DESIGN AND FABRICATION OF A QUARTZ-CRYSTAL RESONATOR USED IN A THICKNESS-MONITOR UNIT

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Abstract This paper deals with the design and fabrication of a quartz-crystal resonator used in a thickness-monitor unit, measuring film thickness in a film-depositing system. A purpose-grown quartz crystal is cut to form the desired wafer. Two gold electrodes are deposited on both surfaces of the wafer to provide electrical contacts. The resonance frequency of the resonator, at room temperature, and the variation of the resonance frequency of the resonator with the temperature are measured. The fabricated resonator is finally used in the thickness-monitor unit of a vacuum coater.

Key Words Crystal, Quartz, Resonator, Thickness Monitor, Crystal Orientation, Crystal Cutting

چکیده دراین مقاله طراحی و ساخت یک تشدید کننده کوارتزی بیان گردیده است. هدف از ساخت تشدید کننده بکارگیری آن دریک دستگاه (unit) ضخامت سنج کریستال کوارتز است. این دستگاه ضخامت لایه نشانده شده دریک سیستم لایه نشانی را نشان می دهد. کریستال کوارتزی رشد داده شده برای این منظور با مشخصات موردنظر به صورت برگه ای (wafer) بریده شده و پس از نشاندن الکترودهای طلا برروی دو سطح برگه، فرکانس رزنانس تشدید کننده (در دمای اتاق) و تغییرات فرکانس رزنانس آن برحسب دما اندازه گیری می شود. در پایان تشدید کننده ساخته شده دریک دستگاه لایه نشانی مورد استفاده قرار می گیرد.

INTRODUCTION

A quartz-crystal thickness monitor essentially determines the thickness of deposited matter, on a substrate, in different film-depositing systems. This was initially explored by Sauerbrey [1,2] and Lostis [3].

A quartz crystal is grown and çut to form a thin (about 0.25 mm) wafer. Two gold electrodes are then deposited on both surfaces of the wafer to provide electrical contacts. This device, called a quartz-crystal resonator (hereafter resonator), is made part of an oscillator circuit. Applying an AC voltage to the circuit give rise to thickness-shear oscillation within the resonator having a resonace frequency, at room temperature, inversely proportional to the wafer thickness, t_q.

$$f_o = \frac{N}{t_q} \tag{1}$$

where N, the frequency coefficient of the wafer, is equal to 1.664×10^6 Hz mm [4]. During the deposition of any matter such as: Al, Ni, Si etc., on a substrate, the surface of the resonator, being positioned nearby the substrate, is covered with a film of the deposited matter. This give rise to a change of the resonance frequency of the resonator, Δf. Thus, measuring this change enables us to determine the film.

Stockbrige [5] calculated a mathematical alternative and obtained the following relations determine the film thickness:

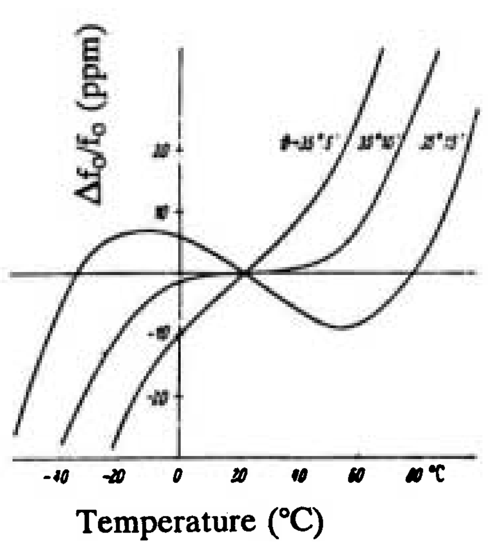

Figure 1. The frequency - temperature characteristics of AT-cut wafers [7].

$$\Delta f = -C\frac{\Delta m}{A_e} = -C\rho_f t_f \qquad (2)$$

$$C = \frac{f_0^2}{N\rho_q} = \frac{N}{\rho_q t_q^2} \qquad (3)$$

where, ρ_f, t_f, and Δm are: the density, the thickness and the mass of the film respectively; ρ_q is the quartz density (i.e. 2.65 g cm^{-3}), A_e is the electroded area of the resonator, and C is the mass-determination sensitivity of the resonator. The frequency-temperature characteristic of the resonator, $\Delta f_o/f_o$ versus temperature, is an important consideration in preparation of resonators. If the plane of the wafer makes an angle of about 35°C, the cutting angle, to the optical axis of the crystal, the frequency-temperature characteristic of the wafer shows a flat portion, in which the Δf_o reaches zero. The orientation is designated as an AT-cut being used in preparation of the resonator used in the thickness-monitor unit (Figure 1). However, the optimum cutting angles are usually within the range of 35° 10' to 35° 20' [6].

Crystals to be fabricated into AT- cut wafers are usually grown in the form of Y-bars, shown in Figure 2.

In order to obtain an accurately oriented AT-cut wafer, the bar should be cut and ground parallel to the Y-Z plane and mounted in such a way that the Z-axis is positioned exactly vertical. Then the saw should be set properly so that the wafer to be cut lies parallel to the X-axis with the right cutting angle, as described before. The accuracy of the cutting angle can be checked using the X-ray technique [9].

EXPERIMENTS

The purpose-grown crystal was cut to form two

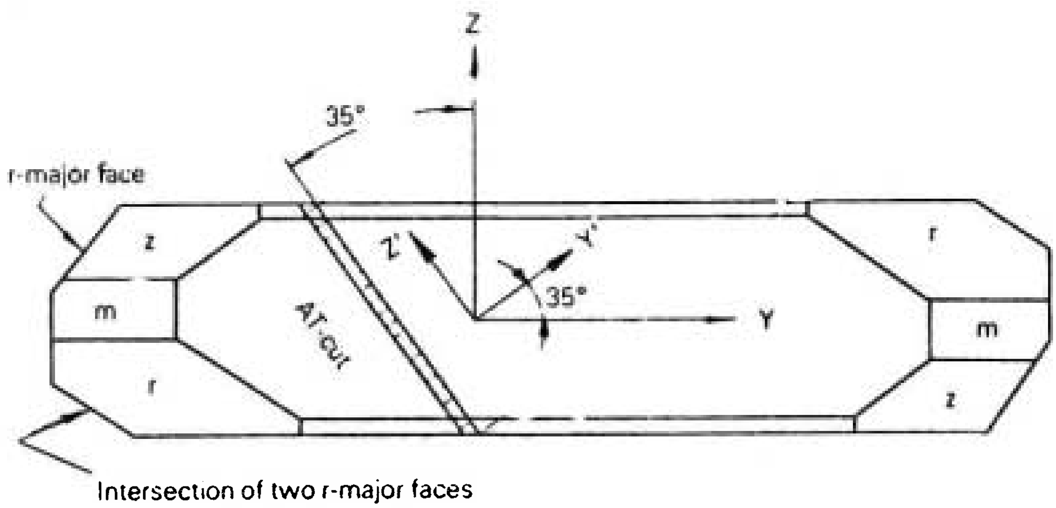

Figure 2. Sketch of a quartz crystal grown in Y-bar form used in the fabrication of AT-cut wafers. The lines sloping left from the Z-axis indicate the saw-cut position for cutting of AT-cut wafers [8].

square wafers (F and J) with lateral dimensions of 12.8mm × 12.8mm having a cutting angle of 35° 10'10". The wafers differed only in thickness measuring 0.248 mm for F and 0.254 mm for J respectively. To cut the crystal with an accurate cutting angle, a multi-wafer diamond saw was used and an accuracy of 30" was obtained. The cutting angle, as accurate as 20", was checked using the X-ray technique. The wafer was mechanically grinded with different grades of SiC abrasive papers and then polished with fine grade (i.e. 1μm) of Al_2O_3 powder followed by 0.25μm diamond paste. The wafer was then chemically polished with 0.1 molar NH_4F for 24 hrs. The gold electrodes were evaporated on both surfaces of the wafer, in the form of circular shape with 5 mm diameter, at a pressure of 2×10^{-6} torr. Finally the fabricated resonator was used in the thickness-monitor unit of an EDWARD'S 306 GENERAL PURPOSE VACUUM COATER.

RESULTS AND DISCUSSION

The resonance frequency of F and J Samples at room temperature, f_o, were measured by an ADVANTEST R3751B NETWORK ANALYSER (having 0.01 Hz accuracy), Table 1.

It can be seen in the Table 1 that there are 0.41% and 0.73% discrepancies between the calculated and measured resonance frequencies of F and J samples, respectively. This may be attributed to a number of factors: (a) the effect of mass of the electrodes, (b) non- parallelism of about 1μm in the thickness of the wafer and (c) damping of oscillation energy due to the presence of the holder.

The temperature variation of the resonance frequency of J sample, within the range of -45°C to 95°C, were measured in a thermal chamber (Figure 3).

It is interesting to see that the trace of the curve (Figure 3) is consistent with the predicted one shown

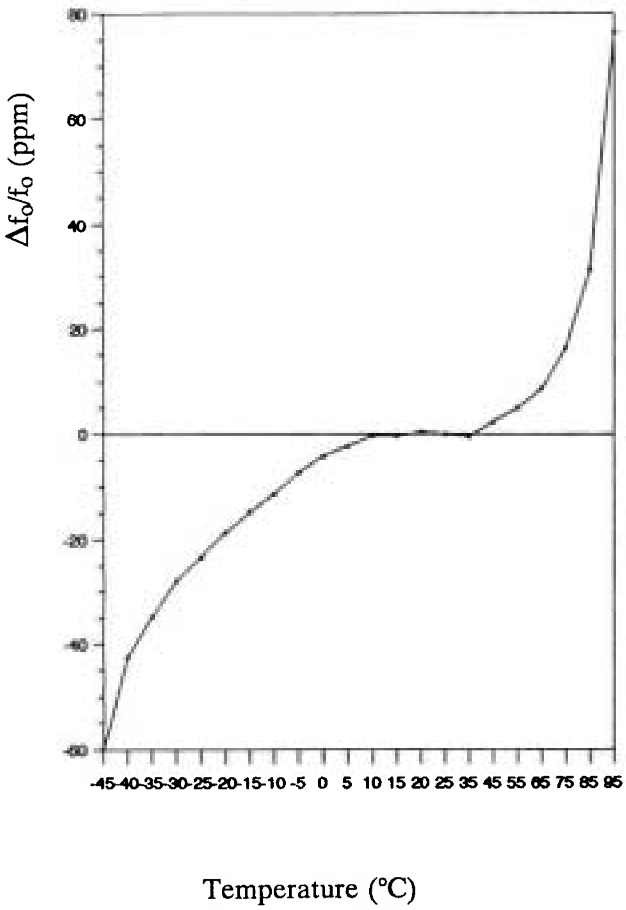

Figure 3. The frequency - temperature characteristic of J sample.

TABLE 1. The Calculated (Equation 1) and Measured Resonance Frequencies of F and J Samples at 25°C.

Sample	t_q (mm)	Calculated f_o (Hz)	Measured f_o (Hz)	Relative differences(%)
F	0.248	6709677.42	6682280.21	-0.41
J	0.254	6551181.10	6503712.17	-0.73

in Figure 1.

CONCLUSION

The optimum function of the designed and fabricated resonator used in a thickness-monitor unit is in accordance with; (a) the agreement between the calculated and measured resonance frequencies of the resonator, at room temperature, (b) the relative temperature variation of the resonance frequency of the resonator lies within the range of -60 ppm to 80 ppm and (c) the temperature range in which the temperature variation of the resonance frequency of the resonator is equal to zero, lies within 10°C to 40°C.

NOMENCLATURE

Ae	Electroded area of resonator
AT	A special orientation of wafer
C	Mass-determination sensitivity of resonator
f_o	Resonance frequency at room temperature
Δf_o	Temperature variation of resonance frequency
Δf	Frequency change due to Δm
Δm	Mass of film
N	Frequency coefficient of wafer
ppm	Part per million
t	Thickness

Greek Symbols

ρ	Density
δ	Dihedral angle between r planes and AT-cut wafers
θ_{AT}	Bragg angle of AT-cut wafers
θ_r	Bragg angle of r planes

Subscripts

f	Film
q	Quartz

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