PZT membrane Piezoelectric Traveling Wave Motor

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Abstract A new type of piezoelectric membrane traveling wave motor has been designed and forbricated. The small motor is composed by the stator which is the combination of annular/circular membrane and metal elastic base using as the common electrode, at some time and the rotor which is placed on the metal elastic body. Thus, the motor structure is simple and easy to fabricate. The material of a piezoelectric membrane is fabricated by sol-gel method or wear-down method. A piezoelectric traveling wave motor has been fabricated with the stator diameter 8mm. The total thickness of the stator is 350μm. Under the alternative excitation voltage 10-12V, the revolving speed of the rotor is more than 100RPM.

Introduction

With the development of microeletromechanical Systems (MEMS), its applications in many fields attract more and more attention in the world. Among kinds of MEMS, micro motor which include electrostatic, electromagnetic type are the typical and impotant ones. As an alternative approach, the piezoelectric traveling wave micro motor, based on membrane material technology and IC technologies, circumvents many of the drawbacks of the above two type of micro motors. It displays its distinct advantages, and can be possibly applied in the research of piezoelectric vibratory gyroscope.

In this paper, we report a new structure for PZT membrane traveling wave motor , and discuss the relationship between rotation speed of rotor and friction, and that between excitation frequency and rotation speed.

Design and fabrication process of the piezoelectric motor

1. Traditional design of the piezoelectric motor structure

The structure of the traditional piezoelectric minimotor or micro motor is shown in Fig.1. In this structure, the common electrode is fabricated on the substrate. Then, the piezoelectric membrane is deposited, sputtered or coated on the substrate. The piezoelectric membrane is patterned to form fans, which support the rotor. The piezoelectric membrane is excited by AC source to produce acoustic vibration that leads to the rotation of the rotor. The design principle for the piezoelectric motor is that the mechanical deformation of the piezoelectric material electrically excited produces the traveling wave that drives the rotor. In the traditional structure, a short possible happens between the metal rotor and the fans. Therefore, another insulator layer on the fans is necessary. However, this extra layer causes a series of disadvantages and increases the complexity of process.

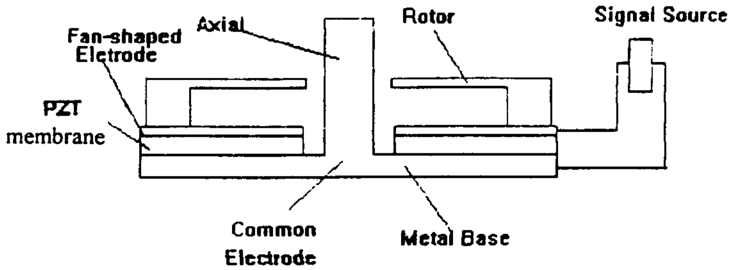

Fig.1 Schematic diagram of the traditional piezoelectric motor

2. New design of the piezoelectric motor structure

The new designed structure is shown in Fig.2. When piezoelectric membrane is excited by AC source, it will deformation, i.e., the particles of the membrane move. The deformation and expand shift of the particle induce lateral wave and vertical wave.

The shift vector $\vec{\mu}$ of the partical includes $\vec{\mu}_1$ and $\vec{\mu}_2$, it is expressed by:

$\vec{\mu} = \vec{\mu}_1 + \vec{\mu}_2$

The moveing partical is expressed by the equation:

$(\mu_1 /A_1)^2+(\mu_2/A_2)^2-(2\mu_1\mu_2/A_1A_2)Cos(\alpha_2- \alpha_1)=Sin^2(\alpha_2- \alpha_1)$

where, A_1 and A_2 , α_1 and α_2 are the amplitude or primary phase angle of the lateral and vertical vibration individually.

This is an elliptical equation, and it show, that a partical of the membrane move in an elliptical trajectory. Moreover , because of the refraction and the reflection of the wave, the common metal electrode with piezoelectric membrane will vibrate. The surface particle of the common electrode move in an elliptical trajectory, i.e the elliptical movement of the surface pints generate propulsion energy in the opposite direction to the direction of propagation of the traveling wave. After analyzing the vibration mode of PZT material for the stator of the piezoelectric motor, we understand that the mechanical deformation of PZT membrane under AC excitation is entirety deformation of the material as shown in Fig.3. Therefore, In this structure, the common electrode, or the stator , of the piezoelectric motor faces upward to support the rotor as shown in Fig.4. while the fans face downward to link leads easily as shown in Fig.5.

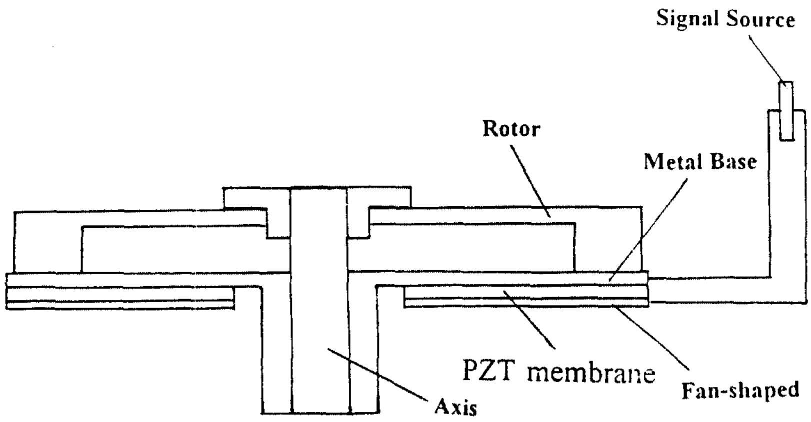

Fig.2 Schematic diagram of the new structure

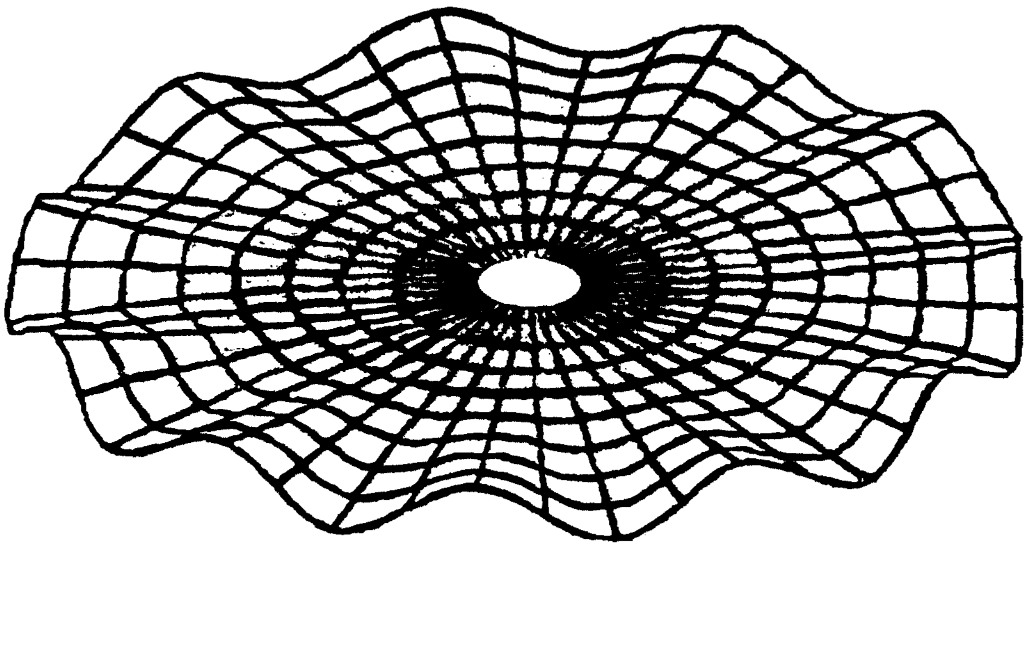

Fig.3 Analogical diagram of the traveling wave

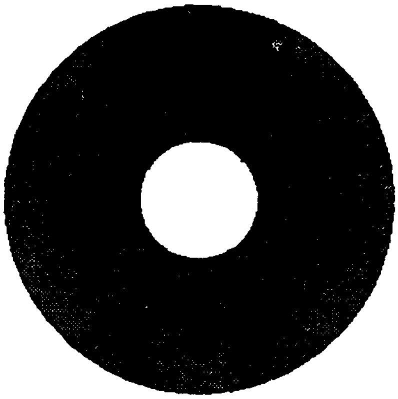

Fig.4 Schematic diagram of the common electrode

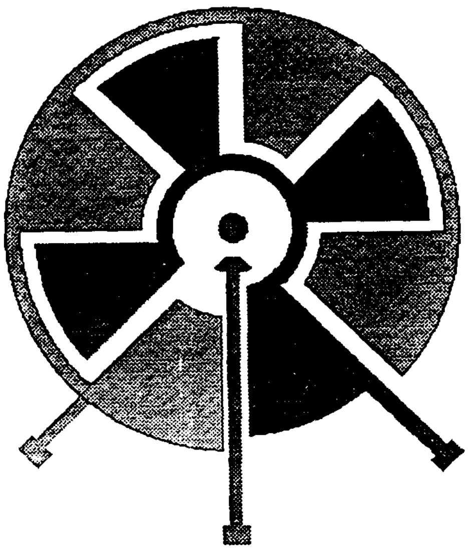

Fig.5 Schematic diagram of the fan shaped electrode

Fabrication processes for the piezoelectric motor

The stator material is commercially available . The substrate is copper with a thickness of less 200μm, which supports the PZT membrane with a thickness of less 150μm. The PZT ($ZrPbTiO_3$) material is made by sol-gel method or wear down method. Both faces of the PZT membrane are fused with silver layers as the electrodes. The outer silver face is also patterned to form eight fans for the connection with AC source. The inner silver face is a ring shaped common electrode and adheres to the copper substrate. The stator is assembled on an axle with the common electrode upward and fans downward. When AC source is applied, the stator with above new structure can drive the rotor of the piezoelectric motor on the common electrode. In our experiment, the piezoelectric motor with a 8mm diameter rotates in a rotation speed of above 100RPM under 10-12V AC excitation. Further, the piezoelectric motor with 2mm diamter has been fabricated last month.

Results

1. Weight of rotor and rotation speed

The rotor on the stator is supported by the metal common electrode. It is important to determine the weight of the rotor. The relationship of the weight of the rotor and the rotation speed is shown in Fig.6. When the rotor is very light, the friction force between the rotor and the stator is too small to drive the rotor. On the other hand, When the rotor is very heavy, the friction force hinders the rotation on the contrary. Only in the case of the rotor with a proper weight, it can rotate steadily and continuously. In addition, the structure of the rotor is another important factor that influences the rotation mode. Therefore, the piezoelectric motor with a proper rotor, i.e., of proper weight and well-designed structure, can be in the best rotation state.

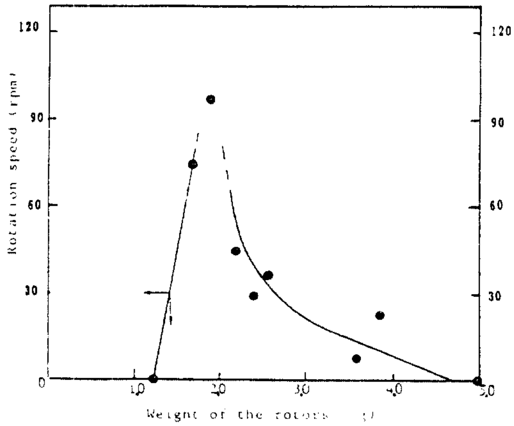

Fig.6 Relationship between the rotation speed and the weight of the rotors

2. Comparison of the rotation speed for the rotor with the two structures

There is no sensible difference of the rotation speed wherever the rotor is supported, by the common electrode or the fans as shown in Fig.7 and Fig.8.

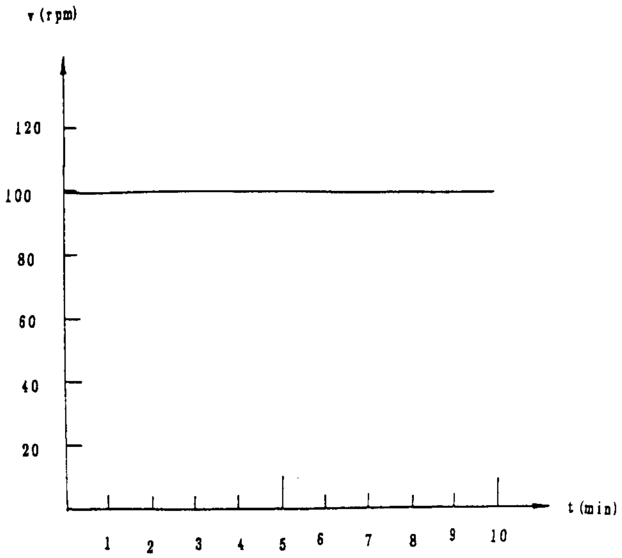

Fig.7 Rotation characteristics of the new motor

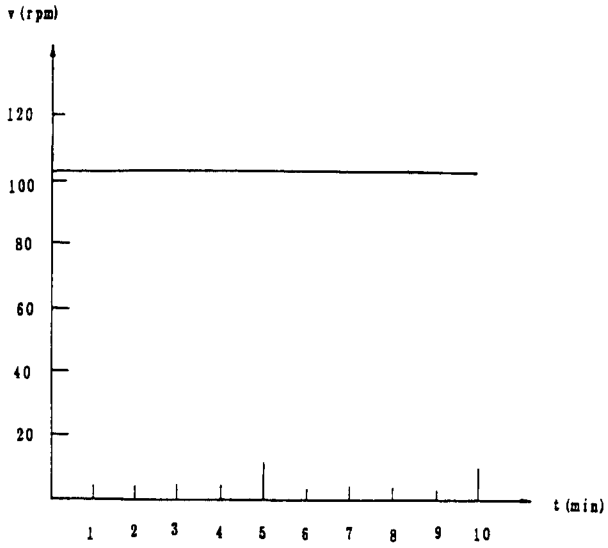

Fig.8 Rotation characteriscics of the traditional motor

3.Relationship between the resonant frequency and rotation speed
The experiment showed that the rotation speed is sensitive to the excitation frequency, i.e., unless the piezoelectric membrane is resonantly excited, it produces large mechanical output to drive the rotor. The rotor of the new structre motor can rotate only at the resonant frequency and its frequency doubling. However, the mechanical output is of a great difference. With a small frequency shift from the resonant frequency or its doubling value, the rotation speed decreases sharply and soon reaches zero. In Fig.9. The relationship between the excitation frequency and rotation speed for the rotor with proper weight is shown.

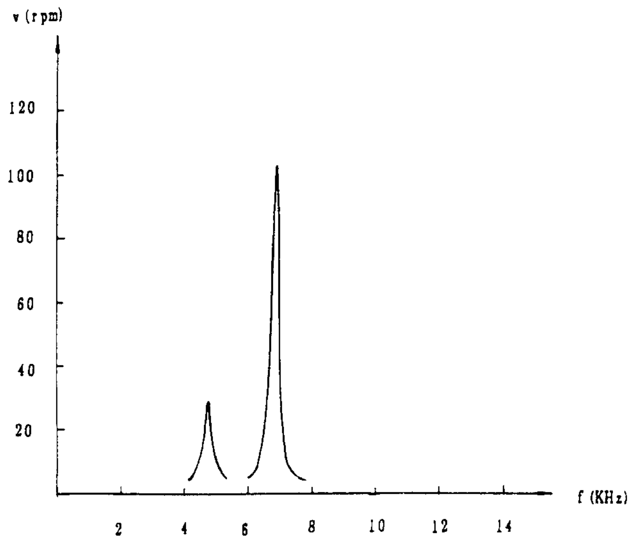

Fig.9 Relationship between the rotation speed

and the resonant frequency

Discussion

In this piezoelectric motor with such a new and simple structure, the rotor and stator of piezoelectric micromotor can be fabricated with IC process.
The problem of the short between fans can be solved in our structure even though the rotor is fabricated with metal materials.

Further, the piezoelectric micromotor with 2mm diameter can be fabricated.

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