Reflections on field-induced insulator to metal transition in VO_2 films

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We review the problem of inducing insulator-to-metal transition by applying an external electric field to a thin vanadium oxide film. Despite multiple reports that observe such an effect and the sound theoretical reasons for its existence, the status of this problem is unsatisfactory and we offer our reflections on the reason why. We believe that for a sufficiently large applied field the transition indeed occurs, but it is confined to a truly infinitesimal sliver at the surface of the sample. In its "insulator" phase, the VO_2 sample is, in fact, a semiconductor with a relatively narrow bandgap and a rather high conductivity at temperatures of the experiment. As a result, the field-induced transition is never observed in a gated bulk sample. The transition is convincingly observed only in double-gated films, but even there the effect is rather small because most of the film remains semiconducting and shunts the emergent metallic sliver.

We discuss the conditions under which the transition can be induced in the entire film, rather than its top sliver. We show that this favorable situation can be realized when the film is sufficiently thin, so that the energy cost of converting the entire film into the metallic phase (which is "thermodynamically wrong" in the part of the film away from the surface) is smaller than the would-be cost of creating a domain boundary between the two phases. At this time, we cannot predict how thin the film should be for the proposed stabilization of the entire-film transition by the domain boundary energy, but we discuss the physical quantities that should be determined to make this prediction.

Finally, we discuss the need for the ground plane, which does not sit well with the technological reality that the best and thinnest VO_2 films are grown on insulating sapphire substrates. In large transistor-like structures with gate lengths of a micron and longer, the ground plane appears indispensible, for otherwise the field configuration would be accommodated with tiny domain boundaries across the film. The phase boundary must be comparable to the film area for its energy to count. Whether or not this can be accomplished with deep submicron gate lengths is an open question.