Transport properties of Ultrathin Nb films

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Motivation

We report on the influence of disorder on the superconducting transition in ultrathin niobium (Nb) films of various thickness in the absence of magnetic field.

The measurements include the resistance versus temperature [R(T)], and current-voltage (I-V) characteristics.

The results are compared to predictions of theoretical models:
(1) Berezinski-Kostelitz-Thouless (BKT) model, which describes thermal unbinding of vortex-antivortex pairs above certain temperature T_{BKT} (in the absence of the magnetic field),
(2) vortex glass-vortex liquid transition at temperature T_g, usually studied in the presence of magnetic field.

Strictly speaking, BKT transition (1) is a special case of transition (2) for 2-dimensional and zero-field case. In the absence of the field, the distances between vortices are large, the T_g extracted from comparison of model (2) to experiment may significantly deviate from T_{BKT}.

Experimental details

- Ultrathin superconducting niobium Nb films of different thickness were synthesized using magnetron sputtering and sandwiched between two silicon wafers.
- The films were optically patternened with Hall bar-structure mask by means of photolithographic patterning technique.
- Then, samples were etched using ion beam etching teqnique.
- Electric contacts were made across the current and voltage channels at the surface using indium solder.
- Transport measurement were preformed by a standard four-probe measurement method using a quantum design physical property measurement system (PPMS).

Structural Properties (XRD)

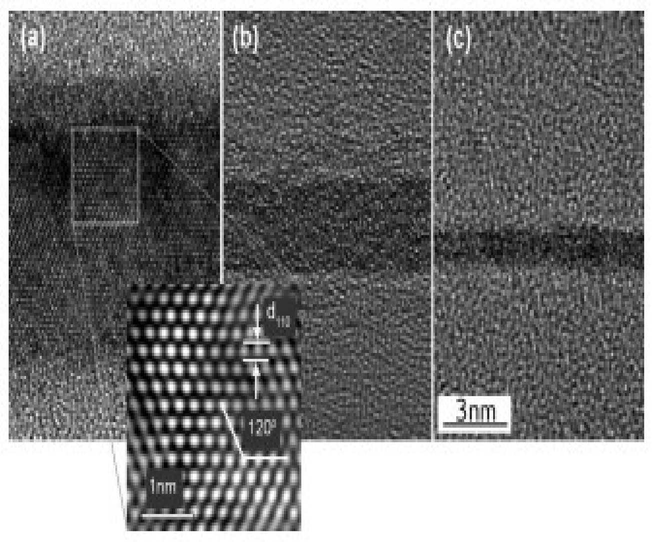

Fig.1. HRTEM images for Si/Nb(d)/Si trilayers, with different Nb thickness.The inset at the bottom shows the enlarged Fourier-filtered part of image (a)indicated by the white square.

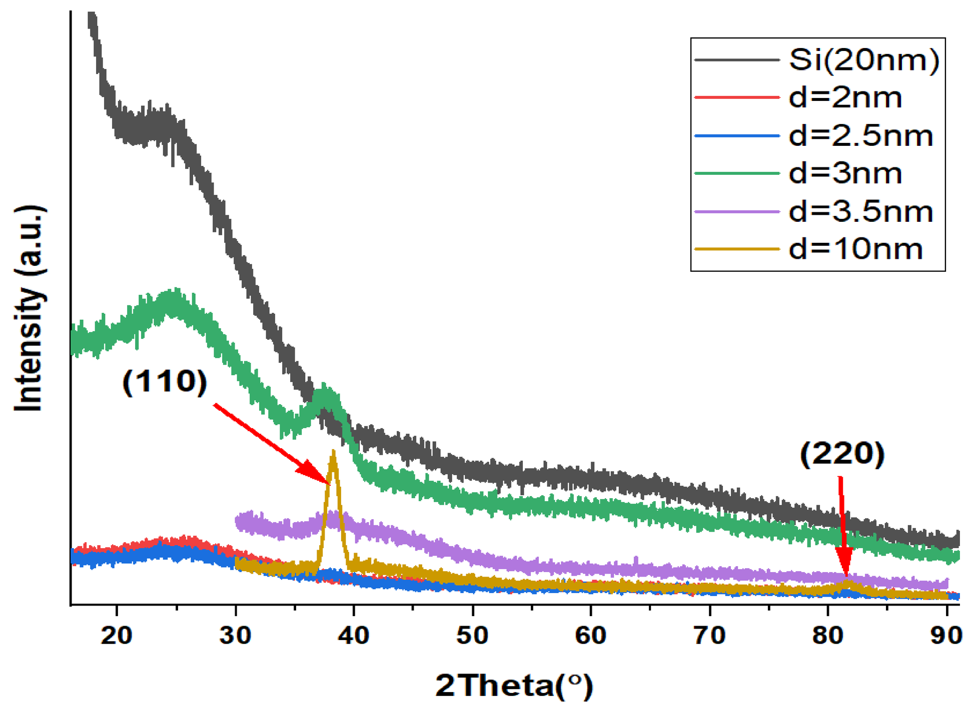

Fig2. XRD pattern of Nb films of different thckness (d).

Transport Results

1. Resistivity -Temperature BKT Analysis

Figure3.(a,b,c, d) shows the low temperature- RT fitting to Halperin-Nelson (H-N) model [Ref.1&2] for the superconducting Nb films of different nominal thickness. The H-N formalism is given by: ***R(T)≈10.8*c*R*exp{-2*sqrt(c(T$_{C0}$-T$_{BKT}$)/(T-T$_{BKT}$))}***. The BCS critical transition temperature T_{C0} and the dimensionless c are adjustable parameters. R is the measured normal state-sheet resistance of a sample.

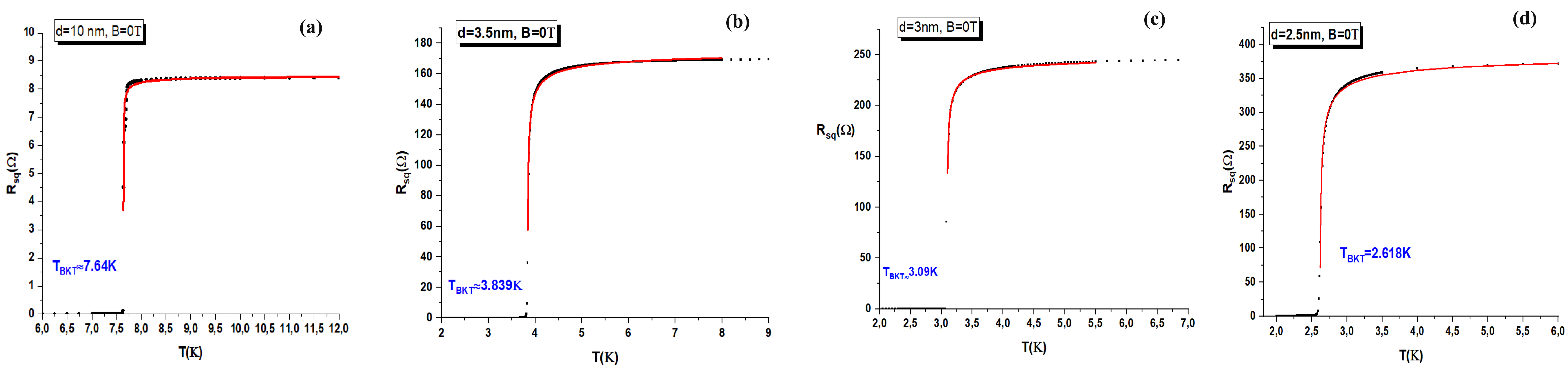

Fig.3. (a,b,c,d): Halperin-Nelson fit to experimental square resistance (in Ohms) Vs. Temperature (in Kelvins) or various film thickness(d) .

2. Vortex glass-liquid transition

Figure 4.(a,b,c,d) shows the vortex glass(solid) phase transition to the liquid state which occurs at the temperature T_g. This transition temperature is extracted by extrapolating the linear part to the temperature axis and the intercept indicates the transition temperature T_g [Ref.3]. The extrapolation line is the melting line beyond which the vortices in their glass phase start to melt into a liquid resistive phase. In the scaling regime of the vortex-glass model, the vertical axis represents the inverse of the the first derative of the logarithmic sheet resistance R_{sq} with respect to temperature T.

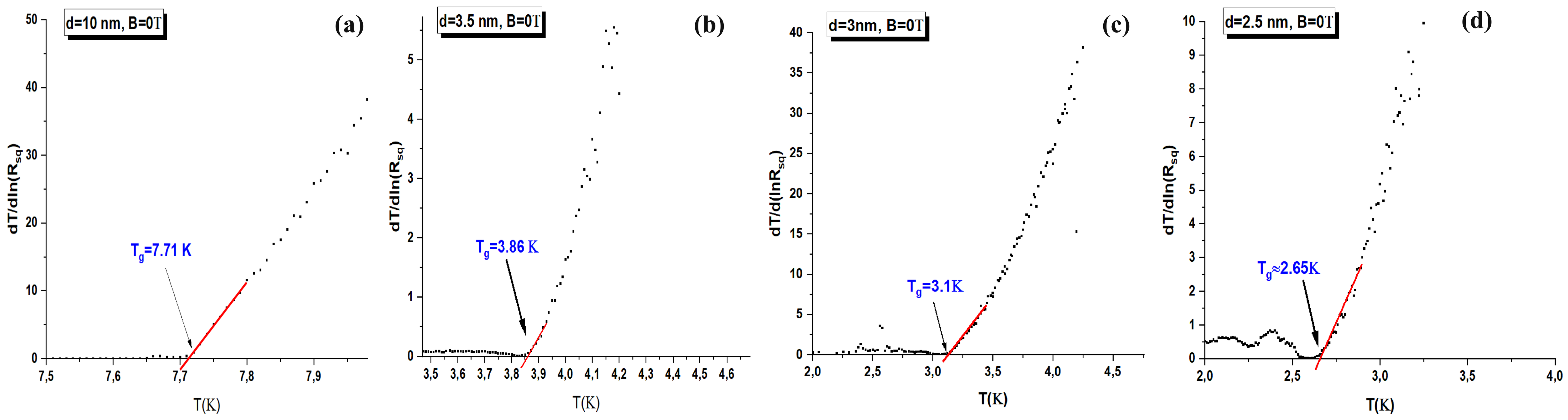

Fig.4. (a,b,c,d):Vortex glass-liquid transition temperature (T_g) of various film thickness(d).

3. IV Characteristics

According to the Berezinskii-Kosterlitz-Thouless (BKT) scenario [Ref.4], for ultrathin superconducting films, the measured voltage in the vicinity of T_{BKT} is expected to follow a power-law function of the applied current, $V \propto I^{n(T)}$, with exponent n(T) proportional to the superfluid stiffness, which is the energy scale associated to the areal density of superfluid carriers.

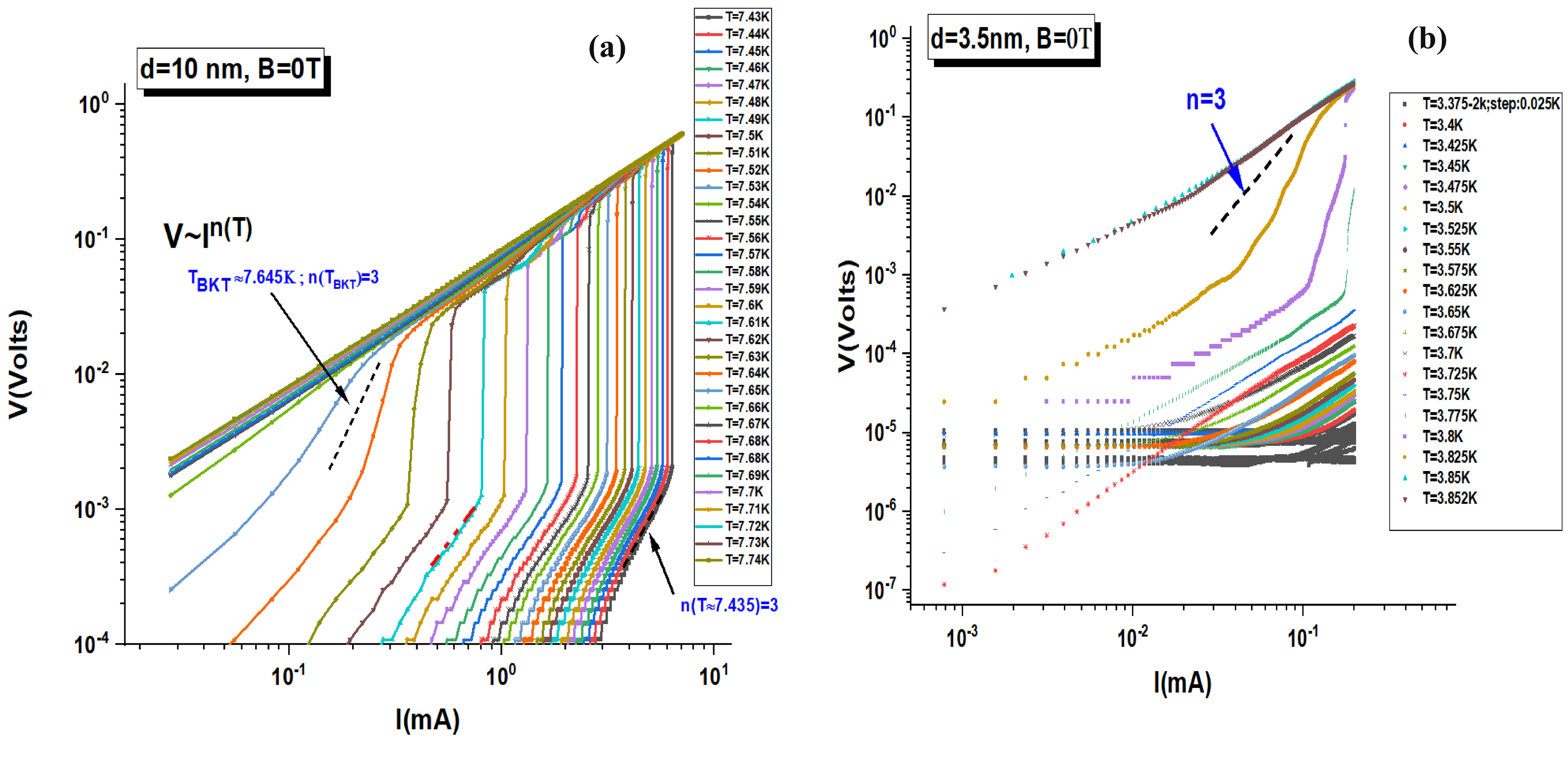

Fig.5. (a,b):Current-Voltage characteristics of Nb films of two different thickness(d).

Conclusions

- *The BKT transition results from H-N fitting models for the Nb films are approximately consistent with those extracted from the low I-V characteristics regime.*
- *The nonlinearity of the I-V characteristics in the polycrystalline films can be simply ascribed to vortex-antivortex unbinding triggered by a high driving current according to the BKT scheme.*
- *This is not exactly the case for the amorphous films which is a signature of film inhomogeneity and disorder effects. The disorder results in significant broadening of the transition, and no negative slope near T_{BKT} is observed in I-V characteristics.*

References

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