Subsurface Imaging with Widefield and Confocal Numerical Aperture Increasing Lens Microscopes

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Abstract- **We obtain lateral spatial resolutions of 0.88 µm and 0.29 µm with custom infrared widefield and confocal numerical aperture increasing lens microscopes, respectively, when imaging subsurface structures. We discuss the relative advantages of each microscope.**

I. INTRODUCTION

As succeeding generations of flip-chip integrated circuit (IC) fabrication technology has pushed minimum feature sizes to less than 100 nm, the need to image subsurface features with deep submicron resolution has grown. This need is evidenced by the recent development of schemes to images such features with increasing resolution [1-3].

Here, we report a lateral resolution of 0.88 µm while imaging subsurface features using a custom infrared widefield microscope and a numerical aperture increasing lens (NAIL). We compare this to results obtained with a confocal microscope and a NAIL and discuss the relative advantages and disadvantages of the widefield microscope.

II. EXPERIMENT

We constructed custom widefield and confocal microscopes to obtain infrared reflection images of subsurface metal structures while using a NAIL.

The widefield microscope body consists of Thales Optem components: a vertical illuminator, a near infrared (NIR) Zoom Module, and a 2X tube lens. The illumination source is an Epitex L1200-66-60 LED array with a peak wavelength of 1200 nm. An infinity corrected NIR 10X objective (NA = 0.26) collects infrared radiation reflected from the sample. The collected radiation is imaged onto the CCD array (320 × 240 pixels) of a Sensors Unlimited InGaAs NIR minicamera. Camera images are recorded using a National Instruments (NI) image acquisition board together with NI Vision Assistant software.

The confocal microscope consists of a diode laser for illumination (λ = 1.3 µm), a 2 × 2 fiber optic splitter, an optical fiber (NA = 0.12), an infinity corrected NIR 5X objective (NA = 0.14) as the eyepiece, and an infinity corrected NIR 10X objective. Infrared radiation reflected from the sample is collected and collimated by the objective, and then focused by the eyepiece onto the facet of the fiber optic. The signal transmitted through the 2 × 2 splitter is detected with a photo receiver and recorded using LabVIEW software. The sample position is rastered using an XY translation stage and piezoelectric controllers.

The NAIL was an undoped silicon hemisphere with radius R = 1.610 mm and central thickness D = 1.955 mm. After cleaning the planar surfaces of the NAIL and a sample with acetone, methanol, and DI water, the NAIL was bonded to the sample with DI water that was then allowed to evaporate.

Samples consisted of metal structures that were produced by depositing a layer of aluminum on 100 µm thick double polished silicon wafers followed by photolithographic patterning. A layer of chromium was subsequently deposited on some of the samples to eliminate observed shadows due to a Goos-Hänchen shift [4]. Aluminum layer thicknesses varied from 50 to 100 nm while chromium layer thicknesses varied from 30 to 100 nm for different samples. Each layer thickness was constant within a single sample. The NAIL was placed on the polished silicon surface opposite that of the metallized surface.

III. RESULTS

We tested the resolution of each microscope in the absence of the NAIL using features contained in a Richardson Test Slide. The widefield microscope achieved a lateral spatial resolution of 3.47 µm and the theoretically expected value was $0.51\lambda/NA = 0.51(1.2\ \mu m)/(0.26) = 2.35\ \mu m$ [5]. The confocal microscope achieved a lateral spatial resolution of 2.41 µm and the theoretically expected value is $0.37\lambda/NA = 0.37(1.3\ \mu m)/(0.26) = 1.85\ \mu m$ [5]. The differences between the observed and theoretical values are thought to be due to aberrations in the zoom module.

The widefield microscope was used to obtain inspection images of subsurface Al and Al/Cr structures. Fig. 1(a) shows the Al structure. The shadow due to Goos-Hänchen shift can be seen along the sides of the pattern. The image of the Al/Cr structure is shown in Fig. 1(b), in which the shadows are absent. A high resolution image of Al/Cr structure was subsequently obtained with the NAIL and is shown in Fig. 1(c). A linecut across the edge of the structure was fit to an error function as shown in Fig. 2 and the resulting fit was differentiated to obtain the point spread function (psf) shown in Fig. 3, which has a full width at half maximum (FWHM)

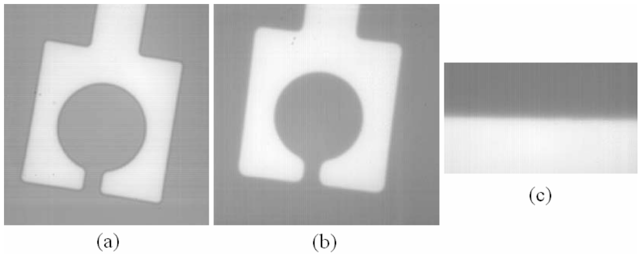

Fig. 1. (a) Widefield image of a subsurface Al structure. (b) Widefield image of a subsurface Al/Cr structure. (c) High resolution widefield image of one edge of the structure in (b) (zoom setting: 3X).

of 0.88 μm. This lateral spatial resolution is approximately three times better than that of the confocal microscope without the NAIL.

We used the confocal microscope to obtain linecut data across the same edge as was done with the widefield microscope. We fit these confocal linecut data (not shown) to the integral of the sinc function, and the corresponding psf has a FWHM of 0.29 μm, which is close to the previously reported lateral spatial resolution of 0.23 μm when using a NAIL with a confocal microscope [6]. Although this is approximately four times better than the widefield microscope using the NAIL, the advantage of the widefield microscope is the enhanced rate of image acquisition because of the elimination of scanning (relative to the confocal microscope). Furthermore, obtaining a better resolution in widefield imaging may also be possible by taking advantage of the increased contrast due to the Goos-Hänchen shift as reported in [7] for the confocal case.

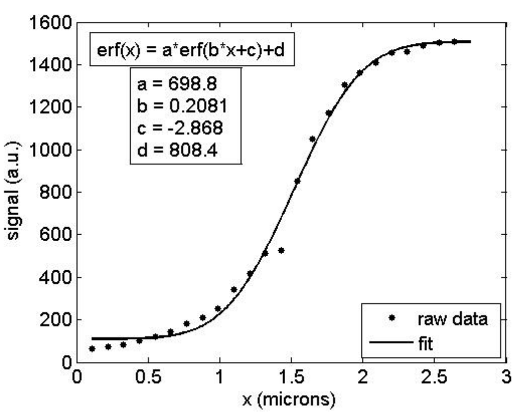

Fig. 2. Points: Linecut data across the edge shown in Fig. 1(c). Solid line: Error function fit to the data.

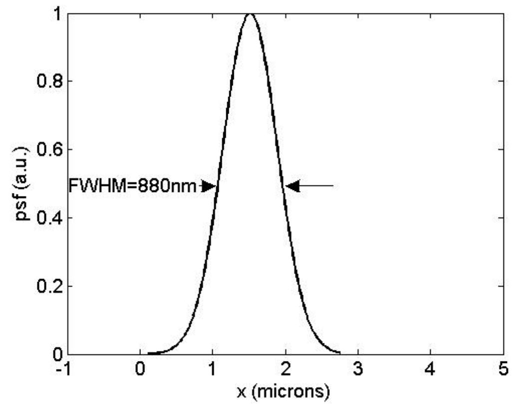

Fig. 3. Point spread function (psf) corresponding to the fit function shown in Fig. 2. The full width at half maximum (FWHM) of the psf is 0.88 μm.

IV. Conclusions

Increasing technical specifications for IC fabrication require enhanced failure analysis capabilities, thereby increasing the need for high resolution subsurface imaging. We have demonstrated lateral spatial resolutions of 0.88 μm and 0.29 μm with widefield and confocal numerical aperture increasing lens microscopes, respectively, when imaging passive subsurface metal structures. Widefield imaging seems to be promising for failure analysis when this submicron resolution is combined with the enhanced rate of image acquisition. Future work will focus on imaging live ICs.

V. References

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