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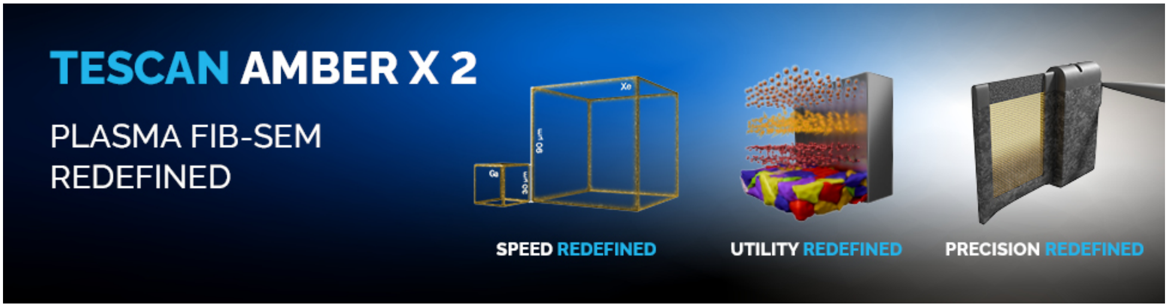

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Evaluation of New Titanium Alloys as Potential Materials for Medical Devices

Cristina Jiménez-Marcos[1], Julia Claudia Mirza-Rosca[1],*, Madalina Simona Baltatu[2], and Petrica Vizureanu[2]

[1]*Department of Mechanical Engineering, University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Spain*
[2]*Department of Technologies and Equipment for Materials Processing, "Gheorghe Asachi" Technical University of Iasi, Iasi, Romania*
*Corresponding author: julia.mirza@ulpgc.es

Introduction

The continuing relevance of research in medicine, biology, chemistry and engineering has led biomaterials science to develop new materials that can resolve many of today's medical problems and improve the quality and longevity of human life [1]. However, as life expectancy has increased in developed countries, the elderly population has increased, as has the obese population, the latter due to the adoption of a more sedentary lifestyle, putting them at greater risk of suffering chronic musculoskeletal diseases such as osteoarthritis, particularly in the hips and knees, and requiring a greater number of surgical implant repairs.

Metal biomaterials, such as CoCrMo alloys, 316L stainless steel, and titanium and its alloys, are often the most frequently employed for medical applications [2–4]. The very superior biocompatibility, great corrosion resistance, high mechanical performance, low modulus, and high thermal stability of titanium alloys make them stand out above the others [5].

Two novel Ti20Mo7ZrxSi ($x = 0.75, 1$) alloys were produced by vacuum arc remelting (VAR) furnace, and this study examined their microstructure, corrosion behaviour, quantitative microanalysis, Young's modulus and hardness. Metallography, scanning electron microscopy, electrochemistry, three-point bending, and microhardness testing were some of the used techniques for this study.

Experimental

The Ti20Mo7Zr0.75Si and Ti20Mo7Zr1Si samples obtained in a vacuum arc remelting furnace were prepared for the subsequent analysis (see Figure 1). Electrochemical testing, Vickers hardness measurements and SEM observations on the embedded samples were performed (see Figure 2). A part of the samples have been cut and the Young's modulus of each specimen was calculated by a three-point bending test (see Figure 3).

Results and discussion

In the metallographic examination, in Figure 4, both samples have biphasic and dendritic structures and the size of dendrites are reduced with the addition of Si, whereas the interdendritic zone grew.

EIS measurements were performed on each sample at different potentials to obtain impedance plots (see Figure 5) where the corrosion resistance increases as the applied potential became more positive and the impedance and phase angle values increase. Thus, the sample with the highest corrosion resistance was Ti20Mo7Zr1Si.

The impedance experimental data were fitted with an electrical equivalent circuit with one-time constant for Ti20Mo7Zr0.75Si and with two-time constant for Ti20Mo7Zr1Si (see Figure 6).

The dispersive energy obtained from the EDS spectra of the samples studied revealed the existence of the alloy's elements together with oxygen (see Figures 7c and Figures 7d), most likely as a result of the past corrosion processes and the creation of the titanium oxide layer. On the other hand, it is evident from the quantitative results that there are two zones, one rich in titanium and the other in Mo, Zr, and Si.

In the three-point bending method, in Table 1, the Young's modulus achieved for both samples were similar to that normally found in human bone, lower than that of commercial alloys and lower for the TiMoZrSi0.5 sample. In addition, the Vickers hardness versus scan length plots for both samples show widely scattered maxima and minima, as the surfaces of the samples have hard and soft areas, and it is confirmed that hardness increases with higher silicon content (see Table 2).

Conclusions

This research investigated the effect of silicon concentration on microstructure, biocompatibility, modulus of elasticity, microhardness and corrosion resistance of the TiMoZrSi alloy in a simulated body fluid, confirming the two-phase and dendritic structure for both samples in metallographic tests. Two zones, one rich in titanium and the other in Mo, Zr, and Si, may be found on the surface of the alloys. Each sample's surface was found to form a passive oxide layer (TiO_2), which was verified. In electrochemical tests, the potential of the TiMoZrSi0.75 sample tended to corrode and showed lower corrosion resistance. The modulus of elasticity was less than that of many commercial alloys. Finally, the Vickers hardness values increased as the silicon content increased. According to the results obtained, the addition of a higher percentage of silicon leads to slightly improved mechanical properties but both alloys can be used for medical devices.

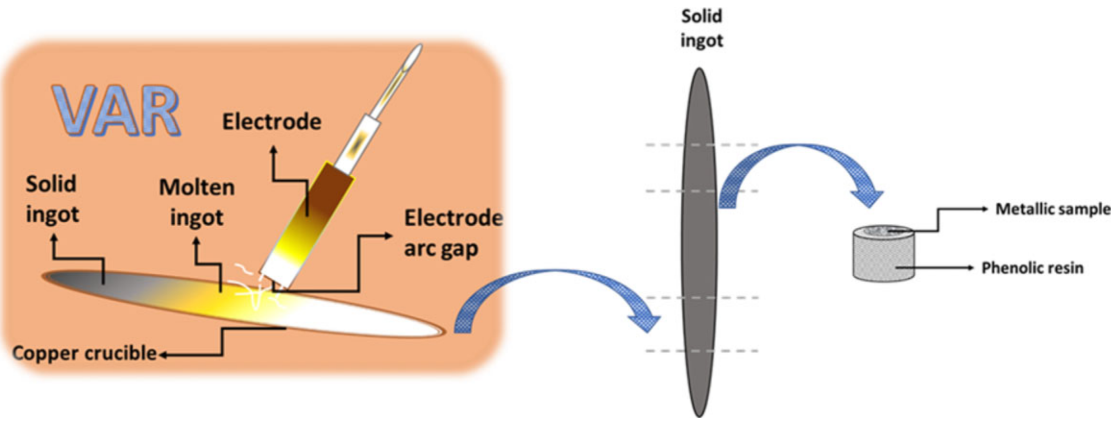

Fig. 1. Fabrication and posterior preparation of the studied samples.

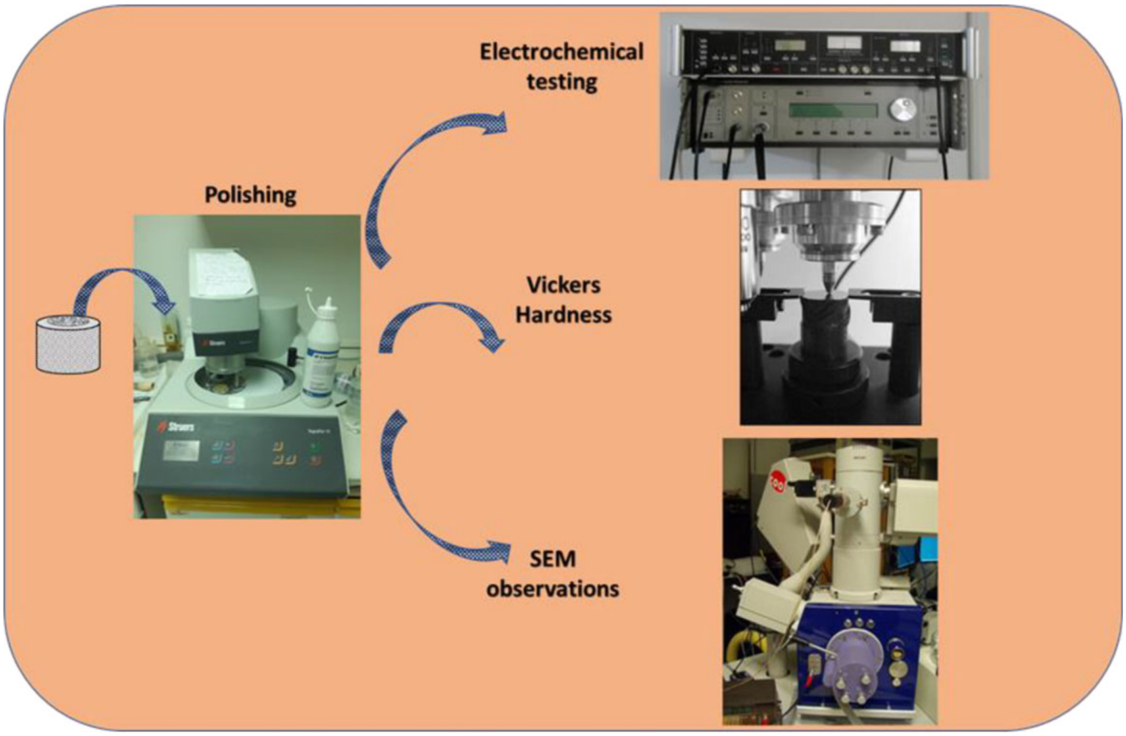

Fig. 2. Part of the experimental procedure for the samples.

Fig. 3. Preparation of the samples and three-point bending test.

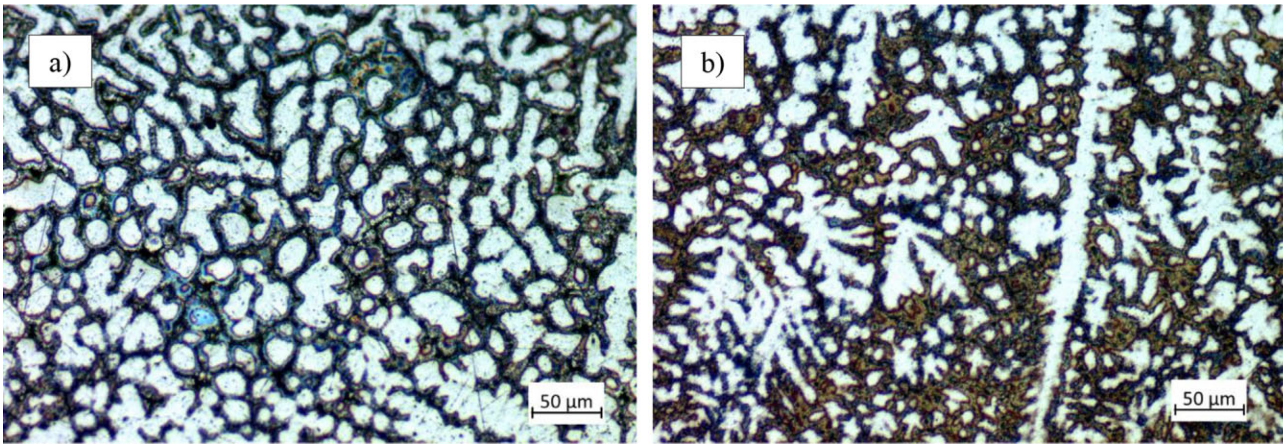

Fig. 4. Microstructure of Ti20Mo7Zr0.75Si (a) and Ti20Mo7Zr1Si (b) samples after chemical etching by optical microscopy.

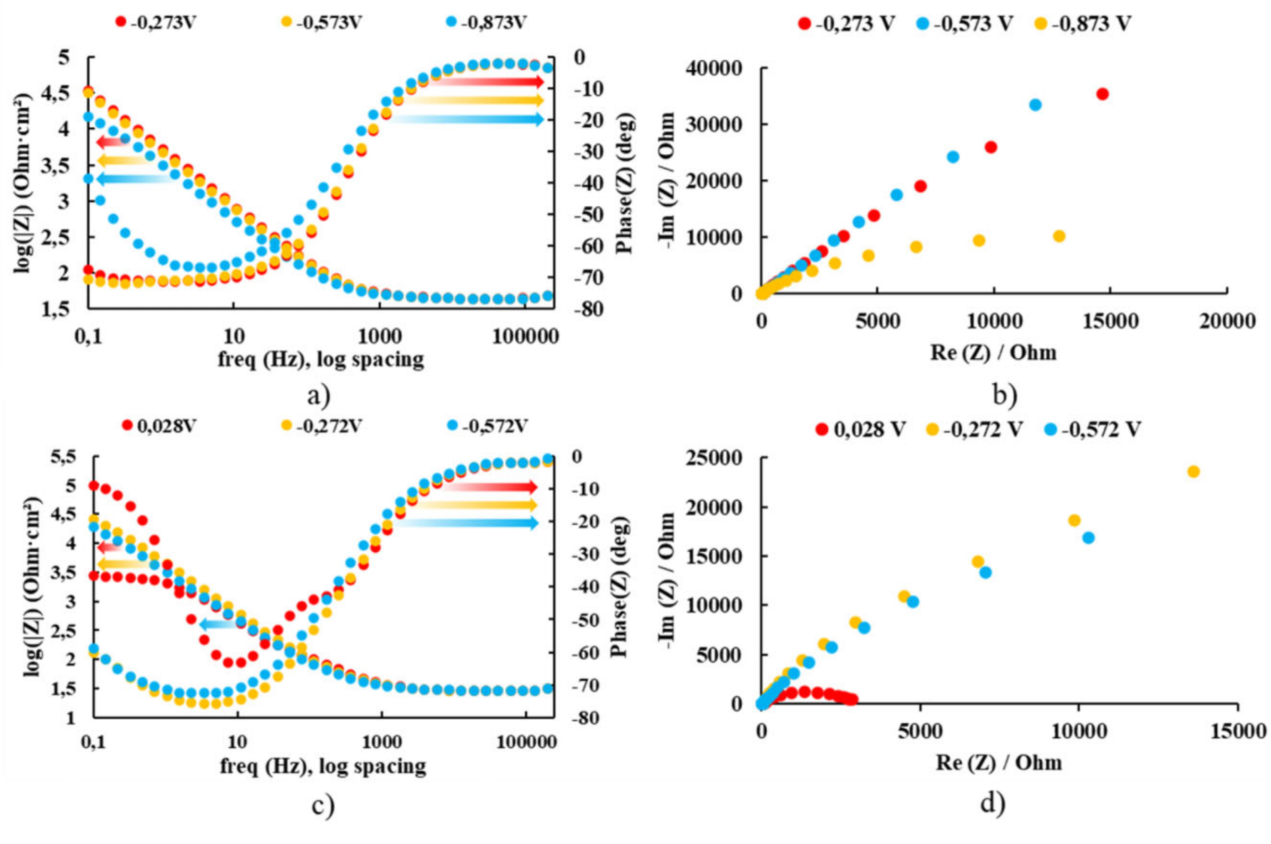

Fig. 5. Impedance diagrams for: Ti20Mo7Zr0.75Si (a and b); for Ti20Mo7Zr1Si (c and d).

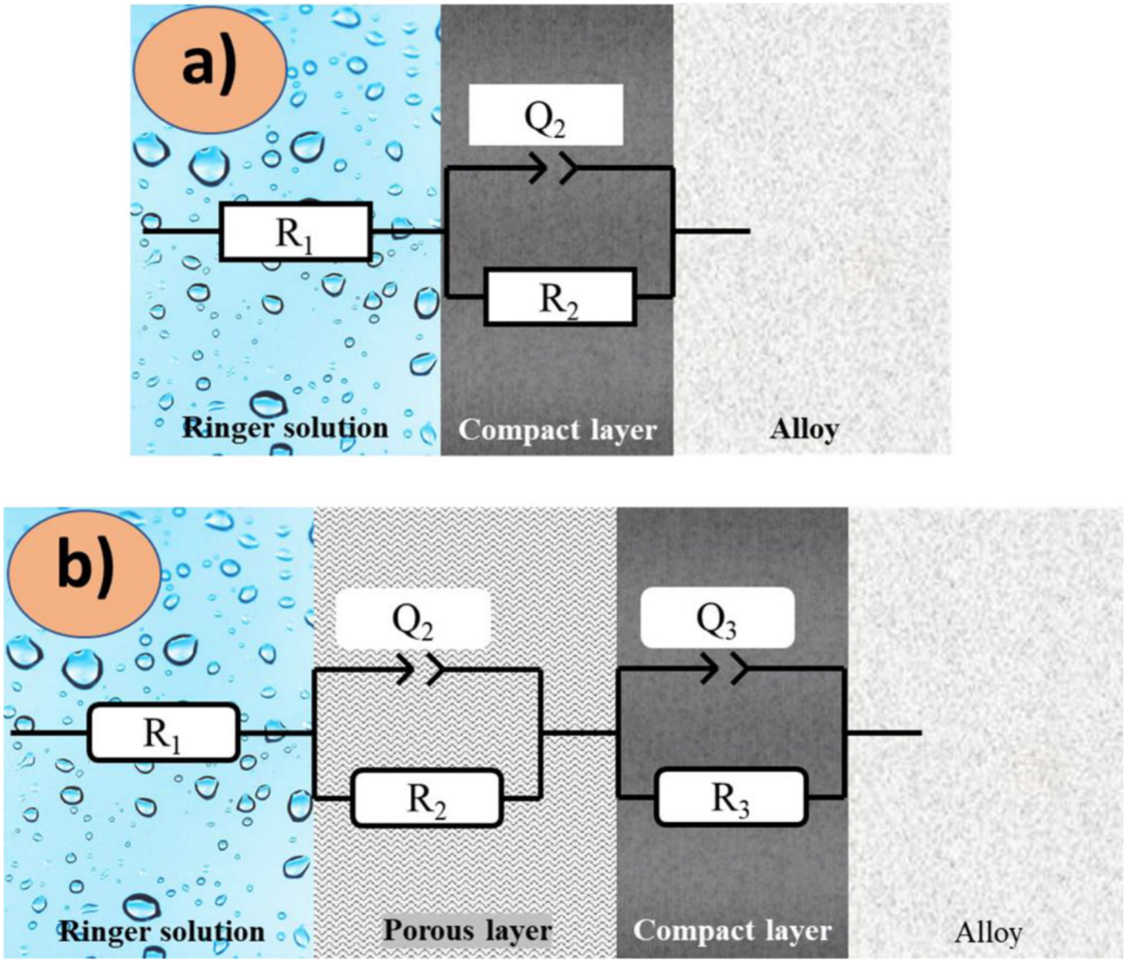

Fig. 6. Equivalent electrical circuits used for the fitting of experimental data for: a) Ti20Mo7Zr0.75Si and b) Ti20Mo7Zr1Si.

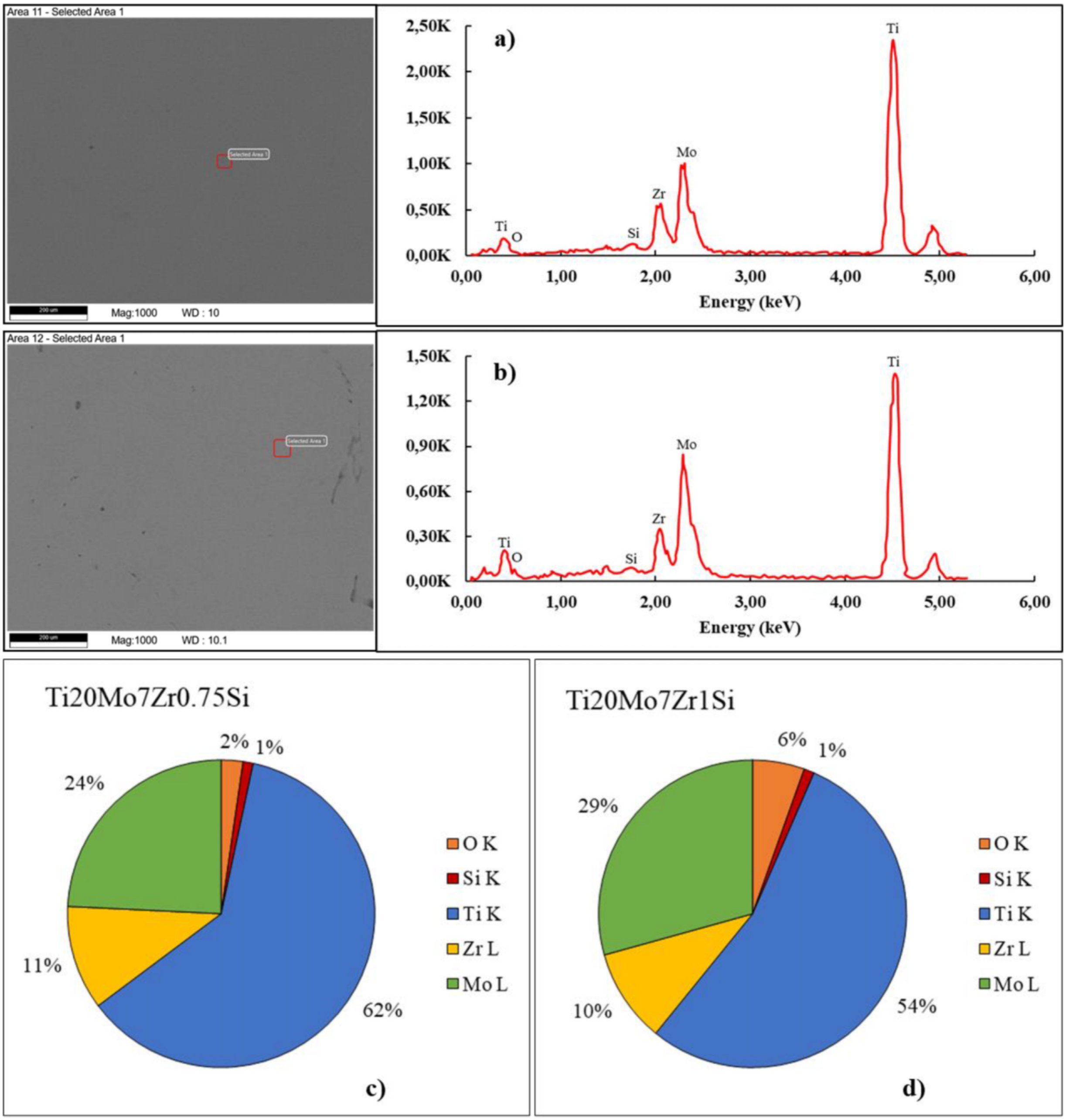

Fig. 7. EDS spectra for Ti20Mo7Zr0.75Si (a) and Ti20Mo7Zr1Si (b) samples and quantification (c, d).

Table 1. Young's modulus values obtained from Ti20Mo7Zr0.75Si and Ti20Mo7Zr1Si specimens.

Sample	Modulus of elasticity E (GPa)
Ti20Mo7Zr0.75Si	54.4 ± 6.5
Ti20Mo7Zr1Si	82.7 ± 21.5

Table 2. Microhardness values of applied loads of soft and hard phases of Ti20Mo7Zr0.75Si and Ti20Mo7Zr1Si samples.

	Ti20Mo7Zr0.75		Ti20Mo7Zr1Si	
	Microhardness (HV)		Microhardness (HV)	
Load (gf)	Soft phase	Hard phase	Soft phase	Hard phase
5	214	365	115	243
25	239	383	137	366
50	319	399	158	356

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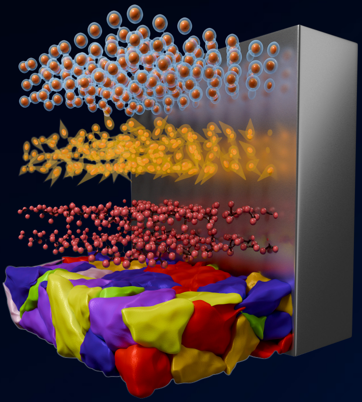

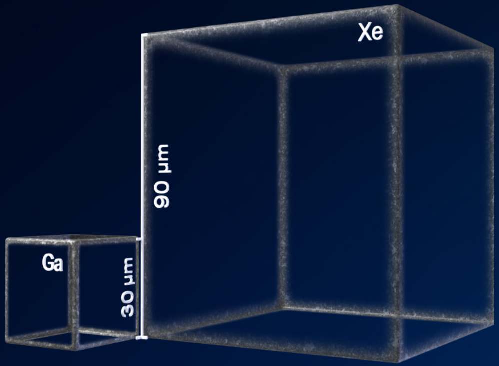
Xe
90 µm
Ga
30 µm