present calculations gave slightly higher values of K^2. It was also found that the effect of gold electrodes thickness on K^2 is very small and can be neglected.

As in the previous work [1], arbitrarily chosen 8th mode, located near the center of the spectrum, was used for the calculations. Calculated amplitude distributions of mechanical displacements of this mode is shown in Fig. 3. It can be seen that the amplitude of u_2 decreases only on the side of the plate at which the gold layer thickness h_2 was increased. It means that maximum sensitivity to viscosity changes will exist for thin gold layer.

3. Measurement methods and results

The same delay line as in [1] was used for the measurements (Fig. 4). A gold layer thickness of about 0.2 µm was used for the delay line, which is approximately equivalent to $h_1 = 0.1$ µm of continues layer used in the calculations [2]. The opposite plane was covered with a 0.1 µm thick continues gold layer. The delay line was mounted in a metal package, with a window for liquid loading. The measured amplitude spectrum and the 8th mode in air (Network Analyzer Type 8753ET, Agilent Technologies, Inc., Santa Clara, CA), with 60 nH parallel inductors [1], are shown in Fig. 5 and 6, respectively. It can be seen that the results are approximately the same as the one that were obtained for 0.6 µm thick aluminium electrodes deposited on the delay line side of the quartz plate[1]. Markers 1 and 2 indicate the surface transverse wave (STW) and the 8th mode, respectively.

Changes of insertion loss ΔIL against $\sqrt{\rho\eta}$, where ρ and η are the mass density and dynamic viscosity of glycerine and water solutions, respectively, were measured

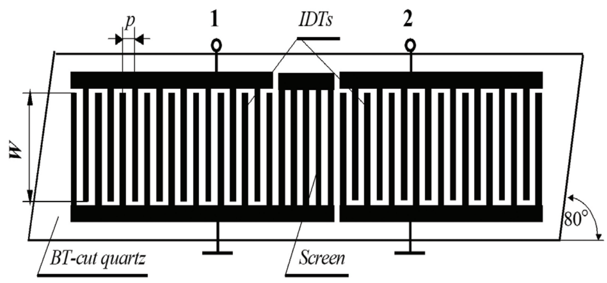

Fig. 4. Structure of the delay line.
Rys. 4. Struktura linii opóźniającej.

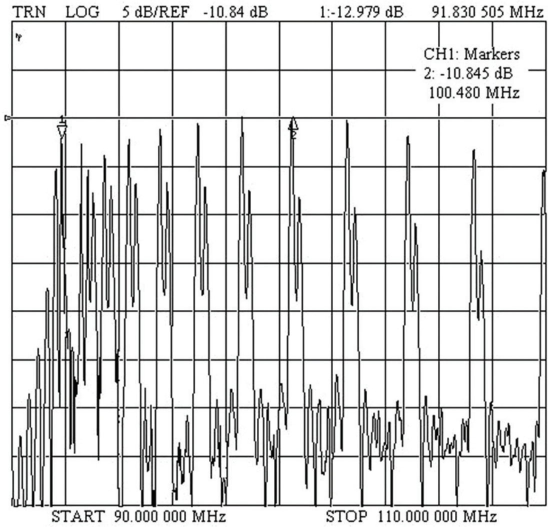

Fig. 5. Amplitude spectrum of SHAPMs in air for $h_1 = h_2 =$ 0.1 μm.
Rys. 5. Widmo amplitudowe PHAMP w powietrzu dla $h_1 = h_2 =$ 0,1 μm.

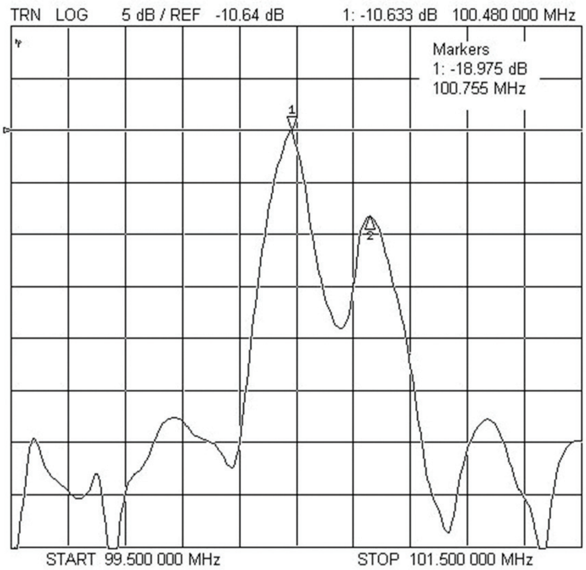

Fig. 6. Amplitude response of the 8th SHAPM.
Rys. 6. Charakterystyka amplitudowa ósmego modu PHMP.

at room temperature for different values of h_2 (Fig. 7). For $h_1 = h_2 = 0.1$ μm in a viscosity range from about 1 mPa·s to 1000 mPa·s, the insertion loss change was of about 14 dB. This value is approximately the same as the value obtained for aluminium electrodes [1]. It can be seen that the sensitivity to viscosity changes decrease with an increase of h_2.

4. Conclusions

It was found that for SHAPMs, amplitude of mechanical motion on the plate surface decreases with an increase of

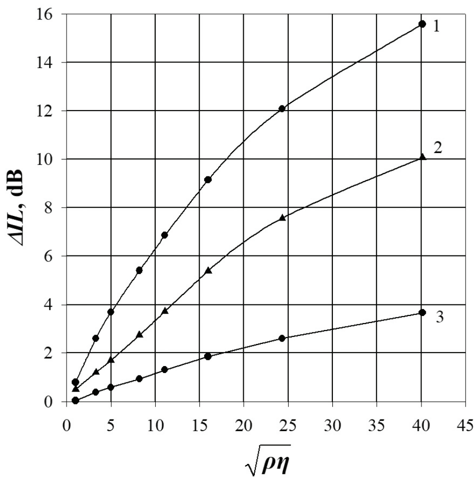

Fig. 7. Insertion loss changes for different thicknesses of gold layer (ρ [g/cm^3], η [mPa·s]): 1- h_2 = 0.1 μm; 2- h_2 = 0.5 μm; 3- h_2 = 1 μm.
Rys. 7. Tłumienność wtrącenia dla różnych grubości warstwy złota (ρ [g/cm^3], η [mPa·s]): 1- h_2 = 0,1 μm; 2- h_2 = 0,5 μm; 3- h_2 = 1 μm.

the gold layer thickness. When the thickness was increased only on one side of the quartz plate, the decrease of the amplitude took place on the same side, whereas it remained unchanged on the other side. For one of the SHAPMs, at a frequency of about 100.5 MHz, the amplitude of mechanical motion become twice as big when the gold layer thickness increased from about 0.1 μm to 1 μm. This effect was confirmed by measurements the SHAPM delay line insertion loss changes against viscosity of glycerine and water solutions for different gold layer thicknesses. Maximum sensitivity to viscosity changes is observed for thin gold layer. Lower sensitivity for thicker gold layers can be used for the changing ranges of viscosity measurements.

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References

[1] Soluch W., Lysakowska M.: Properties of shear horizontal acoustic plate modes in BT-cut quartz, *IEEE Trans., Ultrason. Ferroelectr. Freq. Control*, 2011, 58, 2239 - 2243

[2] Nishikawa T., Tani A., Shirai K., Takeuchi C.: SH-type surface acoustic waves on Y-cuts quartz, *Proc. IEEE Frequency Control Symp.*, 1980, 286 - 291