APPLICATION NOTE

Scanning Capacitance Microscopy (SCM) of a Power MOSFET

INTRODUCTION

Progress in technology largely depends on the continued miniaturization of electronic components. Smaller components will enable increased switching speeds and device densities for faster computing, larger memory capacity, and improved digital image quality. The current state-of-the-art devices are already below 10nm in size. Characterizing these devices is becoming increasingly challenging because traditional techniques, such as Secondary Ion Mass Spectrometry (SIMS), do not have the required spatial resolution to address such small structures. An alternative method to study these devices is Scanning Capacitance Microscopy (SCM), an AFM-based technique. SCM produces maps of the distribution of electrically active carriers in semiconductors with high lateral resolution. During an SCM measurement, a metallized probe is brought in contact with a semiconductor sample to form a metal-insulator-semiconductor (MIS) capacitor, with the insulator often being the natively grown oxide. An AC bias is applied to the sample, which causes the accumulation and depletion of carriers and the resulting capacitance variations are detected with a GHz resonant capacitance sensor. The probe is raster-scanned across the surface to produce several types of SCM images under normal operation:

1. The dC/dV amplitude image shows relative dopant levels.
2. The dC/dV phase image indicates dopant type distribution.
3. The SCM data image combines the information from the prior two image types.
4. Along with the electrical information, height data is also collected during a SCM measurement.

In this application note, a commercially available power Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) was analyzed using SCM. Power MOSFETs are common power devices used in many applications such as consumer electronics, automotive electronics, power supplies, voltage converters, and battery chargers.[1] While the power MOSFET characterized in this application note was an older technology than the current state of the art, it was selected because it was a commercially available, non-proprietary device that could be published externally. It is possible to resolve much smaller structures than this with SCM on current generation samples.

EXPERIMENTAL

A power MOSFET (Vishay Intertechnology, Inc, Malvern, PA, P/N: SiHH26N60E) was de-packaged, cross-sectioned, mechanically polished, and electrically connected to the AFM stage using conductive silver paste. Optical microscopy and SEM mages of the sample top-down and in cross-section, obtained after sample preparation, are shown in Figures 1 and 2.

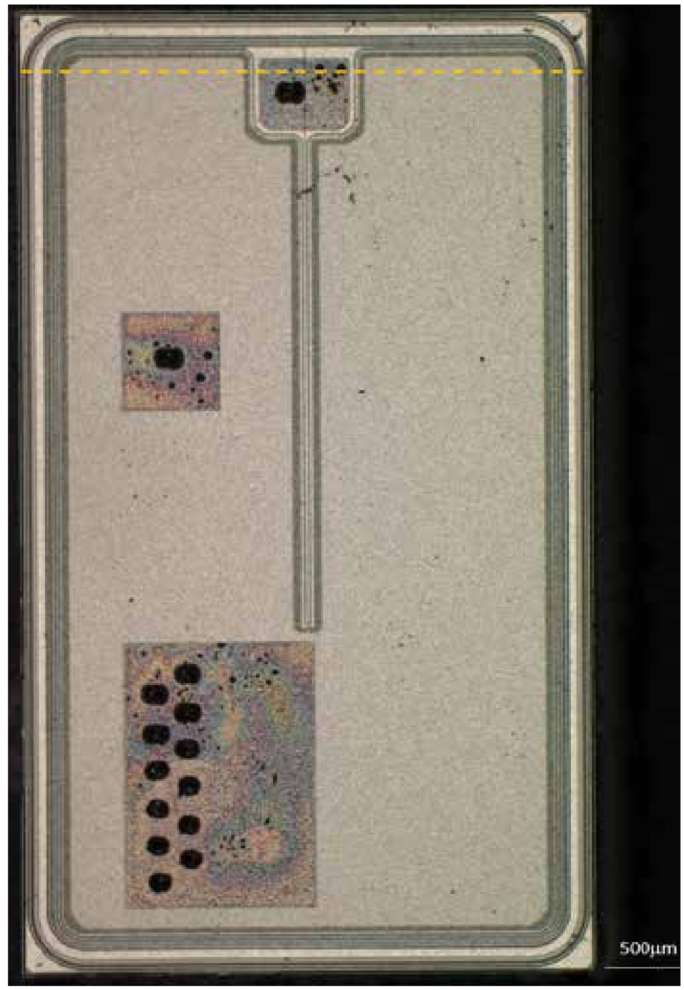

Figure 1: Top-down optical microscopy view of the depackaged die. The dotted orange line shows the plane that was cross-sectioned.

SCM images were acquired on a Dimension Icon AFM instrument (Bruker, Santa Barbara, California, USA). In SCM mode, a 50μm × 50μm area and a 15μm × 15μm area were analyzed. The corresponding 2D and 3D height images are shown in Figures 3 and 5. The topography differences of these images are presented in colors where brown is low and white is high. The z-range is noted on the vertical scale bar on the right side of the images. SCM images were captured concurrently with the topography images (Figures 4 and 6). In dC/dV amplitude images, the brighter colors signify lower dopant concentrations and darker areas have higher

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dopant concentrations. In the dC/dV phase images, the yellow color corresponds with p-type doped regions and the brown color indicates n-type doped regions. SCM Data images combine the information in the dC/dV amplitude and dC/dV phase images, with dark purple indicating low p-type doping and bright yellow meaning low n-type doping.

Section analysis of the SCM images was performed to characterize representative doping profiles (Figure 7). Line profiles were drawn through the dC/dV amplitude and dC/dV phase data, along the lateral distance indicated by the black arrow drawn on the SCM Data image in Figure 7. The two profiles were overlaid in the graph with the red trace corresponding to the relative doping levels and the blue trace indicating the doping type, as a function of lateral distance.

RESULTS AND DISCUSSION

SCM can be performed top-down or in cross-section. Extensive experience in semiconductor device sample preparation, such as de-packaging, cross-sectioning to a specific target region, and expert fine mechanical polishing, is critical for success. In Figure 1, a top-down optical microscopy image of the de-packaged die is shown, where the orange dotted line indicates the cross-section plane. The optical and SEM images of the die after cross-sectioning and polishing showcase the high quality of polish required for successful SCM analyses (Figure 2).

The SCM data was captured at approximately the region shown in the purple box in Figure 2. In the topography images, the source metallization and polysilicon gate are evident near the top of the region, but no details about the doped structures are visible (Figures 3 and 5). The doping distribution is immediately visible in the SCM images, revealing that this is likely an n-substrate power MOSFET device (Figures 4 and 6) [1]. The data indicates that the device is built on a n+ substrate with a n- epi layer, as can be seen from the dark brown contrast in the majority of the dC/dV phase image (Figure 4b). Immediately below the metal and polysilicon layers, are two p regions with thin n+ regions on either side. The elongated, vertical extensions are p columns. A higher resolution set of SCM images were also collected because the thin n well structures were more clearly observable at that scale (Figure 6). Representative doping profiles, shown in Figure 7, can be used to compare relative doping levels and to measure the lateral dimensions of doped regions.

CONCLUSION

As electronic components are further reduced in size, SCM will be an indispensable characterization method for the research and development, failure analysis, quality control, and reverse engineering of these devices. In this application note, a commercially available power MOSFET was analyzed with SCM to illustrate the wealth of information that can be obtained from this technique. Although the selected structures were relatively large,

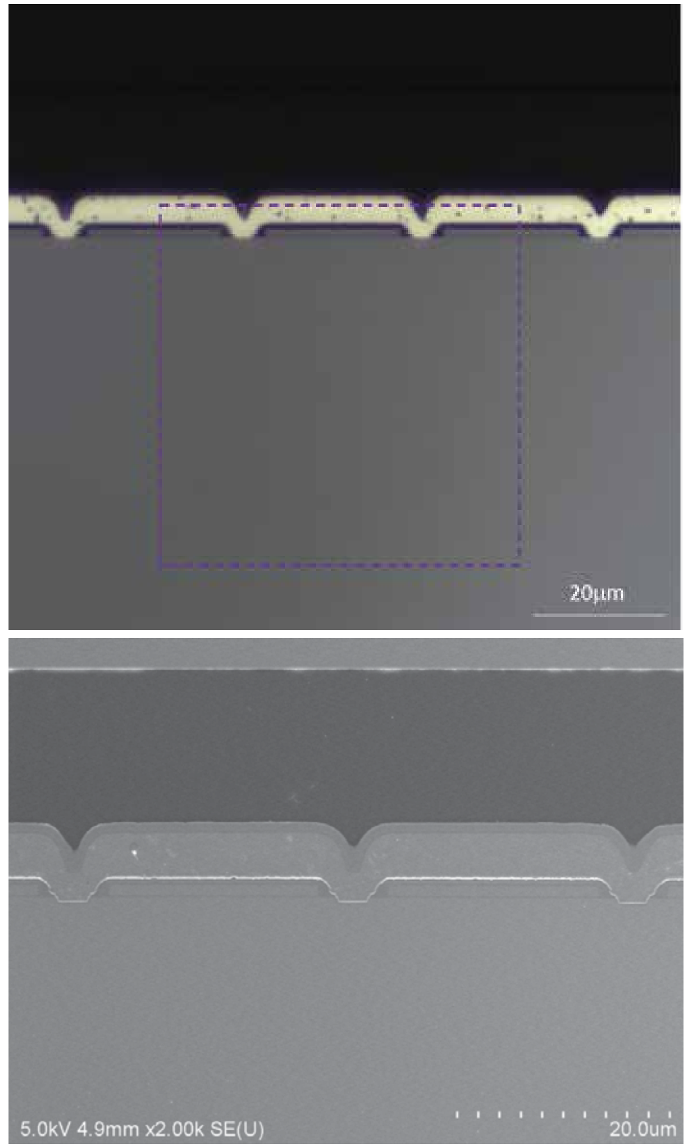

Figure 2: Optical microscopy image (top) and SEM image (bottom) of the prepared cross-section. The purple square indicates the analysis area for the 50µm x 50µm SCM images.

much smaller devices can be investigated with SCM. Additionally, SCM is not limited to silicon-based materials, as shown in this example, but has been successful at characterizing devices on various compound semiconductor substrates as well. When used in conjunction with other techniques (e.g. SIMS, SEM, TEM, OBIRCH, and emission spectroscopy), SCM can contribute to complete picture of complex electronic devices and help explain device performance.

REFERENCES

1. Williams, R.K. et. al, "The Trench Power MOSFET: Part 1 – History, Technology, and Prospects", IEEE Transactions on Electron Devices, 64, 674, (2017).

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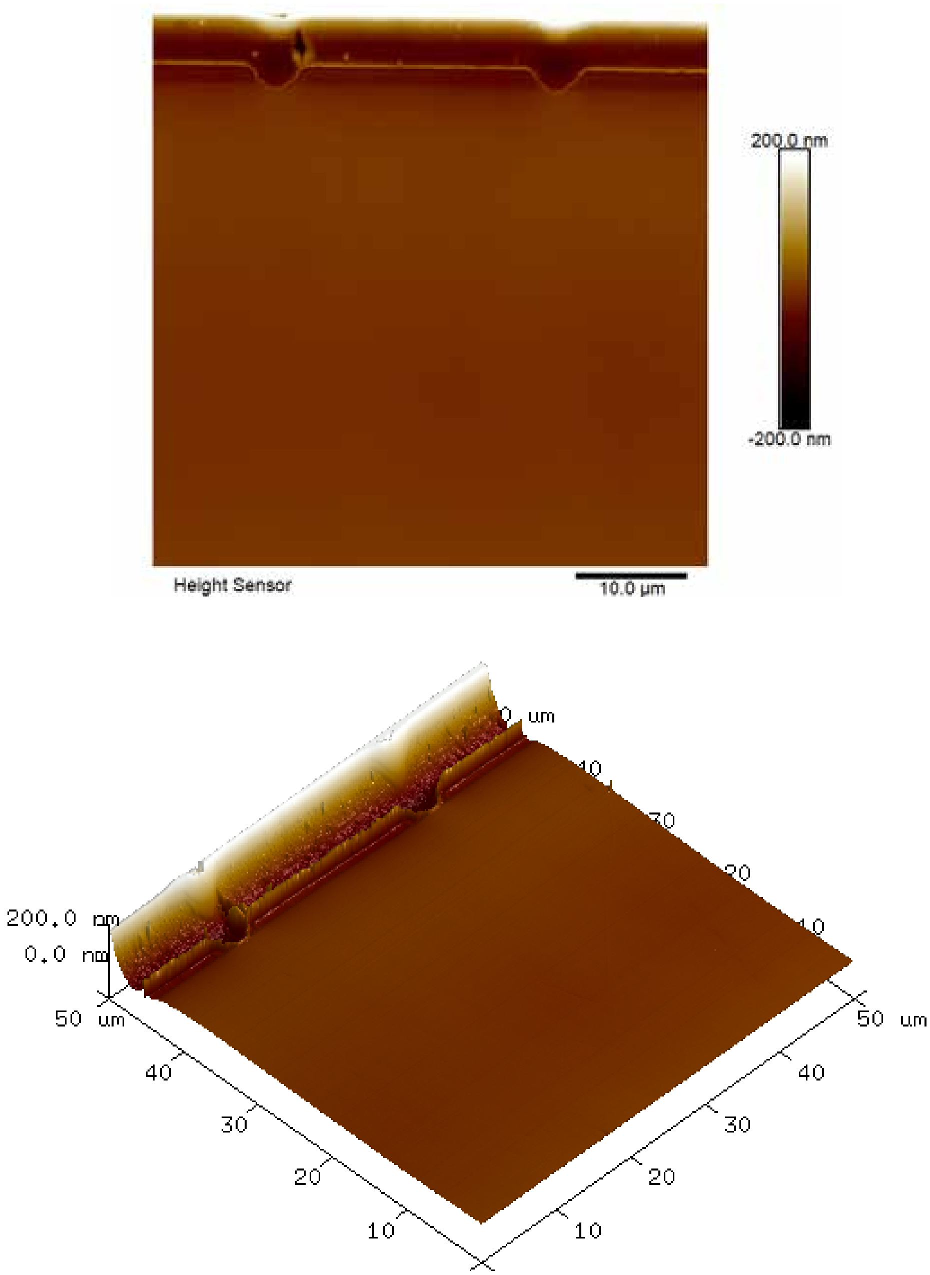

Figure 3: AFM height images of the cross-sectioned MOSFET (50µm x 50µm x 400nm)

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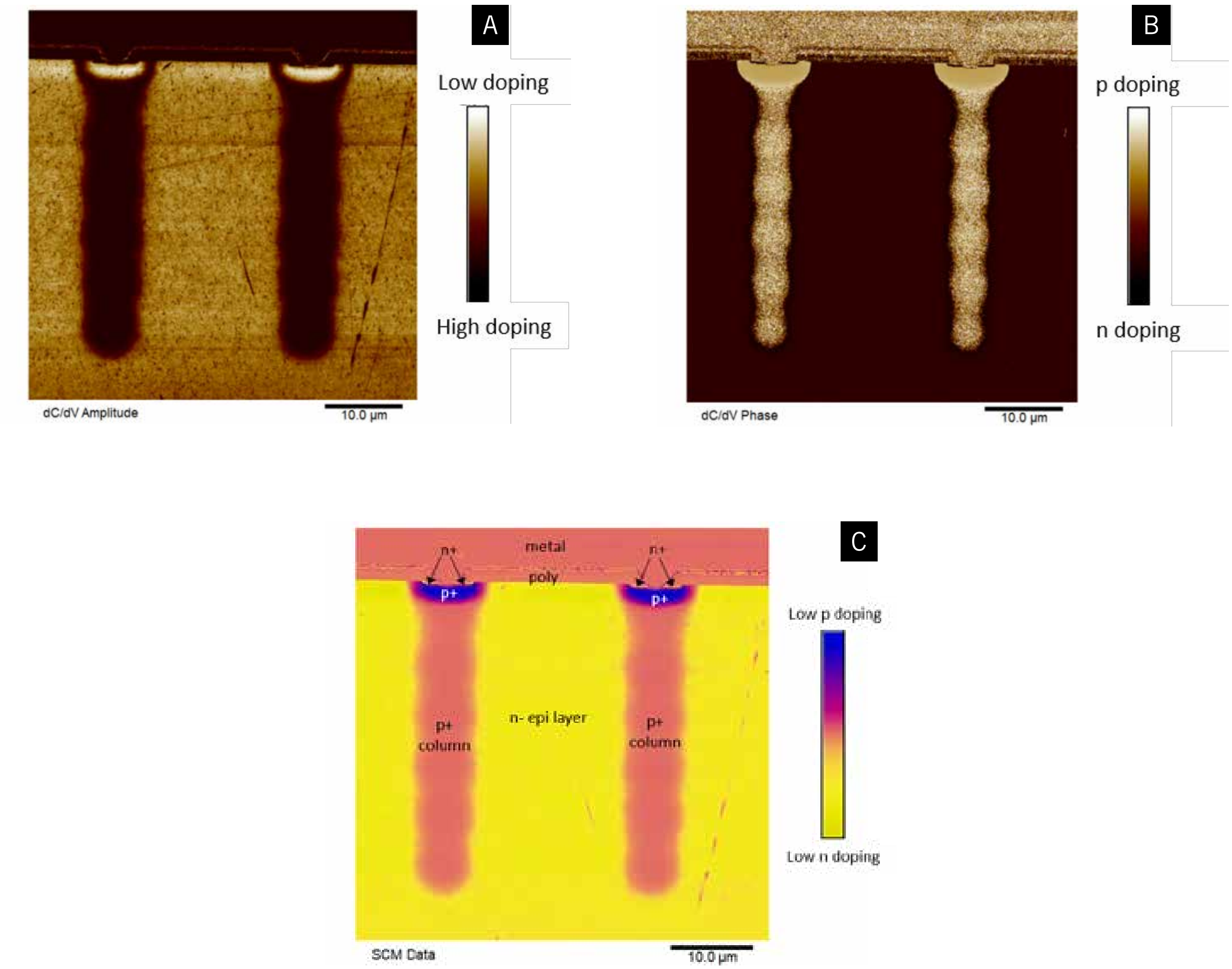

Figure 4: SCM images of the cross-sectioned MOSFET (A) dc/dV amplitude (relative dopant levels, bright = low doping), (B) dC/dV phase (dopant type, brown = n type, white = p type), (C) Combined SCM data image (50µm x 50µm)

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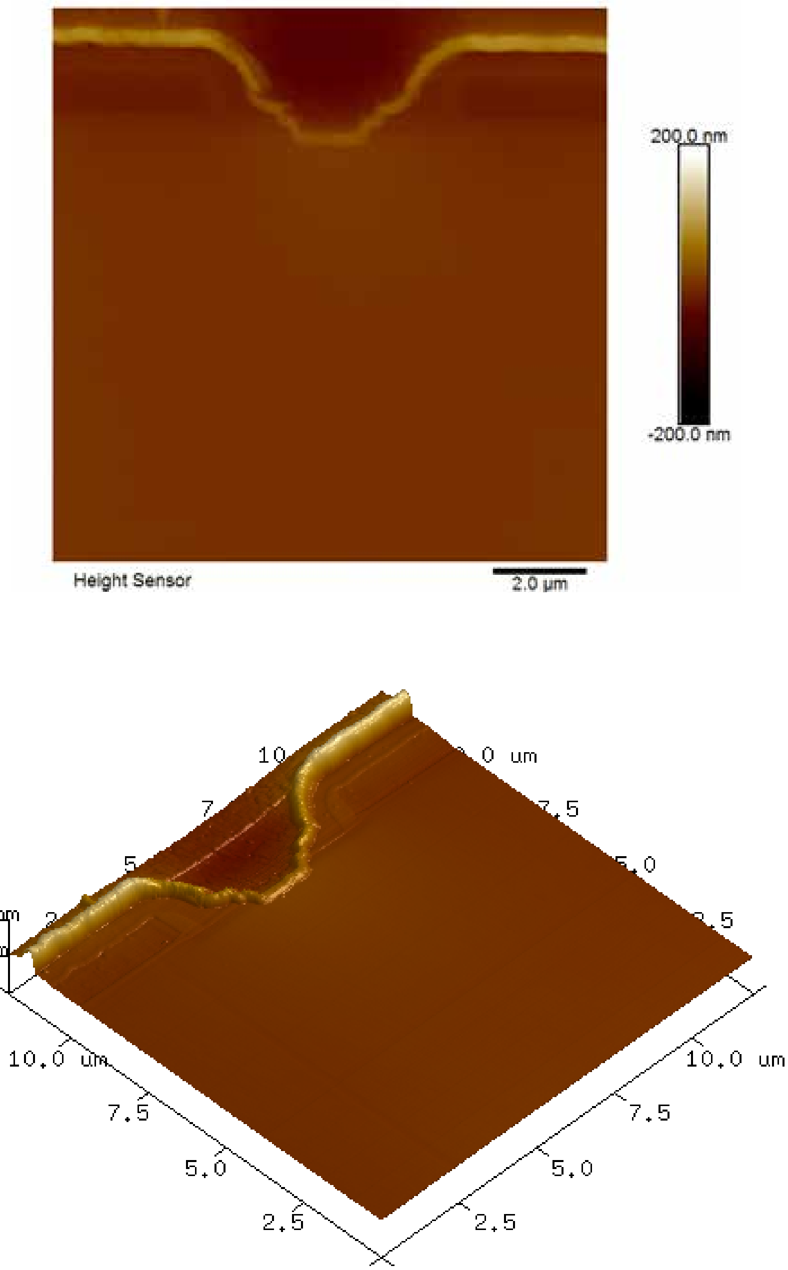

Figure 5: AFM height images of the cross-sectioned MOSFET (15µm x 15µm x 400nm)

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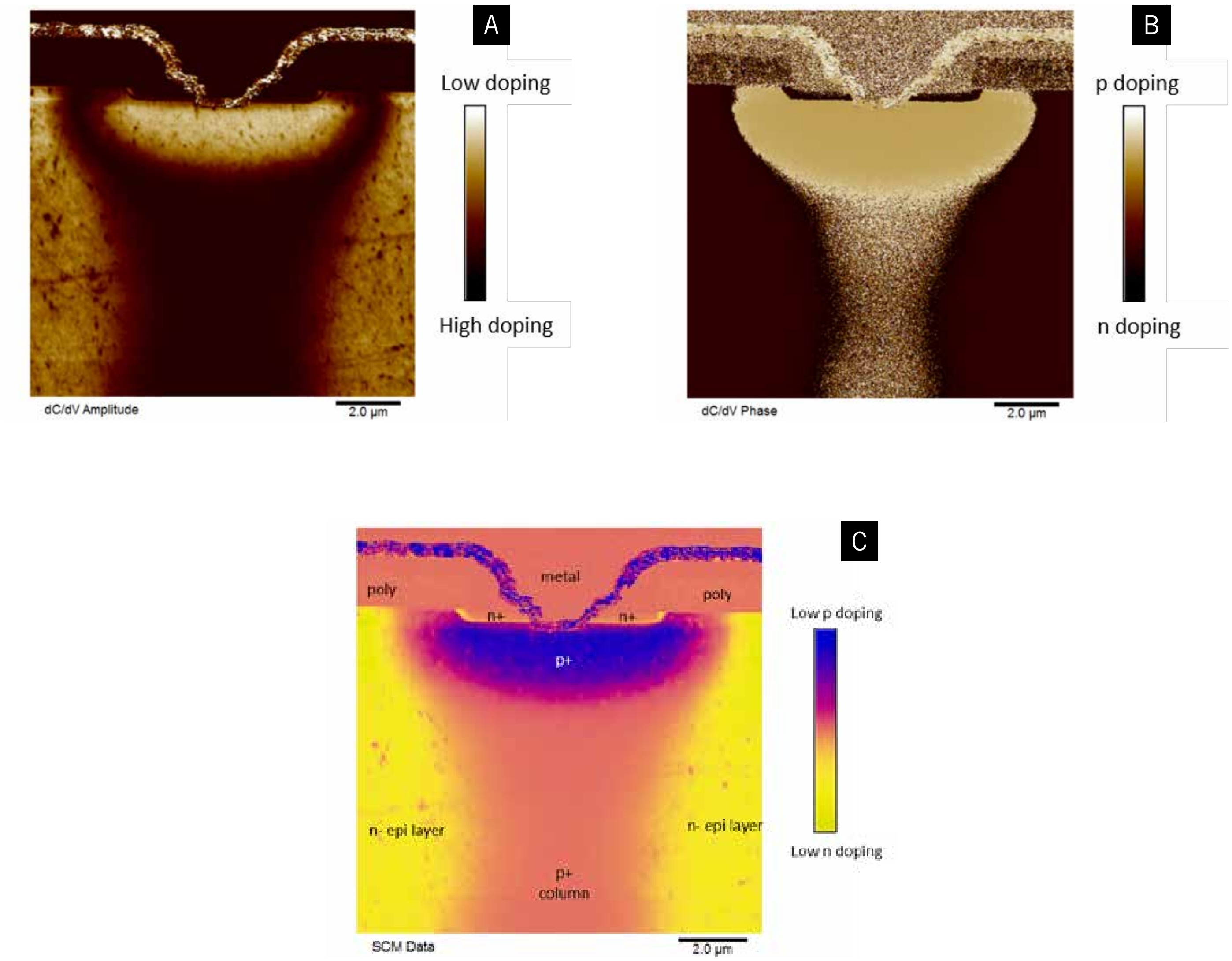

Figure 6: SCM images of the cross-sectioned MOSFET (A) dc/dV amplitude (relative dopant levels), (B) dC/dV phase (dopant type), (C) SCM data image (15µm x 15µm)

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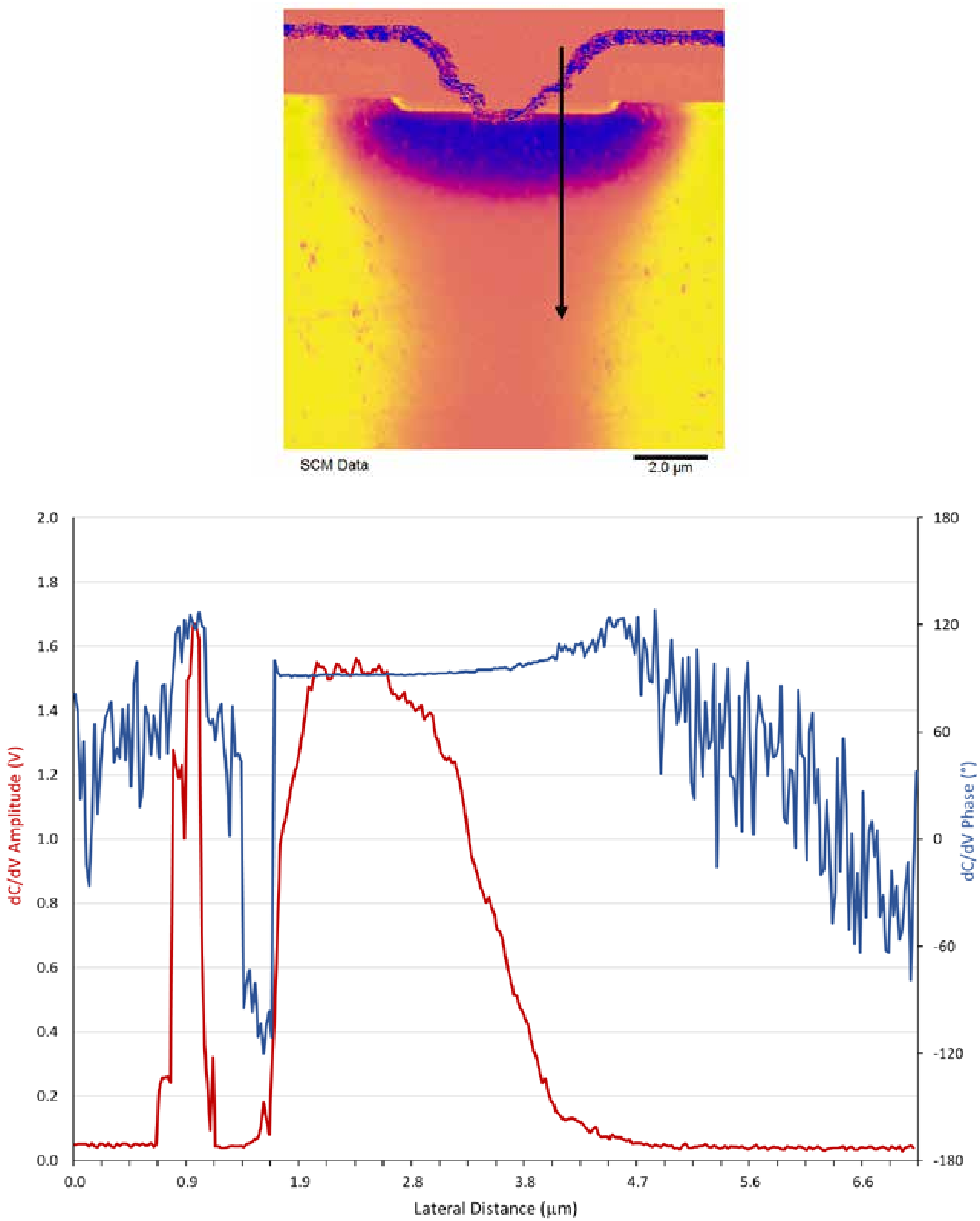

Figure 7: Representative doping profiles taken along the black arrow in the SCM Data image. The red trace is dC/dV amplitude (relative doping levels) and the blue trace is dC/dV phase (relative doping type)

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