MICROMACHINED ULTRASONIC MATERIALS

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ABSTRACT

Ultrasonic matching layers are necessary for efficient coupling between piezoelectric ceramics and either air or water. Current materials are formed by suspending particles in an epoxy matrix. We propose a new technique using silicon micromachining techniques and IC fabrication technology to build low loss, high purity, and controllable acoustic matching layers. We have demonstrated the fabrication technique, and have measured the performance of micromachined matching layers as compared with theory. With this technique it is possible to fabricate ultrasonic matching layers with impedances between .02 and 20 MRayls for operation at frequencies between 1 and 200 MHz.

INTRODUCTION

Acoustic matching layers are commonly used to increase coupling efficiency and to increase bandwidth. These materials must have specific acoustic properties for optimum performance. Traditionally, for coupling of ultrasound into water, a mixture of silicon nitride or tungsten powder in epoxy resin is used. By carefully controlling the amount of powder, a chosen acoustic impedance is obtained.

We propose using a new technique for the fabrication of materials with controlled acoustic properties. This technique relies on processes developed for micromachining and integrated circuits. By using silicon as an ultrasonic material, we gain the low cost, high purity, and low acoustic losses associated with simple crystals.

FABRICATION OF COMPOSITE MATERIALS

To fabricate our composite material, we etch deep vertical wall trenches and holes in a silicon substrate. Two techniques are used for this purpose. In the first technique, described by Petersen,[1] <110> oriented silicon wafers are patterned with a grating such that the lines in the grating are parallel with the <111> planes of the wafer. By using silicon nitride as a mask, and etching in hot potassium hydroxide (80°C, 11 M KOH), deep, high aspect ratio silicon structures are fabricated. Such a structure is shown in Fig. 1. These silicon structures are then vacuum impregnated with epoxy resin and bonded to PZT ceramic. The sample is then lapped to the appropriate thickness. A cross section of one such device is shown in Fig. 2. The epoxy resin is obsereved to completely fill the silicon trenches with no visible air bubbles.

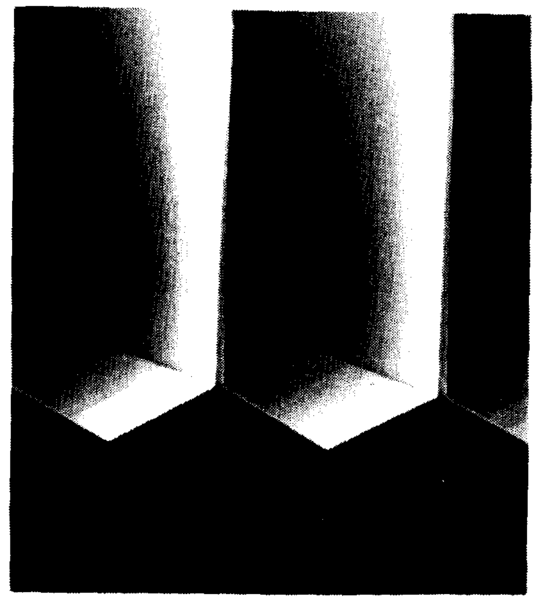

Fig. 1. Anisotropically etched silicon grating of 50 μm period. Structures are 250 μm tall and 2 μm wide.

Another technique for fabricating high aspect ratio structures in silicon is plasma etching, a dry etching process. This technique allows two-dimensional patterns to be built, but suffers from long etch times and less anisotropy than the orientation-dependent chemical etching. We use this method to fabricate a matching layer for coupling into air at approximately 200 MHz (shown in Fig. 3). Note that the acoustic properties of this structure were not measured.

THEORETICAL PERFORMANCE OF COMPOSITES

A good theoretical model for calculating the acoustic properties of composite structures was developed by Smith et al[2] for piezoelectric composites. We modified this model to calculate the mechanical properties of the different types of composites that are made by micromachining. The theoretical performance of the KOH etched structures (type 2-2 composites), the plasma etched structures (1-3 composites), and particles of silicon suspended in resin[3] (0-3 composites) are shown in Fig. 4.

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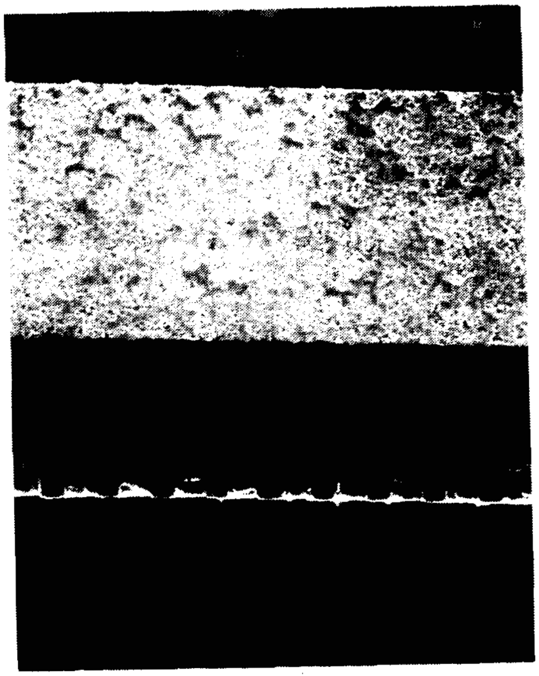
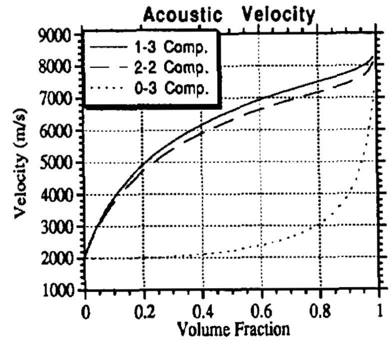


Fig. 2. Cross section of piezoelectric transducer with silicon-epoxy composite matching layer. PZT is 240 µm thick. Composite is 145 µm thick with 50 µm period.

Fig. 3. Silicon posts on silicon substrate. Posts are 5000 Å tall, 400 Å thick, and on a grid with 3500 Å spacing.



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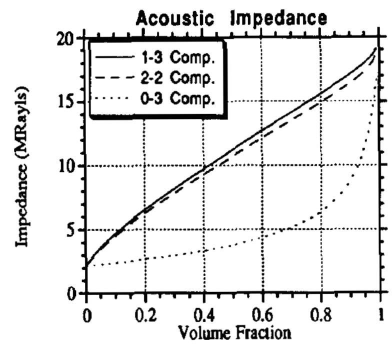


(b)

Fig. 4. (a) Theoretical acoustic velocity of 0-3, 1-3, and 2-2 composites. (b) Theoretical acoustic impedance of 0-3, 1-3, and 2-2 composites.

ACOUSTIC MEASUREMENT SYSTEM

Measurements of the acoustic properties of the matching layer were performed by measuring the electrical impedance of an air backed transducer, as shown in Fig. 2. Using the KLM model[4] for predicting the response of this transducer, and knowing the properties of the piezoelectric material, the acoustic properties of the matching layer can be inferred. Since we know the density and thickness of the matching layer, the only parameter we derive from the measurement is the effective stiffness of the composite (the acoustic velocity is the square root of the stiffness divided by the density; the acoustic impedance is the square root of the stiffness multiplied by the density). A typical measurement of the electrical input impedance of a transducer with a composite matching layer and its comparison to theory are shown in Fig. 5.

EXPERIMENTAL RESULTS

Samples were prepared with a variety of volume fractions of silicon and epoxy resin. We measured the effective stiffness of two samples with high confidence. The comparison of these results with theory is shown in Fig. 6. The agreement with theory is excellent.

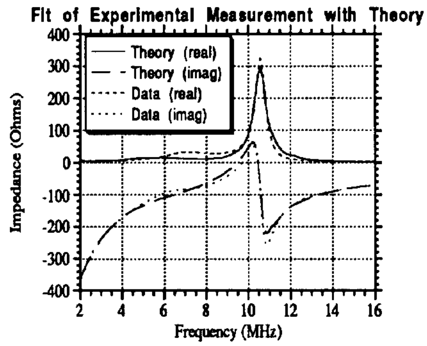
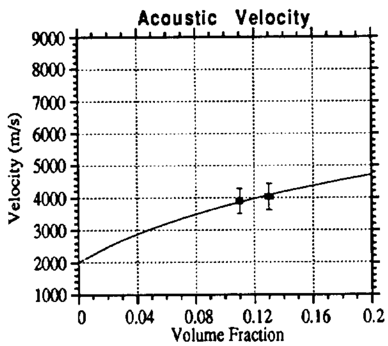


Fig. 5. Comparison of measured electrical impedance and KLM model result with 'measured' effective matching layer stiffness.



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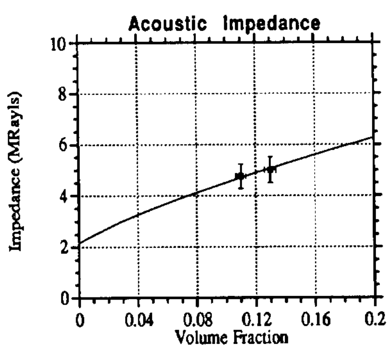

(b)

Fig. 6. (a) Comparison of measured acoustic velocity with theoretical prediction. (b) Comparison of measured acoustic impedance with theoretical prediction.

CONCLUSION

We have introduced a new technique for the fabrication of acoustic matching layers. This technique offers excellent control over a wide range of acoustic impedances, low cost, and use between 1 and 200 MHz with current fabrication techniques. We believe that this technology has applications for medical ultrasound transducers, acoustic microscopy, and for the efficient coupling of high-frequency ultrasound into air. We are presently investigating the use of the technology for making higher impedance materials for use with multiple matching layers.

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REFERENCES

1. K. Petersen, "Silicon as a Mechanical Material," Proc. of the IEEE **70** (5), 420 (1982).

2. W. Smith, A. Shaulov, and B. Auld, "Tailoring the Properties of Composite Piezoelectric Materials for Medical Ultrasonic Transducers," Proc. IEEE Ultrasonics Symp., IEEE Catalog No. 85CH2209-5SU, Ed: B. R. McAvoy, 746-749 (Institute of Electrical & Electronics Engineers, Inc., New York, 1985)..

3. M. G. Grewe, *Acoustic Matching and Backing Layers for Ultrasonics*, M.S. Thesis, Solid State Science, Pennsylvania State University, University Park, PA (1989).

4. R. Krimholtz, D. Leedom, and G. Matthaei, "New Equivalent Circuits for Elementary Piezoelectric Transducers," *Electron. Lett.* **6**, 398-399 (1970).