Chapter 10

Thin Film Piezoelectrics for MEMS

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Thin film piezoelectric materials offer a number of advantages in microelectromechanical systems (MEMS), due to the large motions that can be generated, often with low hysteresis, the high available energy densities, as well as high sensitivity sensors with wide dynamic ranges, and low power requirements. This chapter reviews the literature in this field, with an emphasis on the factors that impact the magnitude of the available piezoelectric response. For non-ferroelectric piezoelectrics such as ZnO and AlN, the importance of film orientation is discussed. The high available electrical resistivity in AlN, its compatibility with CMOS processing, and its high frequency constant make it especially attractive in resonator applications. The higher piezoelectric response available in ferroelectric films enables lower voltage operation of actuators, as well as high sensitivity sensors. Among ferroelectric films, the majority of the MEMS sensors and actuators developed have utilized lead zirconate titanate (PZT) films as the transducer. Randomly oriented PZT 52/48 films show piezoelectric $e_{31,f}$ coefficients of about $-7$ C/m$^2$ at the morphotropic phase boundary. In ferroelectric films, orientation, composition, grain size, defect chemistry, and mechanical boundary conditions all impact the observed piezoelectric coefficients. The highest achievable piezoelectric responses can be observed in $\{001\}$ oriented rhombohedrally-distorted perovskites. For a variety of such films, $e_{31,f}$ coefficients of $-12$ to $-27$ C/m$^2$ have been reported.
1. Introduction

The field of MEMS is a large and growing one, with numerous means reported for both sensing and actuation on-chip. Given the plethora of mechanisms by which the environment can be detected and/or useful responses made, it is worth considering the impetus for integrating piezoelectric thin films into MEMS devices (i.e. what advantages offset the need to introduce new materials into the cleanroom environment?). As usual, the answer to such a question depends significantly on the device or function in question. However, a couple of attributes come to the fore in promoting the use of piezoelectric devices in MEMS applications. These include:

1) The relatively straightforward manner in which high frequency resonant structures, with good temperature stability, can be implemented. At present there is a substantial research effort in developing MEMS devices with high electrical quality factors for rf circuits. Low frequencies are straightforward to obtain via MEMS techniques [1, 2]. While considerable progress has been made recently in the development of electrostatically actuated devices with high resonant frequencies [3, 4], these devices are inherently rather small, require sophisticated patterning techniques, and are susceptible to mass-loading changes on environmental exposure. In contrast, piezoelectric resonators with resonant frequencies in the high MHz—GHz range are widely used in scanning acoustic microscopes [5], and have seen considerable development in thin film bulk acoustic resonators (FBAR) [6, 7].

2) Piezoelectric sensors do not require power themselves (although of course any associated electronics such as charge or voltage amplifiers, etc, will need to be powered). As a result, piezoelectric MEMS are interesting for low power requirement sensors. Indeed, in situations where the sensor is operated only on an intermittent basis, it is also possible to visualize using any such sensor in a mechanically noisy environment as a power source the remainder of the time. Such energy harvesting schemes have been implemented in bulk and thick film piezoelectrics [8, 9, 10, 11]. Moreover, as sensors, it is possible to design piezoelectric devices with broad dynamic range and low noise floors.

3) The ability to perform large amplitude actuation with lower drive voltages and low hysteresis. The preponderance of MEMS literature utilizes electrostatic actuation of flexural structures. Electrostatics is relatively easy to implement, and offers the possibility of large amplitude actuation, though typically at the cost of large driving voltages and substantial hysteresis. Current-based actuation approaches, such as those utilized in many thermal and magnetically driven devices, typically require high power to operate, and in some cases are inherently slow (e.g. due to thermal time constants). In contrast, the piezoelectric effect can be utilized to drive large displacements in MEMS structures at modest voltages, low powers, and with low hysteresis.

4) The fact that piezoelectricity shows good scaling with size. That is, the energy density available for actuation remains high, even as device sizes drop. Poor scaling is, of course, one of the principal reasons that electromagnetic motors are not attractive at MEMS size scales.