SIMULATION OF VANADIUM AND MANGANESE X-RAY WINDOW MEMBRANE MICROSTRUCTURES

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Abstract

This submission epicentres on the unravellings from the simulation of vanadium (V) and mangansese (Mn) membrane structures of a rotating X-Ray window; V showed more promises as a prospectve X-Ray window membrane compared to Mn owing to its prefered optical and thermal properties.

Conveyed thermal energy resulted to deformation in the microstructure of these membrane materials; thermal stress and temperature distributions on both materials are presented. Employing Rayleigh's criterion, spatial resolution of $1\mu m \geq \varsigma \geq 600nm$ *is achievable; details of images of these Nano-probed microstructures may be viewed with X-Ray microscopes.*

Introduction

As cited by Winter and Moore (2009), Butler *et al* (2001) and Rehder (1991) has identified vanadium as the second most abundant transition metal in the ocean, with concentrations of 100mgkg^{-1} and 1.3 µg/liter in carbon-containing sediments of marine origin and freshwater respectively.

Additionally, Vanadium is identified as an effective supplementation for glycaemic control in type 2 diabetes (Smith *et al*, 2008).

Manganese, an essential element for all species, does protect cells against the superoxide free radical O_2^{-}; Emsley (2013) highlights that the lack of Manganese in sedimentary rocks in the period between 400 and 1,800 million years ago indicated a time when the oceans had low oxygen levels[1].

Vanadium and Manganese are considered as target materials owing to 4.952KeV VKα_1 and 5.899KeV MnKα_1 Soft X-Rays emitted from each material which best suits micro-probing of biological and earth sample. These membrane materials are affixed onto silicon frames positioned within an X-ray window of a microprobe.

Optical and Thermal response of membrane materials

Figure 2 (a) is a 3d schematic of the proposed rotating Vanadium (or Manganese) structure of dimension 6µm by 6µm by 1µm. This structure is imparted at the top central region by a cylindrical-shaped electron beam with $\varsigma \leq 1\mu m$ (spot size). The region within which the spread is effected is assumed to be hemispherical in shape

Figure 2 (b) is a 2d schematic of Vanadium (or Manganese) structure imparted by electron beam of $1\mu m \geq \varsigma \geq 600nm$; the Vanadium structure seats on a silicon nitride (Si_3N_4) structure. Vanadium and Manganese serves as target or membrane materials while the Si_3N_4 serves as frame.

Vanadium and Manganese, potential membrane materials, will be impinged by fast moving electron beam; these materials are expected to emit 4.952KeV VKα_1 and 5.899KeV MnKα_1 X-Rays; photon energy values were excerpted from National Physical Laboratory table (Kaye and Laby 2016); energy equivalents are 7.934x10-19J and 9.451x10-19J respectively; both membrane materials will be delivering heat fluxes of 1.0101x10^{-6}W/m^2 and 1.2032x10^{-6}W/m^2 every second, respectively.

Electrons will be released from tungsten filament at electron energy of ≤ 15 KeV and at electron current of ≤ 0.5 mA. Assumed heat flux of rapidly moving electron beam, emitted from the tungsten filament every second is 3.0595x10^{-6}W/m^2.

Simulations alongside some plotted graphs of deformed Vanadium and Manganese structures are presented by employing COMSOL 4.2 Multiphysics software.

As in the case with titanium and chromium, membrane breakage may occur owing to pressure differential between the top of the Vanadium and

Manganese membrane materials and the bottom of the Si_3N_4 frame material; additionally, breakage may also occur owing to the maximum temperature imparted at the point of impact—the 600nm hotspot.

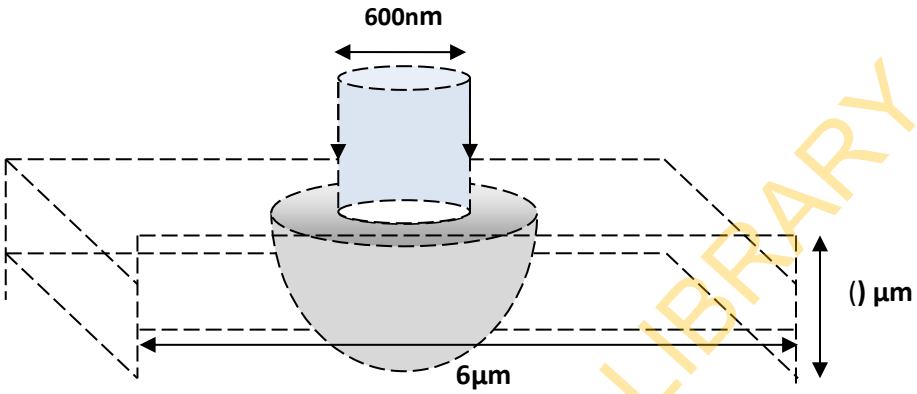

Figure 2 (a) Schematic of the proposed vanadium (or manganese) structure imparted by a cylindrical shaped electron beam of ς ≤1µm

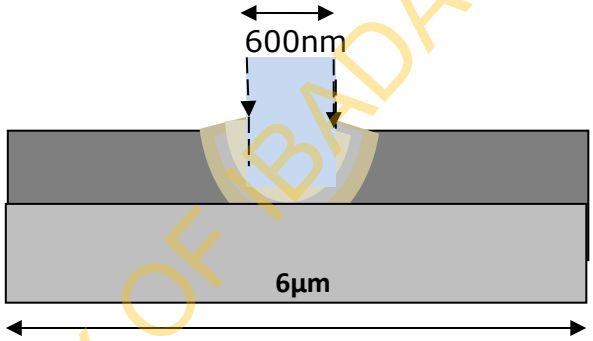

Figure 2 (b) A schematic of the side view of vanadium (or manganese) structure imparted by a cylindrical shaped electron beam of 1µm spot size.

Results and discussions

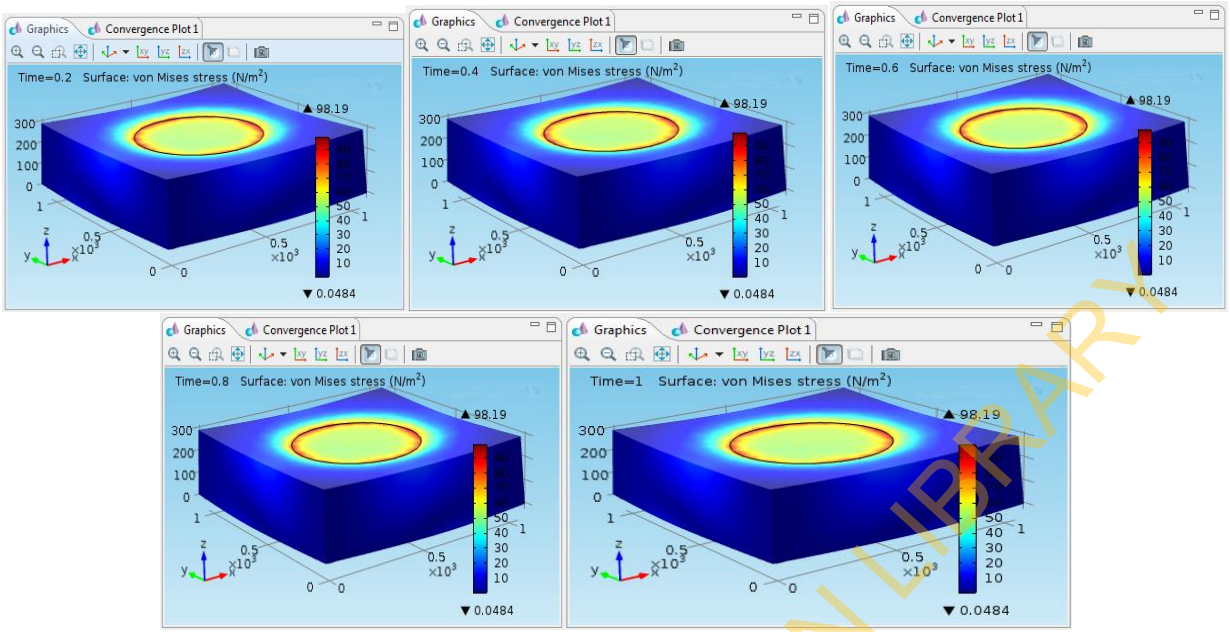

Figure 3 (a) simulated structure of Vanadium displaying transient thermal stress distribution in time steps of 0.2, 0.4, 0.6, 0.8 and 1.0s

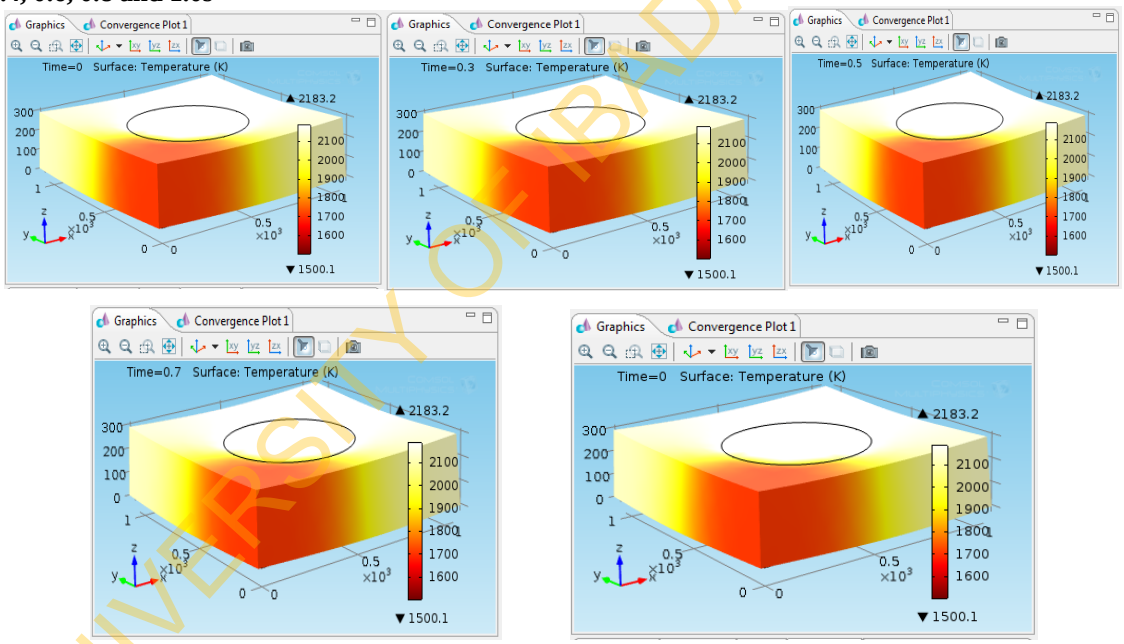

Figure 3 (b) simulated structure of Vanadium displaying transient temperature distribution in time steps of 0, 0.3, 0.5, 0.7 and 0.9s

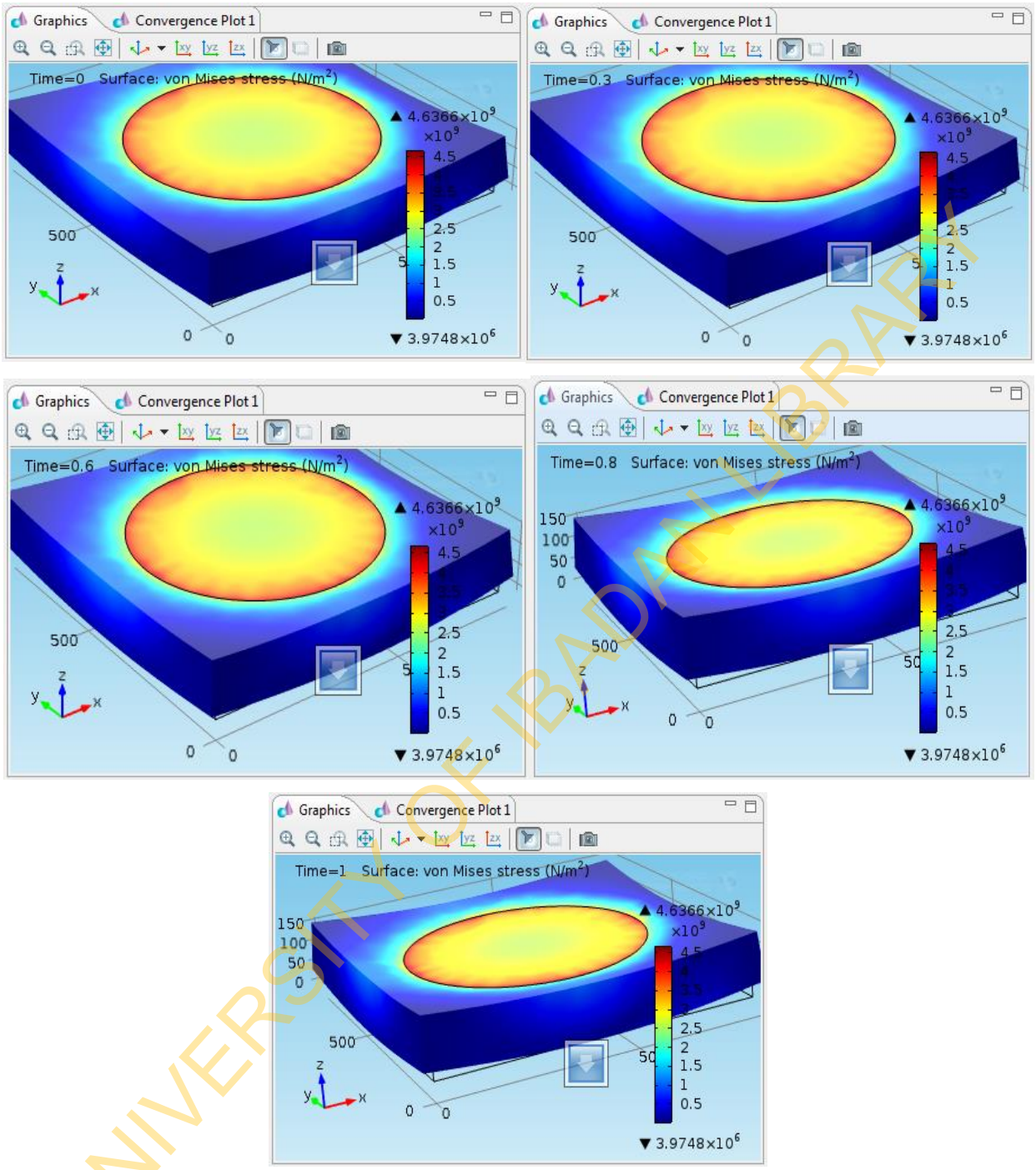

Figure 3 (c) simulated structure of Manganese displaying transient thermal stress distribution in time steps of 0, 0.3, 0.5, 0.7 and 0.9s

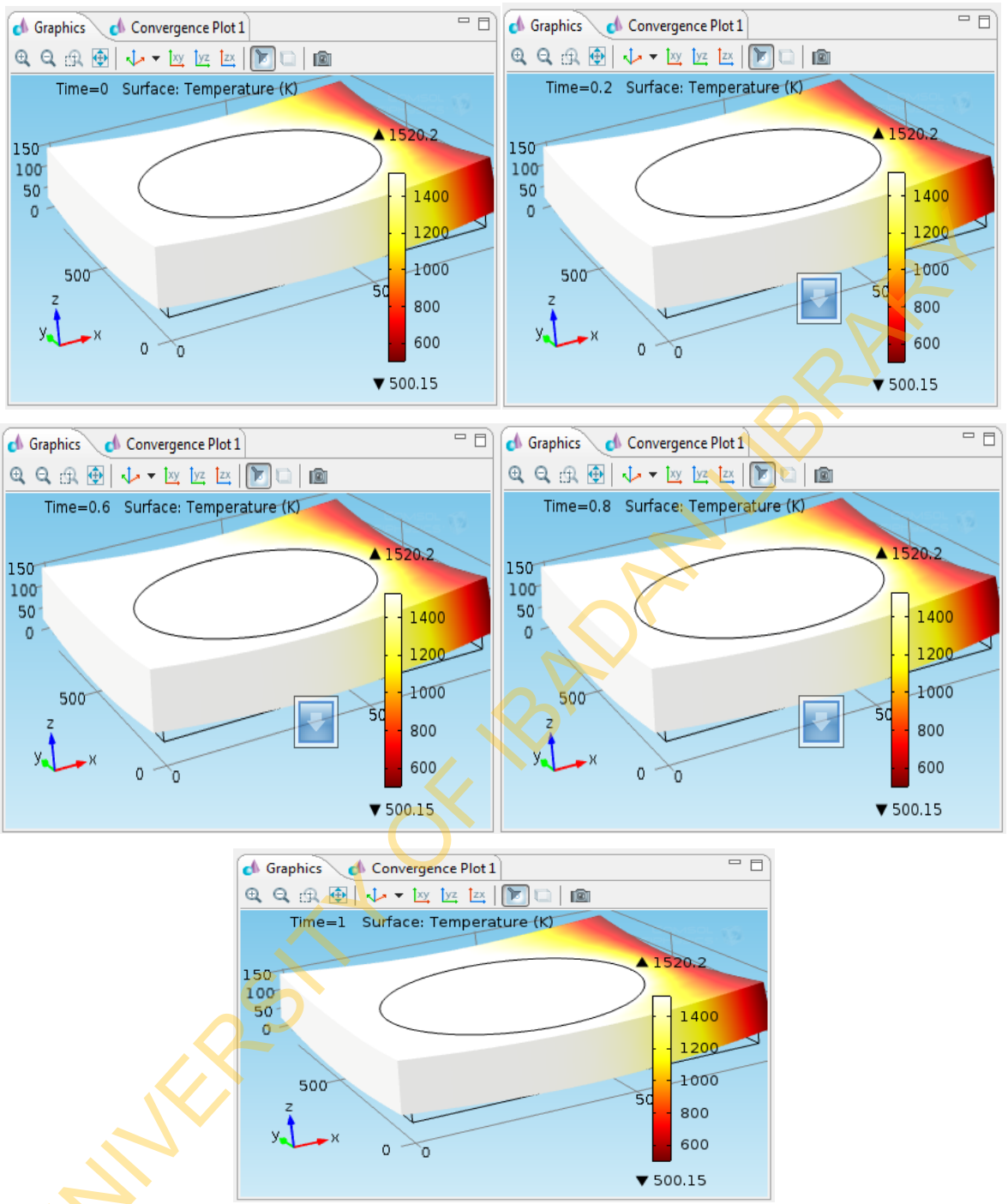

Figure 3 (d) simulated structure of Manganese displaying transient temperature distribution in time steps of 0, 0.2, 0.6, 0.8 and 1.0s

This simulation embodies buckling under thermal load or stress.

In material science, two criteria are employed in the analysis of buckling of a member such as the cuboid-shaped Vanadium and Manganese; they are Tresca stress and Von misses stress.

In this analysis, a transient Finite Element Model (FEM) of Heat transfer equation (Rolfes *et al*., 2003;

Enikov *et al*., 2005) coupled with Linear Elasto-Dynamic equation (Ursin and Zhao 1995) are applied; this expression is represented as:

$$\rho C_p \frac{\delta T}{\delta t} + \rho C_p u \nabla T = \nabla(K\nabla T) + Q + (\lambda+\mu)(\nabla.\sigma) \quad (3.1)$$

Where λ and μ are Lamie's constants, ∇ is a Del operator, ρ is density of the material and Cp is the specific heat capacity of the material.

The governing equation is solved over the initial and boundary conditions given below:

Initial Condition:- $T_{(x_i,0)} = T_{(a)}$

Boundary Conditions

for (i=1,2,3)

$$\left\{ \begin{array}{l} -\nabla_{x_{ij}} T = h_{ij}\left[T_{(x_{ij},t)} - T_{(\infty,t)}\right] \\ -\nabla_{x_k} T = f(E_p) \end{array} \right\} \quad \begin{array}{l} \text{(i, j=x, y)} \\ \text{(k=z)} \end{array}$$

Where $E_p = we^{-\beta t}$ (3.2)

w =constant β is the magnitude of the emission energy. $T_{(a)}$ is the ambient temperature.

Conclusion and application of findings

Conveyed thermal energy resulted to deformation in the microstructure of the Vanadium and Manganese materials called 'Buckling'.

Samples of Vanadium and Manganese exposed to Power Density of 2.0×10^{11} Wm^{-2} each, would attain Maximum Temperatures of 1302.93k and 5128.21k respectively—here, Vanadium attained about a quarter of Manganese' Maximum Temperature.

Vanadium demonstrated a greater ability to survive heat flux imparted on it than Manganese—higher Maximum Temperature puts a material at risk of being broken; by implication, Vanadium is less likely to break after buckling than Manganese.

Temperature and thermal stress distributions does contribute to microstructural deformation; however the damages done to these membrane materials, owing to

The heat dissipation along the z-direction is the given by the exponential decay of electron energy released from the tungsten which causes thermal increasing load and deformation captured by the Von Misses criterion when coupled with the equation below.

These constants are expressed as:

$$\lambda = \frac{E\upsilon}{(1+\upsilon)(1-2\upsilon)};\ \mu = \frac{E}{2(1+\upsilon)} \quad (3.3)$$

Where *v* is Poisson ratio and *E* is Young modulus

These expressions well explain the effect of thermal transport and material deformation along the direction of imparted heat flux.

Since impinging electron beam conveys thermal energy; this energy results to deformation in the microstructure of the Vanadium and Manganese materials; this deformation is called 'Buckling'.

Vanadium and Manganese structures in Figures 3 (a) to (d) are imparted by a 600nm spot size of electron beam; the Vanadium structure of 1200nm by 1200nm dimension is 265nm thick and the Manganese structure of 1000nm by 1000nm dimension is 110nm thick—these are optimized dimensions. 600nm electron beam spot size.

deformation are ameliorated by passing helium gas at 0.01mbar for cooling and by allowing these structures to rotate via inbuilt electric motors. Rotation ensures a circularly patterned heat energy spread over the surface of the membrane material.

Optimized dimension of 1200nm by 1200nm by 265nm for Vanadium and 1000nm by 1000nm by 110nm for Manganese are recommended if these structures must survive a 600nm electron beam spot size impact.

However, the Vanadium material stands a lesser chance of breaking.

With such resolution, contents of a bacterium (1μm), animal cell (10μm), plant cell (100μm), fossils of faunas and floras embodied in rock samples, may be imaged.

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