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집속 이온빔을 이용한 투과 전자 현미경 시편의 표면 영향에 관한 연구

(Study on Surface Damage of Specimen for Transmission Electron Microscopy(TEM) Using Focused Ion Beam(FIB))

김 동 식*

(DongSik KIM)

요 약

TEM(Transmission Electrion microsopy) 투과전자현미경은 재료의 기초 구조 분석과 반도체 또는 생물시편의 미세 구조 분석에 널리 사용되는 장비이다. TEM 분석은 필수적으로 목적에 부합되는 적절한 시편제작이 수반되어야 한다. 다양한 전자 현미경 시편 제작 방법 중 본 논문에서는 FIB(Focus Ion Beam)를 이용한 시편 제작법 중 시편에 입사되는 에너지와 이온 Gun과 시편과의 상호 각도, 이온 밀링 깊이 조절 등의 실험을 통하여 표면 손상 최소화를 벌크 웨이퍼와 패턴화된 시편에서 실험하였다. 최소화된 표면 영향성(약 5nm)을 패턴화된 시편에 구현하였다.

Abstract

TEM is a powerful tool for semiconductor material analyses in structure or biological sample in micro structure. TEM observation need to make to coincide specimens for special purpose. in this paper, we have experimented for minimum surface damage on bulk wafer and patterned specimen by various conditions such as accelerating energy, depth of ion beam, ion milling types, and etc. in various specimen preparation methods by FIB(Focus Ion Beam). The optimal qualified specimens are contain low mounts of surface damage(about 5 nm) on patterned specimen.

Keywords : SEM, TEM, FIB, surface damage

Ⅰ. INTRODUCTION

Recently, semiconductor device's design rules continuously are shrunk to deep sub-micron. These devices demands more complicate process and high resolution analysis tools which are Scanning Electron Microscopy (SEM), Focused Ion Beam(FIB) and Transmission Electron Microscopy (TEM). TEM is a powerful tool in structure and elemental analyses. Since TEM observation is limited by specimen preparation, So we have to consider the designed size of devices and reduce the physical thickness of specimen.

Fig 1. show semiconductor process integration, devices road-map. Proper specimen thickness is to be a half of design rule.

Thin specimen can be done by conventional grinding methods or Focused Ion Beam(FIB) milling Methods. Grinding methods can make very thin specimen, which thickness is zero to a few nano

* 평생회원, 인하공업전문대학 컴퓨터시스템과
(Dept. of Computer Systems & Engineering, Inha Technical College)

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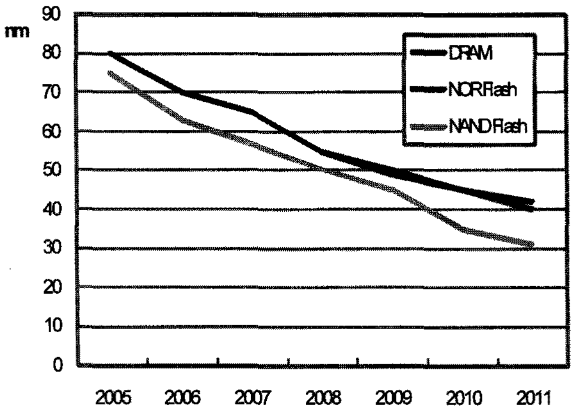


그림 1. 2005 반도체 국제기술 로드맵
Fig. 1. The international technology road-map for semiconductors : 2005.

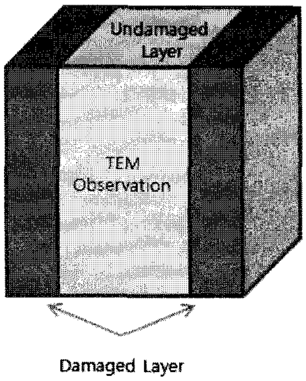


그림 2. TEM 시편의 투시도
Fig. 2. Perspective scheme view of TEM specimen.

meters, very low specimen surface damage. However, It is not suitable for patterned device or specific failure analysis. In FIB, Specific and patterned area of specimen can be made easily from FIB imaging capability which has SEM detector in chamber. Nevertheless, FIB has a wide damage layer caused by the Ga+ ion implantation as shown Fig 2.[1]

These damaged layers can be reduced by additional argon ion beam milling after FIB Ga+ ion milling or using the low energy milling in FIB. conventional FIB specimen preparation methods have about 20nm thickness of side wall damage in specimen at 30KeV[2~4]. It means that specimen is fully amorphousness, so we can't observe TEM image under 50nm designed devices. We experiment the technique for reducing sidewall damage by using low energy ion beam milling.

Ⅱ. EXPERIMENTAL

2.1 Experiment Tools

Specimen preparation are done by energy ranges from 30KeV to 5KeV respectively. Previous specimen preparation technique is used only 30KeV. Our all process are used Omni probe in-situ lifting system, and final step low energy treated. We have divided specimen groups as follows: non patterned specimen, real patterned specimen. For each group, I have performed two kinds of milling energy: 5KeV after 30KeV, 5KeV+2KeV after 30KeV. In addition, we have tested the tiling angle of specimen, incident ion beam depth on specimen, including ion milling types: the box clean cross section and the whole surface clean cross section

2-2 Specimen preparation process

The specimen preparation process is followed respectively.

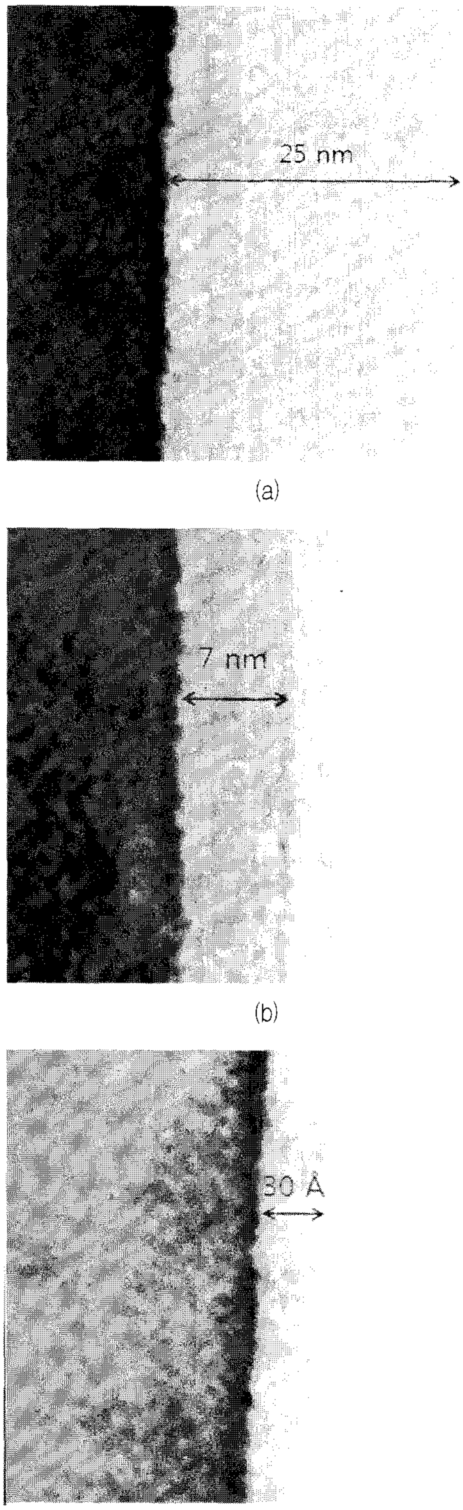
(a) Deposition a platinum protective layer on specific area
(b) Rough ion milling
(c) Pre-cutting for lift-out
(d) Lifting out specimen
(e) Attachment specimen to side of grid
(f) Fine milling front side
(g) Low energy treatments front side
(h) Fine milling back side
(i) Low energy treatments back side
(h) Checking the final thickness

We have replaced a top-attached type with as side-attached. Side-attached type give a advantage of preventing contamination from grid. materials: Cu, Ni

Ⅲ. RESULTS & DISCUSSIONS

3.1 Low energy test in non patterned specimen.

We have tested damage layer thickness and for



(a)

(b)

(c)

그림 3. 에너지별 손상층 HR-TEM 영상; (a) 30KeV, (b) 30KeV after 5KeV 5분 추가, (c) 30KeV after 5KeV 5분 after 2KeV 10분 추가

Fig. 3. HR-TEM image for side wall damage in non patterned specimen; (a) 30KeV only, (b) 30KeV after 5KeV 5min, (c) 30KeV after 5KeV 5min after 2KeV 10min.

various ion beam energy range such as 30KeV, 16KeV, 10KeV, 8KeV, 5KeV. Ion beam energy decreasing is less affect on surface of specimen from the Ga+ ion bombardment[5~6]. This test means ion beam energy is strongly related to thickness of damaged layer.

To apply real patterned specimen, we have pre-tested combination of energy in bare wafer: 30KeV only, 30KeV after 5KeV, 30KeV after 5KeV after 2KeV in non patterned specimen. The specimen was pre-thined until 70nm thickness of specimen by 30KeV, then additional treated by 5KeV, 2KeV. There were very small mounts of thickness of damage about 3nm. HR-TEM analysis shows Fig 3.

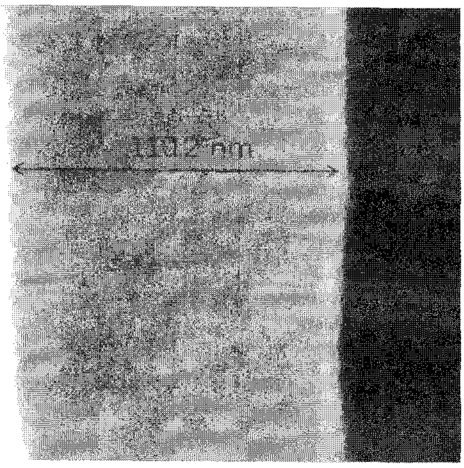
As decreasing energy, Specimen has poor surface roughness, it make overlapped image during the TEM observations.

3.2 Low energy test in patterned specimen

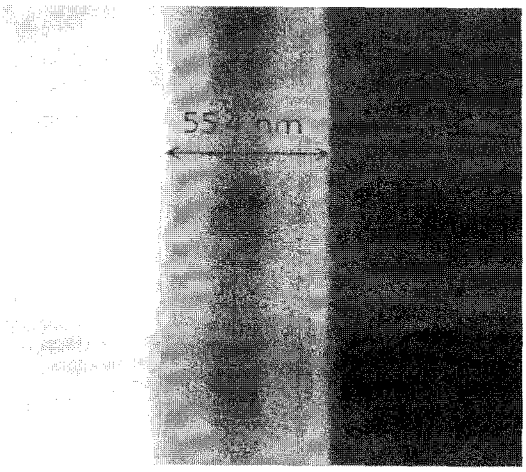
We have three way tested to make very thin and small mounts of damage in patterned specimen: tilting angle splits (52±3°, 52±6°, 52±8°), incident ion beam depth splits (30nm, 50nm, 70nm) at 5KeV and 52±6°, ion milling types(the box clean cross section, the whole surface clean cross section). As ion incident beam depth are deeper, The specimen thickness are gradually thinned, most thin condition is 70nm in Fig 4.

Tilting is used to remove tapered specimen. But excessive tilting angle make not only accelerating side wall damage but also changing the specimen profile like inverted triangle. the best tilting angle is 52±6° at 60nm incident ion beam depth. Fig 4.

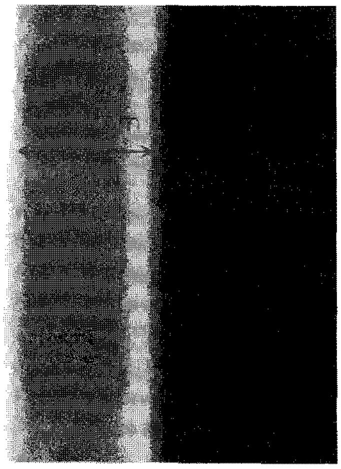
In combination energy split, we can't exactly draw ion milling box caused by ion beam detector resolution is low. So we have separated type of each ion beam milling box for each energy(the box clean cross section at 5KeV, the whole surface clean cross section at 2KeV) in Fig 5 and Fig 6.



(a)



(b)



(c)

그림 4. 시편 두께에 따른 FIB 영상(tilting angle(52±6°)); (a)30nm, (b) 50nm, (c) 70nm

Fig. 4. The FIB cross section images for specimen thicknessat same tilting angle(52±6°) and energy(5KeV); (a) 30nm, (b) 50nm, (c) 70nm

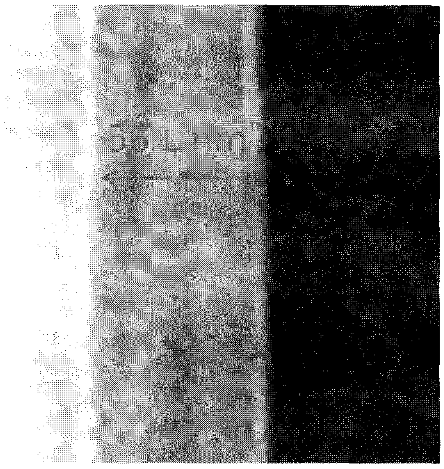


그림 5. 2KeV 스퍼터링 후 FIB 영상

Fig. 5. The FIB cross section image for specimen thicknessafter 2KeV sputtering

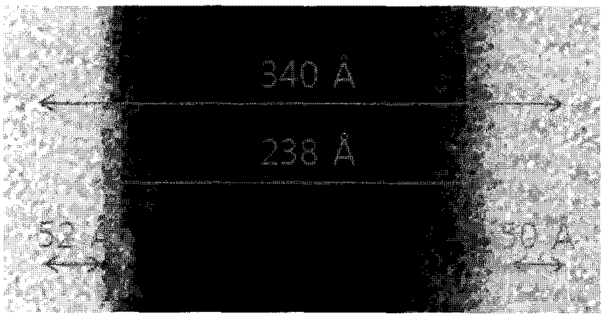


그림 6. 2KeV 스퍼터링 후 시편 측면 손상 HR-TEM 영상

Fig. 6. HR-TEM image for side wall damage in patterned specimen.

Ⅳ. CONCLUSIONS

We have found optimized condition in low energy region as summarized: energy 5KeV, tilting angle 52±6°, and incident ion beam depth 50nm, box clean cross section and have calculated etch rate in etch energy: · 5KeV 3.1nm/min, 2KeV 0.29nm/min. From this experiments, we have successfully developed specimen preparation methods which used to under 50nm designed semiconductor devices TEM analysis. As Device are more smaller & small. We have to develop more lower energy Ion beam and higher resolution , Stable beam FIB.

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저 자 소 개

김 동 식(평생회원)
대한전자공학회 논문지
제45권 IE편 제3호 참조
현재 인하공업전문대학 컴퓨터시스템과 부교수