Pushan Ayyub, Res. Rev. J Mat. Sci. 2018, Volume 6
DOI: 10.4172/2321-6212-C2-017

4th International Conference on

Condensed Matter and Materials Physics

August 16-17, 2018 | London, UK

Can superconductivity persist in arbitrarily small particles?

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The study of superconductivity in nanostructured systems is particularly fascinating due to the existence of a multitude of length scales, such as the coherence length (ξ) and the penetration depth (λ_L). Here, we focus on quasi-zero dimensional superconductors, such as isolated nanoparticles or nanocrystalline solids. In such systems, superconductivity usually persists down to length scales much smaller than ξ and λ_L. Ultimately, the lower size limit for superconducting order to exist is set by the 'Anderson criterion', which arises from quantum confinement and is believed to be remarkably accurate and universal. We report, however, a recent result that questions the validity of the Anderson criterion. We show that phase-pure, nanocrystalline bcc-Ta remains superconducting (with, $T_C \approx 0.9K$) down to sizes 40% below the conventional estimate of the Anderson limit for Ta (4.0nm). Further, both the T_C and H_C exhibit unusual, non-monotonic size dependences, which we explain in terms of a complex interplay of quantum size effects, surface phonon softening and lattice expansion. An estimation of T_C within first-principles density functional theory shows that even a moderate lattice expansion allows superconductivity in Ta to persist down to sizes much below the Anderson limit. This indicates the possibility of bypassing the Anderson criterion by suitable crystal engineering and obtaining superconductivity at arbitrarily small sizes, an obviously exciting prospect for futuristic quantum technologies. We take a critical look at how lattice expansion modifies the Anderson limit, an issue of fundamental interest to nanoscale superconductivity.

Recent Publications

1. S K Mohanta et al. (2016) Size-induced crossover from itinerant to localized magnetism observed for isolated Fe impurities embedded in different structural polymorphs of silver. Physical Review B. 94:184431.
2. M Dalui et al. (2015) Preferential enhancement of laser-driven carbon ion acceleration from optimized nanostructured surfaces. *Scientific Reports* 5:11930.
3. S Chattopadhyay et al. (2015) Local structure, composition and crystallization mechanism of a model two-phase composite nanoglass. J. Chemical Physics. 144(6):064503.
4. S Bose and P Ayyub (2014) A review of finite size effects in quasi-zero dimensional superconductors. Reports Progress Physics. 77(11):116503.

Biography

Pushan Ayyub is a Senior Professor and Chair in the Department of Condensed Matter Physics at the Tata Institute of Fundamental Research, Mumbai, India. He has over 160 publications in the general area of nanoscience. He was a Member of the International Committee on Nanostructured Materials (1998-2008) and is currently a Member of the Nano Mission Council of the Government of India. He is a Fellow of the Indian National Science Academy. His research interests include the size dependence of superconductivity and ferroelectricity. He is particularly interested in size-induced structural phase transitions and stabilization of novel crystal structures.

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