Effect of crystal orientation and environment on fatigue lifetime of single crystal silicon

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This paper deals with the effect of crystal orientation and environment on fatigue lifetime of single crystal silicon (SCS). Fatigue lifetime was examined with the same shape of specimen, with same level of applied stress in two different environment of lab air and hydrogen with two different crystal orientation specimens of (100) wafer with <110> notch orientation and (111) wafer with <11-2> notch orientation. The resulting lifetime shows slight difference in between two different crystal orientation specimens. But for the case of different environment there is no significant difference in lifetime for the both two type of specimen even though level of difference in relative humidity was 30%.

Key Words: Single crystal silicon, Crystal orientation, Fatigue lifetime, Relative humidity

1. Introduction:

Miniaturization is the modern trend in the fast growing world, in which silicon MEMS technology plays an important role in field of micro-machines. But the fatigue failure in MEMS devices raises the reliability issue, that fatigue issue should be cleared to further expand commercial application to critical equipment. The reason for the fatigue failure was still a mystery. Which will be the dominant factor that leads the delayed fatigue failure was brittle fracture or dislocation associated slip deformation fracture. In this paper a small attempt has been made to identify the dominant factor of fatigue failure by comparing the lifetime between the two different crystallographic orientation specimens and between the two different environments.

2. Specimen and Experimental setup

2.1. Specimen preparation:

In this experiment, the specimen of 60 mm × 6 mm was used. This specimen prepared from the p-type single crystal silicon (SCS) wafer which has dimensions of 76.2 mm diameter and 380±25 μm thickness. The notch for stress concentration was made with a dicing machine (DAD322, Disco corp.). The notch length was 100 μm and width was 30 μm. As the initial defect, some sort of dislocation was mechanically induced into specimen by way of the dicing process. The stress ratio R (minimum stress/maximum stress) for our experiment was set as -1, equal tension and compression in cycling. To identify the dominant factor of fatigue failure clearly, the two different crystal orientation specimens were chosen among from the possible four crystal orientation the stress on the entire slip system was calculated by using Abaqus FEM analysis and stress transformation equations with Euler’s angle. In that the three crystal orientation stress level except (111) wafer with <11-2> gives more or less the same ratio with shear stress have the influence on the activation energy of slip plane to shear stress on slip plane that the shear stress on the slip plane is twice higher than the compressive stress on the slip plane. So the two different crystal orientation specimen may give the evidence to identify the dominant factor of fatigue failure through comparing fatigue lifetime and fractographic analysis. Because lot more researches reported that the compressive stress aids to the accumulation of defects (2) and compressive along with shear stress have the influence on the activation energy of dislocation nucleation (3).

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![Fig. 1 Different type crystal orientation specimens](image)

The experimental setups and the procedures are the same as the previous experiments (1).

3. Observation and results:

The following fig. 2 shows the cumulative failure probability for two different crystal orientation specimens in two different environments. The static fracture stress was slightly differed in two different environments for both cases of crystal orientation specimen. But the difference was not at the significant level. Even though the shape and dimension of the specimen was same for the both cases, the static fracture stress was varied because of the change in the crystal orientation anisotropic silicon yields different value of static fracture stress. For the case of (100) wafer with <110> notch orientation specimen the static fracture stress in lab air was 1.26GPa and in hydrogen environment was 1.22GPa. As like for the case of (111) wafer with <11-2> notch orientation specimen lab air was 1.39GPa and in hydrogen was 1.37GPa. The fatigue test results obtained were plotted in Fig.3, with the number...
of cycles to failure in horizontal axis and the applied normalized stress level in vertical axis. The lifetime curve obtained from the lab air environment showed that it is well within the common trend of lifetime curve of silicon (4). The fatigue lifetime curve shows that the lifetime was slightly high in (111) wafer with <11-2> notch orientation specimen than (100) wafer with <110> notch orientation specimens. Also there was no significant difference in the lifetime between two different environments for both cases even though the level of relative humidity was decreased from 35% to 5%

4. Discussion:
As all we know shear stress plays a major role in fracture of mechanic materials. Also Kamiya et.al (2) reported that the compressive stress should accumulate the defect present inside the specimen. Izumi et.al (3) reported that compressive stress has the influence on the activation energy of the dislocation nucleation. Also as per Izumi et al. hypothesis compressive stress enhances the shear deformation on the slip plane and inversely, tensile stress on the slip plane would have reduced the shear deformation. In our cases the (100) wafer with <110> notch orientation specimen stress calculation results shows that the compressive stress was 0.819 GPa and the maximum shear was 0.691 GPa. So the effect of defect accumulation and the shear deformation enhancement was higher than (111) wafer with <11-2> notch orientation specimen. Because the compressive stress (111) wafer with <11-2> notch orientation specimen was 0.202 GPa, which was half the time lesser than the maximum shear on the same slip plane 0.496 GPa. So the defect accumulation and shear deformation enhancement effect by the compressive was less, that’s so the lifetime was slightly higher. But with the current data it is not possible to say quantitative how much amount the lifetime was higher. For that I planned to do the experiment more than three times on the same amount of applied normalized stress level with two different specimens in two different environments.

The fatigue lifetime was slightly high in (111) wafer with <11-2> notch orientation specimen, where the amount of compressive stress was half the amount of shear stress. There is not much significant amount of difference in the fatigue lifetime in between two environments even though the relative humidity was decreased to 5% from 35%, so hydrogen might have the same effect as like relative humidity. Have to do fractography analysis to identify the dominating factor of fatigue failure.

Fig. 3 Lifetime curve of silicon under different environment

5. Conclusion:
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References: