Process-structure-property relationship of nanocrystalline vanadium oxide thin films used in uncooled infrared focal plane arrays

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Uncooled infrared focal plane arrays, MEMS devices fabricated on CMOS read out integrated circuits, are the heart of portable military and commercial night vision cameras. The structure and chemistry of vanadium oxide thin films currently used in the microbolometer arrays necessary for uncooled infrared detection are not well understood or characterized. Furthermore, the descriptions in the literature of these VO_x films are either contradictory or vague. In the mid 80's, Honeywell developed an ion beam deposition method[#1] and this technology is currently being licensed to a number of camera and bolometer manufacturers; vanadium oxide based systems now make up ~70% of the uncooled infrared detection market[#2]. Microbolometer-based devices which use VO_x have the competing requirements of large thermal coefficient of resistivity (TCR) yet low room temperature resistivity. Large TCR leads to increased device responsivity, which is increasingly important as increased resolution requirements demand decreased pixel size with equivalent or better sensitivity. Low room temperature resistivity enables high sensitivity low power read-out circuitry to be employed. Since the inherent 1/f noise of a material tends to increase with increased material resistivity [#2], a lower resistivity will lower the 1/f noise and improve responsivity. Without an accurate description of the microstructure, intelligent processing decisions cannot be made in order to improve device performance.

Our recent examination of ion beam deposited vanadium oxide thin films, provided by both industrial manufacturers and deposition system manufacturers, has shown that microbolometer grade films exhibit three distinct microstructural features: nano-crystalline rocksalt-structured vanadium oxide (VO_x, wherein bulk or epitaxial material phase diagram indicates $0.8 < x < 1.3$), significantly disordered grain-boundary material (amorphous), and a high density of micro-twin planar defects within the VO_x nanocrystals. These microstructural features are accompanied by average oxygen contents outside the equilibrium phase diagram limits for the rocksalt-structured VO_x phase, suggesting excess oxygen is also a required characteristic. We have also been actively investigating reactive magnetron sputtering[#3, #4], varying parameters such as power, total pressure, relative oxygen flow rate, and sputtering target composition and have produced and characterized a myriad of films with resistivity ranging from 0.02 ohm cm to 68,000 ohm cm with TCR ranging from 0.5 to 5.0%/deg C. We have characterized these films using Raman spectroscopy, spectroscopic ellipsometry, and TEM analysis as well as detailed electrical characterization. In this paper we compare these films with those made by ion beam deposition and discuss how the deposition process affects film structure and the critical properties necessary for uncooled infrared imaging.

[1] B. Cole, C. Zins, Honeywell International Inc (2002) Flexible high performance microbolometer detector material fabricated via controlled ion beam sputter deposition process, U.S. Pat. 6,495,070.
[2] A. Rogalski, Acta Physica Polonica A 116 (2009) 389 – 406.
[3] B.D. Gauntt, M.W. Horn, E.C. Dickey, J. Mater. Res. 24 (2009) 1590 – 1599.
[4] N. Fieldhouse, S.M. Pursel, R. Carey, M.W. Horn, S.S.N. Bharadwaja, J. Vac. Sci. Technol. A, 27 (2009) 951 – 955.

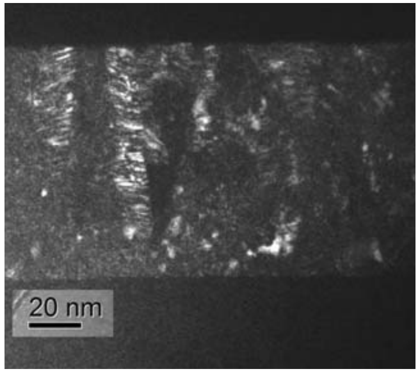

Figure 1. Ion beam deposited VO_x on Si_xN_y.

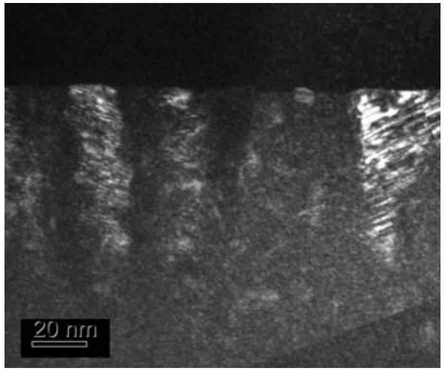

Figure 2. Ion beam deposited VO_x on SiO_2.

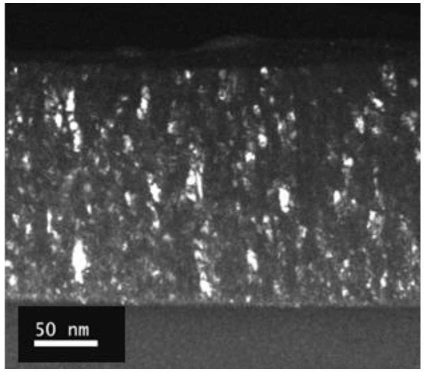

Figure 3. Typical pulsed DC sputtered VO_x on SiO_2.

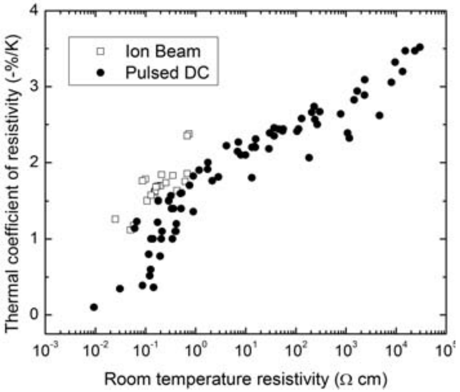

Figure 4. TCR vs. temperature resistivity for both ion beam deposited films and pulsed DC deposited films.