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Improvement in the Efficiency of Thermally-Induced Ultrasonic Emission from Porous Silicon by Nano-structural Control

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1. Introduction

The thermal conductivity α and heat capacity per unit volume C of nanocrystalline porous silicon (nc-PS) are extremely low in comparison to those of single-crystalline silicon (c-Si). This high contrast of thermal properties induced by strong quantum confinement makes it possible to use the nc-PS device as an ultrasonic emitter by efficient heat transfer at the surface without any mechanical vibrations [1,2].

In this device, the most important key parameter is the product αC, since the theoretical output sound pressure is inversely proportional to $(\alpha C)^{1/2}$ [1,3]. Taking account of that α and C values of nc-PS should strongly depend on its nanostructure, the acoustic characteristics have been studied for the nc-PS samples with various porosities in this work.

2. Experiment

The fabricated device is composed of a thin-film surface electrode, an nc-PS layer, and a c-Si substrate. The substrates used were p^--type (80-120 Ωcm) or p^+-type (0.01-0.02 Ωcm) (100) c-Si wafers. The nc-PS layers were prepared by electrochemical anodization of c-Si wafers in a solution of 55%HF:ethanol=1:1-1:3 at a current density of 20-150 mA/cm^2. Under these conditions, the porosity determined separately from the gravimetric method was varied in the range from 38 to 90%. For the samples with porosities higher than 70%, supercritical drying in CO_2 was employed to avoid neither mechanical collapses nor cracks due to internal local stress. The nc-PS layer thickness was about 50 μm. After anodization, a thin tungsten film (50 nm thick) was deposited by rf-sputtering onto the nc-PS layer. The electrode size corresponding to the ultrasound emission area was 5×5 mm^2.

The electrical input is provided to the Al electrode pad as a sinusoidal ac current. Following the induced Joule's heating, the temperature at the device surface fluctuates effectively, since the nc-PS layer acts as an efficient thermal insulator. This surface temperature change is quickly transferred into expansion and compression of air, and then an sound pressure is generated. The emitted sound pressure is measured separately by a microphone located at a distance of 5 mm from the device surface.

3. Results and discussion

Table 1 shows the porosity values of experimental nc-PS layers prepared on the p^--type substrates under various anodization conditions. The porosity becomes higher at high anodization currents and at low HF concentrations as expected. Cross-sectional SEM images of nc-PS layers without and with supercritical drying are shown in **Fig. 1** (a) and (b), respectively. This sample (porosity: 90%) was anodized in a solution of 55%HF:ethanol=1:2 at a current density of 50mA/cm^2. We can see from Fig. 1 (b) that supercritical drying is very useful for fabricating a high-porosity nc-PS layer tightly on the c-Si substrate without making rugged and cracked surface features.

The measured sound pressure amplitudes at a constant ac input power (1 W in this case) are plotted in **Fig. 2** as a function of the porosity. The device with a low porosity of 38% was fabricated on the p^+-type substrate. The sound pressure is increased in proportion to the porosity of nc-PS layer. This result suggests that the αC value is rapidly decreased with increasing the porosity.

Table 1. Porosity values of nc-PS layers formed on the p^--type wafer at various anodization conditions.

55% HF:EtOH ratio	Porosity (%) Current densitiy (mA/cm^2) 20	50	100	150
1:1	60	62	68	65
1:1.5	62	68	72	87
1:2	73	90	>90	>90
1:3	>90	–	–	–

– : electropolished

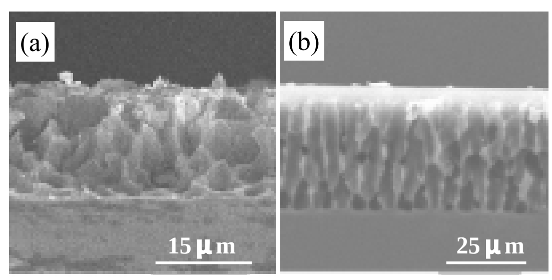

Fig. 1. Cross-sectional SEM images of nc-PS layers with a porosity of 90%. (a) Conventionally dried in air. (b) Supercritically dried in CO_2.

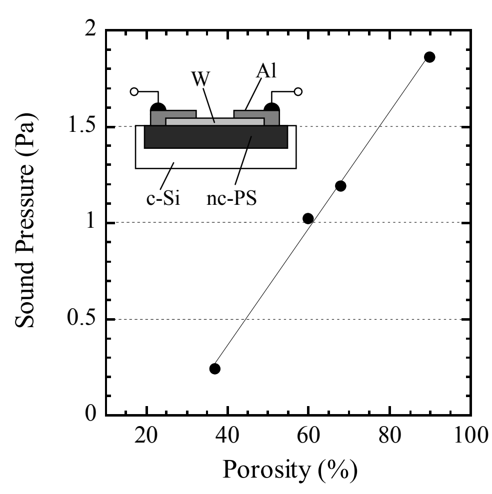

Fig. 2. Measured sound pressure amplitudes at 100kHz as a function of the porosity. Schematic cross section of the device is also illustrated.

References

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