Etch, Deposition, and Metrology Options for Cost-Effective Thin-Film Bulk Acoustic Resonator (FBAR) Production

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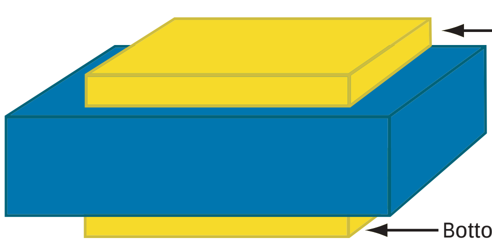
Figure 1
Veeco is driving System on a Chip Technology



Introduction

Next-generation wireless communication devices depend on cost-effective, high-frequency components for 2.5G and 3G services. Device manufacturers need bandpass filters that are smaller, consume less power, have lower insertion loss and that operate at higher frequencies. Thin-Film Bulk Acoustic Resonators (FBAR) technology, developed by several leading component providers, has the necessary capabilities to achieve these requirements simultaneously, and at a competitive cost.

Figure 1 depicts a generic FBAR structure. Although these components are still usually manufactured as discrete, passive components, there will be demand within the industry to integrate them with other RF devices, such as power transistors and digital-to-analog converters.

This application note discusses how critical FBAR can be accomplished using Veeco's NEXUS™ Cluster Tool with an assortment of process modules and focuses on Ion Beam Etch of electrodes and Gas Cluster Ion Beam* (GCIB) frequency trimming. The NEXUS Cluster Tool has the capability to manufacture these devices as either discrete components on silicon wafers or as integrated devices on GaAs or other compound semi-conductor wafers. This application note also discusses the usefulness of Veeco's Atomic

* manufactured by Epion Corporation

Table 1
Typical Manufacturing Process for FBAR Devices

FBAR Processing
Insulator Deposition **PVD**
Insulator Smoothing **IBE, GCIB and AFM**
Bottom Electrode Deposition **PVD**
Bottom Electrode Smoothing **IBE and GCIB**
Piezo-electric Deposition **PVD**
Top Electrode Deposition **PVD**
Device Definition & Release **IBE**
Wafer Level Frequency Centering (Sample RF Test-Trim) **IBE and GCIB**
Pick Die and Package

Table 2
Critical Process Requirements for FBAR fabrication

Process	Critical Requirements
Electrode Deposition W, Pt, Ta, Mo	TCR Control Uniformity Control Phase Control Stress Control
Piezo-electric Deposition AlN	Extreme Phase and Texture Control Excellent Thickness Uniformity Pristine Vacuum Environment
Electrode Etch IBE	Excellent Etch Rate Control
Resonator Trimming & Electrode Smoothing GCIB	Location Specific Processing Improve Surface Roughness by 50% or more

Force Microscope (AFM) for characterizing the surface roughness of thin films in the FBAR process.

Smooth Electrodes

Table 1 presents the typical manufacturing process flow for FBAR devices. Veeco's Ion Beam Etch (IBE) and Epion's Gas Cluster Ion Beam (GCIB) equipment is used for insulator smoothing, electrode smoothing and frequency centering. Veeco's Physical Vapor Deposition (PVD) equipment is used for insulator, electrode and piezo-electric resonator deposition. Table 2 lists corresponding FBAR fabrication critical process requirements.

Electrode Etch Rate Control and Frequency Trimming

Ion beam etching may be used to define metal electrodes for difficult to etch materials such as Pt, Au, and Mo. Veeco's IBE system offers a wide range of controllable and repeatable etching rates. Etching rate uniformity across a 200mm diameter and run-to-run repeatability are both typically less than 3%. Etching rates as low as 10Å/minute (depending on the material to be etched) can be used to trim resonators in a controlled and consistent manner. To pattern thicker metal electrode layers, etching rates in the range of 1000-3000Å/minute can be achieved for metals such as Au and Pt. In addition, the collimated beam and the ability to tilt the sample fixture allow precise control of the electrode sidewall profile and the minimization of redeposition.

Epion's Gas Cluster Ion Beam (GCIB) tool may be used to selectively trim resonators to achieve the desired center frequency. Extreme etch rate control and uniformity are required to shift the device Fc to the specified Fc, which necessitates removing only a select few angstroms of material. By using the GCIB technique to selectively etch specific areas of a wafer, the center frequency can be shifted and the standard deviation reduced around the specified frequency. This location-specific processing enables significant increases in device yield by compensating for variations in not only the piezo-electric, but in the entire acoustic path, encompassing both top and bottom electrodes when combined with a closed-loop control on device center frequency (see Figure 2). The use of IBE in the patterning of FBAR applications is a well-established and production-proven process done in other applications as well as FBAR technology. IBE is advantageous over other plasma based etching processes because IBE is a physically based process where all materials can be etched, especially materials that are chemically inert, such as Au, Pt and Cu. Also, since the angle of ion impact can be controlled, fine controls of CD'sand elimination of redeposition are easily accomplished.

Three-Dimensional Surface Characterization and Measurement

Veeco provides a complete suite of three-dimensional surface metrology instruments: scanning probe microscopes (SPM), stylus profilers, optical profilers and interferometers, and atomic force profilers. The atomic force microscope (AFM), which is an SPM, offers resolution and localization well suited for characterizing and measuring surfaces in FBAR process technology.

Figures 3a and 3b show 1 micrometer square AFM images of the Ta film surface on a resonator before and after GCIB trimming, which is used to shift and control the resonance frequency of FBAR-processed filters (also, refer to Figure 10). These images clearly visualize the impact of GCIB trimming, but visualizing is only one part of characterizing the surface.

Figure 2
Center Frequency Shift and Variation Reduction

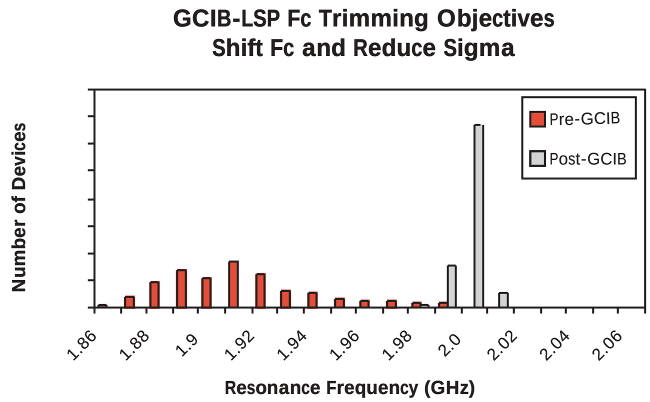


Figure 3a
AFM Image of Ta Films

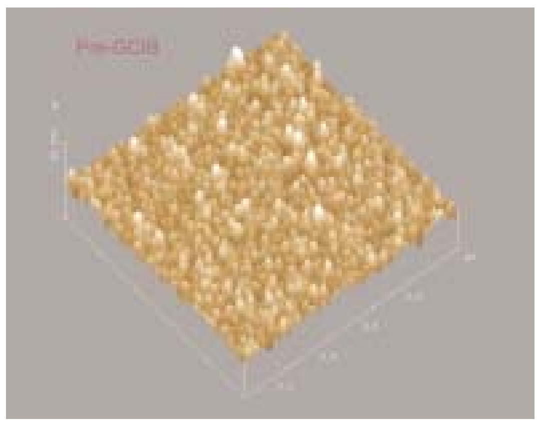


Figure 3b
AFM Image of Ta Films

Figure 4a
AFM height histograms for images in Figures 11a and 11b.

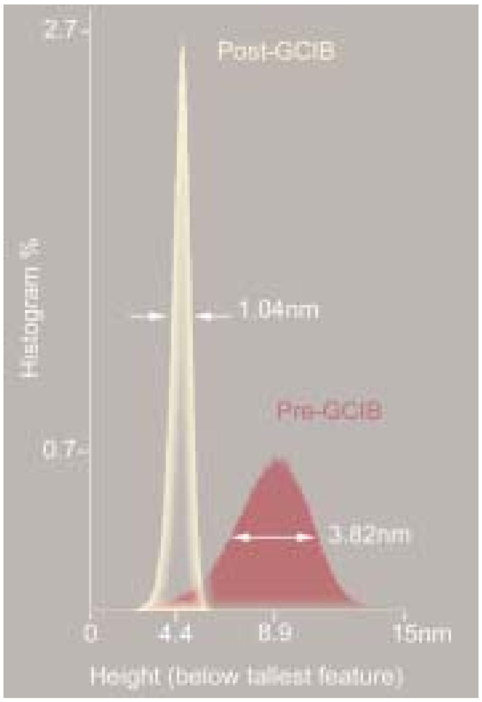
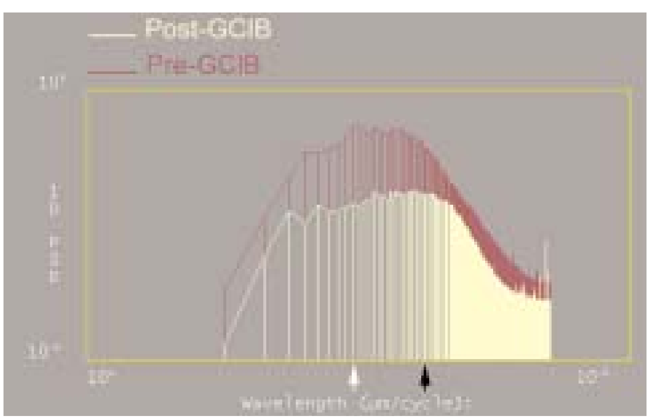


Figure 4b
AFM power spectral density plots for the images in Figure 11a and 11b.



To correlate the performance of a resonator with its surface topography, Veeco AFM built-in analysis software offers a myriad of options to quantify the images. It can measure the rms roughness, identify the dominant wavelengths that contribute to the roughness, and can compare roughness before and after critical process steps at a given location or between different locations.

In Figure 4a, the height histograms for the pre- and post-GCIB films quantify the visible difference in smoothness between the two films beyond a simple RMS number. (The AFM measures the RMS roughness 18.5Å pre-GCIB, and 4.9Å post-GCIB.) In Figure 4b, AFM power spectral density plots reveal that the dominant contributions to the roughness come from different in-plane (X, Y) wavelengths for pre- and post-GCIB films. Post- GCIB, the power spectral density levels off at around 30nm (black arrow), and drops off as the wavelengths lengthen (towards the left). But the pre-GCIB curve continues to grow well past 30nm, and does not level off until about 100nm (white arrow), indicating major contributions to the roughness at wavelengths between 30 and 100nm. This statistically quantifies the presence of the larger grains visible in the pre-GCIB film shown in Figure 3a.

Veeco AFMs are available with automation options that streamline and increase roughness, as well as numerous other measurements, while providing choices for the process engineer to customize the measurements.

Summary

Veeco's NEXUS Process Equipment and AFM product lines provide equipment for all critical steps of the FBAR manufacturing process. NEXUS Physical Vapor Deposition is used to deposit smooth electrodes with excellent stress control, and highly structured AlN piezo-electric films with extreme thickness uniformity. NEXUS Ion Beam Etching is used to pattern thicker metal electrode layers for difficult to etch materials such as Pt, Au, and Mo. Epion's Gas Cluster Ion Beam deposition is used to selectively trim resonators to achieve the desired center frequency. NEXUS Ion Beam Etch & trim equipment is used for both electrode definition and resonator frequency trimming to maximize product yield. Lastly, Veeco's AFMs enable unmatched, three-dimensional roughness measurements for process control and defect characterization. Veeco's AFM's are available with automation options that streamline and increase roughness, as well as numerous other measurements, while providing choices for the process engineer to customize the measurements to suit the needs of a given application.

■

Further Reading

1) Manufacturing and Performance Considerations for Thin Bulk Acoustic Resonator (FBAR) USPCS band duplexors, Domingo Figueredo, et al, Agilent Technologies
2) A Noble Suspended Type Thin film Resonator (STFR) Using the SOI Technology, Hyun Ho Kim, et al, Korea University
3) A Brief Overview of FBAR Technology, Dec 1999

Authors

Frank M. Cumbo received an MBA at the University of Maryland in 1996 and a BS in Engineering at Clarkson University in 1984. He joined Veeco in 1996 as a project manager. Currently he is the Director of Marketing for Veeco's NY Process Equipment Group.

Kurt E. Williams received a PhD in materials science and engineering at the State University of New York, Stony Brook in 2000. He joined Veeco in 1995 as a process engineer. Currently he is the Director of Process Engineering and is directing research into all areas of ion beam etching including RIBE & CAIBE.

John J. Hautala received a PhD in materials science at the University of Utah in 1991. He worked for Tokyo Electron for seven years as the Sr. Scientist in CVD development. He joined Epion Corporation in 1999 and currently is directing the Process, Applications and Analytical Lab efforts for Gas Cluster Ion Beam (GCIB) technology.

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About Veeco

Veeco Instruments Inc. is a worldwide leader in process equipment and metrology tools for the telecommunications/wireless, data storage, semiconductor and research markets.

Veeco's Process Equipment Group provides the etch and deposition technology that data storage manufacturers require to increase areal density. Veeco's combination of ion beam etch, ion beam deposition and physical vapor deposition makes us the undisputed leader in current and next generation GMR (giant magneto-resistive) TFMH solutions for the data storage industry.

Veeco is the leading supplier of ion beam deposition equipment to the fast-growing dense wavelength division multiplexing (DWDM) filter market—a crucial part of the world's telecommunications and data infrastructure. Veeco's broad line of leading edge technology allows customers to improve time-to-market of next generation products. Veeco is driving forward to narrower bandwidth filters for higher overall capacity.

Veeco's Metrology Group is the world leader in 3D surface metrology—advanced measurement tools that allow data storage and semiconductor manufacturers, and researchers, to see features in their process with high resolution. Our broad array of technologies and range of products provide industry leaders with high resolution measurement and yield-improving tools.

In data storage, telecommunications/ wireless and semiconductors, Veeco helps our customers improve their critical time-to-market for next generation products. We provide total solutions for advanced etch and deposition processes, as well as improving yield and process control in both manufacturing and research environments.

Veeco's manufacturing and engineering facilities are located in New York, California, Colorado, Arizona and Minnesota. Global sales and service offices are located throughout the United States, Europe, Japan and Asia Pacific.

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