IMAGING OF OVERLAY AND ALIGNMENT MARKERS UNDER OPAQUE LAYERS USING PICOSECOND LASER ACOUSTIC MEASUREMENTS

AM: Advanced Metrology

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ABSTRACT

I. INTRODUCTION

Optically opaque materials present a series of challenges for alignment and overlay in the semi-damascene process flow or after the processing of the magnetic tunnel junction (MTJ) of a Magnetic Random-Access Memory (MRAM). The overlay and alignment of a lithographically defined pattern on top of the pattern and the underlying layer is fundamental to device operation in all multi-layer patterned process flows. There are a wide variety of optical techniques and specially designed targets (Figure 2) that are used to address this problem in conventional flows. Typically, either an ultraviolet, visible, or infrared light is coupled through the top photoresist layer or an etched hard mask to be aligned to the bottom layer [1]. However, in some MRAM flows this coupling may not be possible as there may be an intervening opaque layer (Figure 1). In such cases, conventional methods of alignment using light fail. To overcome this issue, extra patterning operations may be used to open areas around the alignment features, but these operations add significant process cost.

In this paper we evaluate the use of picosecond laser acoustics (PLA) measurement as an alternative method to characterize the overlay and alignment patterns that are embedded under opaque metal films. We selected the MRAM process flow for this study where the different overlay and alignment markers were underneath opaque layers including an MTJ layer. These specific markers are imaged with the help of PLA employing an ultrafast laser in a pump and probe configuration to generate and detect acoustic waves capable of propagating through optically opaque layers. This technique, in sharp contrast with other competing acoustic imaging techniques such as scanning acoustic microscopy (SAM) [5,6], does not require the sample to be submerged in a coupling medium such as water.

II. MEASUREMENT METHODOLOGY

PLA is a well-established technique with an extensive publication history [9,10]. Briefly, a sub-picosecond laser pulse (< 0.5 nJ) is absorbed near the surface of a structure inducing a thermal stress which in turn produces a propagating acoustic strain pulse. A portion of the acoustic pulse will reflect from buried layers and return to the surface altering the reflectivity upon arrival. Another pulse, the probe, from the same laser is time delayed with respect to the pump to monitor the change in reflectivity. The impact of the pump may also be detected by monitoring the deflection of the surface using the probe pulse [7].

Shown in Figure 1 is a schematic sketch of the sample used for this study. The W/TaN bottom electrode is located under the magnetic tunnel junction (MTJ) stack and a 100 nm thick TiN layer. Visible and near-infrared light can be attenuated by as much as ~1000X when propagating through the TiN layer [8]. There is additional attenuation due to the metal based MTJ layer thus rendering the stack on top of the bottom electrode to be optically opaque. When aligning the memory-element layer of an MRAM device to its buried bottom electrode, this opacity leads to the failure of optical alignment and overlay measurements.

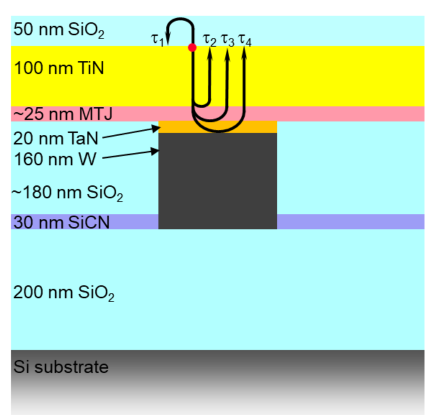

Fig 1. Cross-section of the samples used for picosecond laser acoustic measurements.

The experimental setup of this technique has been discussed in detail elsewhere [7]. The measurements performed in our study were collected using a short pulse laser at 520nm. The pulse duration of the laser is ~200 fs and the repetition rate ~63 MHz. The samples were placed so that the pump and probe beams were incident on the sample at an angle of incidence of 45°. The plane of incidence was perpendicular to the direction of the gratings. The pump was p-polarized and the probe s-polarized. The focal $1/e^2$ diameter was ~7x10 μm^2. Deflection measurements were collected in a raster scan mode in the approximate region of the structure. The PLA signals have characteristic signatures that help differentiate the measurements and determine if the signals are from on-or-off the underlying patterns.

III. RESULTS

Measurement of Patterned Structures

Shown in Fig 2. is the target structure of the buried patterns used for alignment purpose. Critical dimension (CD) and pitch (in microns) of the structures are provided for reference. Cross-section of the measurement structure is shown in Fig 2

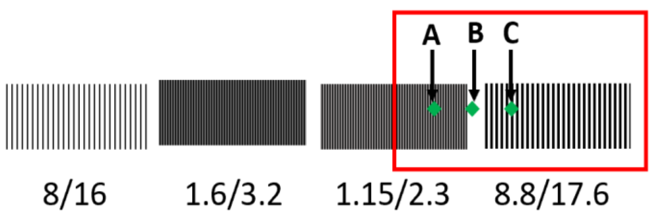

Fig. 2 Target structures used for measurement along with their CD/ pitch (in microns).

The objective of this study is to differentiate between acoustic signals collected on top of the W structure and those collected off the structure.

A raster scan was performed in the general area (180 µm x 360 µm) of the feature (outlined by the red box in Fig.2). Data was collected in 2 µm intervals in x direction and 10 µm intervals in y direction. Measurement sweep time was set up to scan from 5ps to 50ps in steps of 26fs. This is used to locate the appropriate time delay plane which contains the relevant image information from which the position of the buried structure can be determined.

Fig. 3 shows the temporal signal comparison for measurements corresponding to three different locations identified as A, B and C representing different underlying patterns as shown in Fig. 1

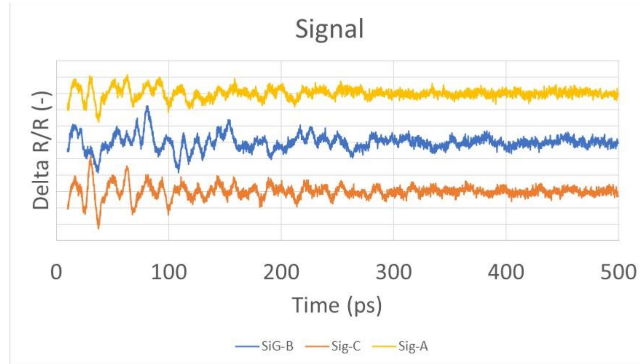

Fig 3. Differential reflectivity signal (after background subtraction) as a function of pump-probe delay plots corresponding to measurements from regions A, B and C.

Fig. 4 shows Fourier Transform (FFT) plots of select data points of the PLA raster scan. The overlay plots correspond to locations identified as A, B and C in Fig.2. Distinct differences between the different sites can be seen from the analysis.

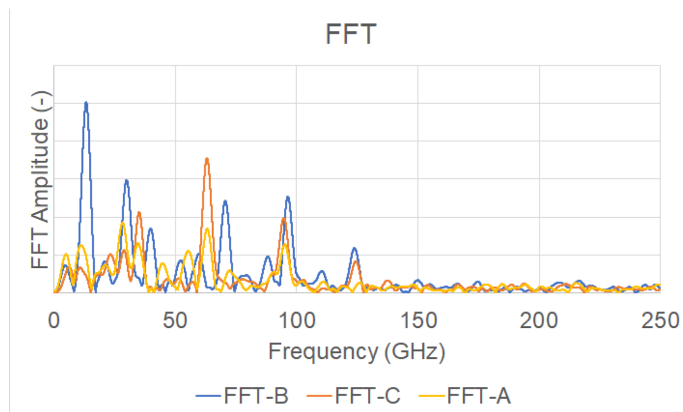

Fig 4. FFT overlay plots corresponding to measurements from regions A, B and C.

The time delay (τ_x) for each of the images is representative of the arrival time of the reflected acoustic wave from interfaces between different layers as illustrated in the schematic in Fig. 1. Near time zero signal represents the topography of the structure and proves to be a useful tool for imaging the surface of samples with 3D topography without running a longer temporal measurement for the entire scan as illustrated in Fig. 5a. The first echo (τ_3) from the blanket metal to patterned interface returns to the surface at about 30 ps. The acoustic impedance mismatch at the blanket metal to patterned interface is set by the materials and the nature of the pattern. The evolution of the signal is different depending on where the measurements are made. The spatial variation of the change in reflectivity when this echo arrives maps to the shape of the buried pattern. Our analysis of the signals captures the differences and is used in the generation of an image that represents the underlying structure.

Fig. 5b-e is the spatial map at select time delays from the acoustic time domain measurements. Images were collected by combining all the processed data from every coordinate of the raster scan. Data processing involved second order polynomial background subtraction and tracking of the signal amplitude at various time delays indicated in each figure.

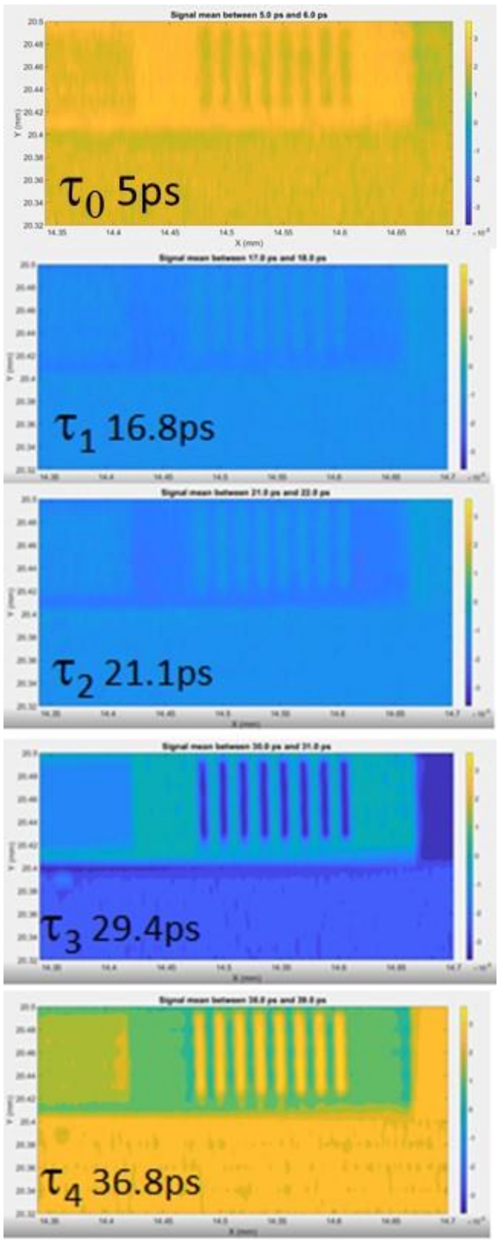

Fig. 5 a-e. Evolution of spatial maps corresponding to time delay (τ) from 5 to 36.8ps.

Figs. 6a,b show the images of an overlay marker (buried under the opaque layers) generated using the PLA measurements. The raster scan was carried out across a 100 x 100 µm square with a step size of 2µm. Images in Fig. 6a were collected by combining all the processed data from every coordinate of the raster scan at the temporal delay of ~30ps corresponding to the blanket metal to patterned interface. For Fig. 6b, data processing involved second order polynomial background subtraction and FFT padded to 0.5 GHz resolution. The inset in Fig. 6 is the schematic representation of the target structure for comparison.

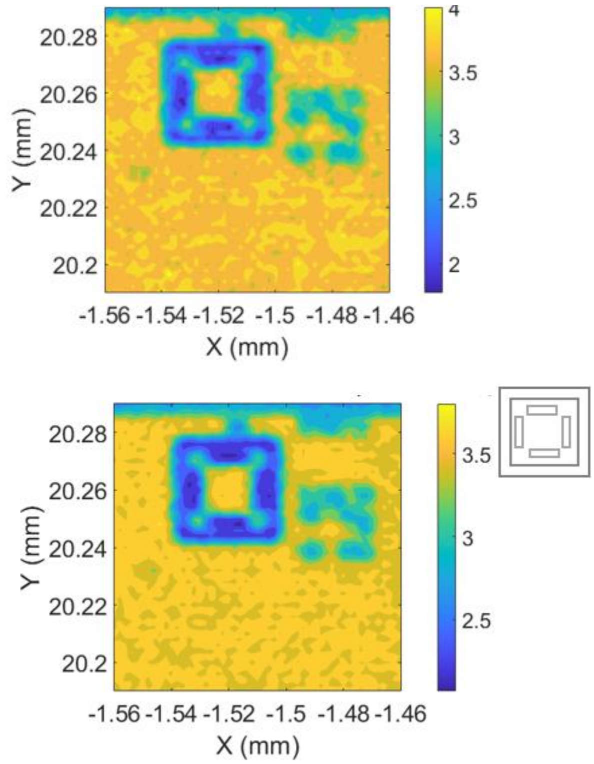

Fig 6a-b. Image of overlay marker under opaque layers using temporal and FFT signal analysis. Inset to the right shows the schematic of the target.

Discussion:

The lateral resolution of images is defined by the laser beam spot size (~10µm) and raster scan step size. Using acoustic information, the appropriate time delay plane containing the relevant image information to determine the position of the structure can be defined with a temporal scan limited to <50 ps based on the product. Using the entire time delay span, one could use the raw acoustic data, its Fourier transform, or the thermal background in combination with a variety of other signal processing algorithms to form an image of the structure from which the position could be readily derived. Furthermore, a 3D image of a structure can also be generated by analyzing scanned signal planes at different time delays.

III. Conclusions

In summary, we have presented the capability of picosecond laser acoustic technique for measuring overlay and alignment markers buried under opaque MTJ layer stack in the MRAM process flow. The images generated using the signal at a specific time delay or the FFT collected by raster scanning the area surrounding the specific markers show good resolution and correlate very well with the target structures. Our future work will also investigate at length generation of images using the thermal background information extracted from the time resolved measurements for all coordinates in the raster scan. In addition to providing 2D lateral images of the structures, this method can also be used for determining the thicknesses of different layers in the stacks on-and-off the patterns. Further, this technique can also be utilized for imaging structures that are embedded under opaque layers at different z planes with a resolution of several nm. Picosecond ultrasonic technology has found widespread adoption in leading edge wafer fabs and with this work, we have demonstrated the extension of the technique to addresses the emerging need in advanced processes for imaging through opaque layers.

VII. References

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