Berezinskii-Kosterlitz-Thouless transition in ultrathin niobium 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 Berezinski-Kosterlitz-Thouless (BKT) model, which describes thermal unbinding of vortex-antivortex pairs above certain temperature T_{BKT} (in the absence of the magnetic field) leading to the specific evolution of the nonlinear exponent of the current-voltage(I-V) characteristics. However, many recent studies suggest that this is restricted to the case of homogeneous films. Since these films are prone to various types of diorder, which may lead to inhomogeneity, it is important to understand how disorder modifies the I-V characteristics.

Experimental details

- Ultrathin superconducting niobium Nb films of different thickness were synthesized using magnetron sputtering and sandwiched between two silicon wafers for protection against oxidation.
- 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 performed by a standard four-probe measurement method using a quantum design physical property measurement system (PPMS).

Structural Properties (XRD)

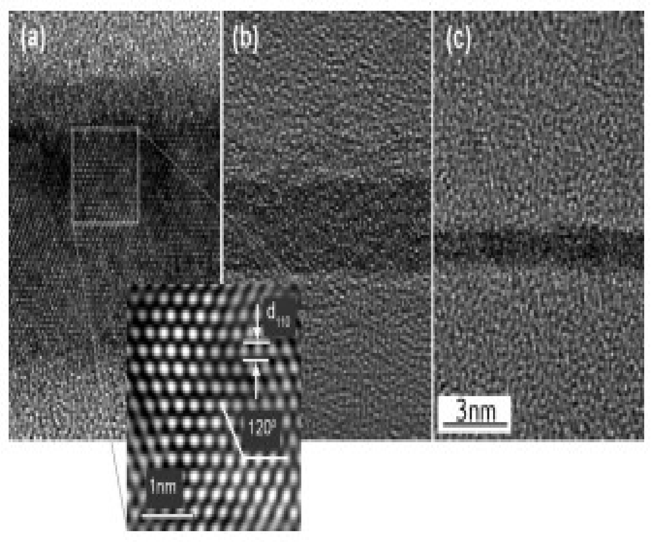

Fig.1. HRTEM images for Si/Nb(d)/Si trilayers, with different Nb thickness.The inset at the bottom shows the enlarged Fourier-filtered part of image (a)indicated by the white square.

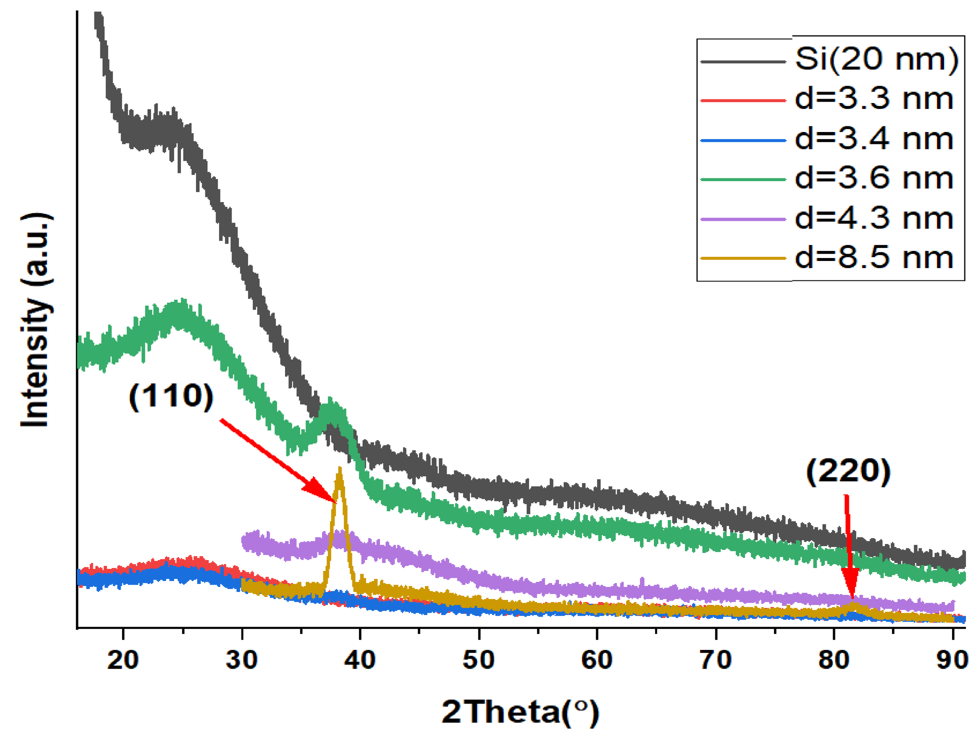

Fig2. XRD pattern of Nb films of different thckness (d).

Transport Results

1. Resistivity -Temperature BKT Analysis

Figure3.(a, c, d) shows the low temperature- RT fitting to Halperin-Nelson (H-N) model [Ref.1&2] for the superconducting Nb films of different thickness in the absence of magnetic field. 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.

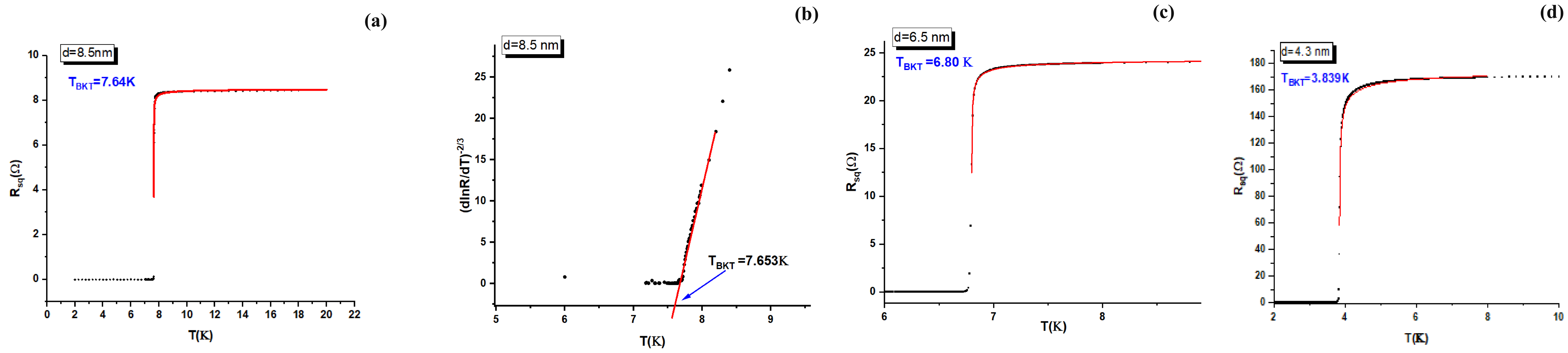

Fig.3. (a,c,d): Halperin-Nelson fit to experimental square resistance (in Ohms) Vs. Temperature (in Kelvins) or various film thickness(d) . (b) T_{BKT} estimation of 8.5 nm film using the logaritmic RT fitting [Ref.3].

2. 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 dependence 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.

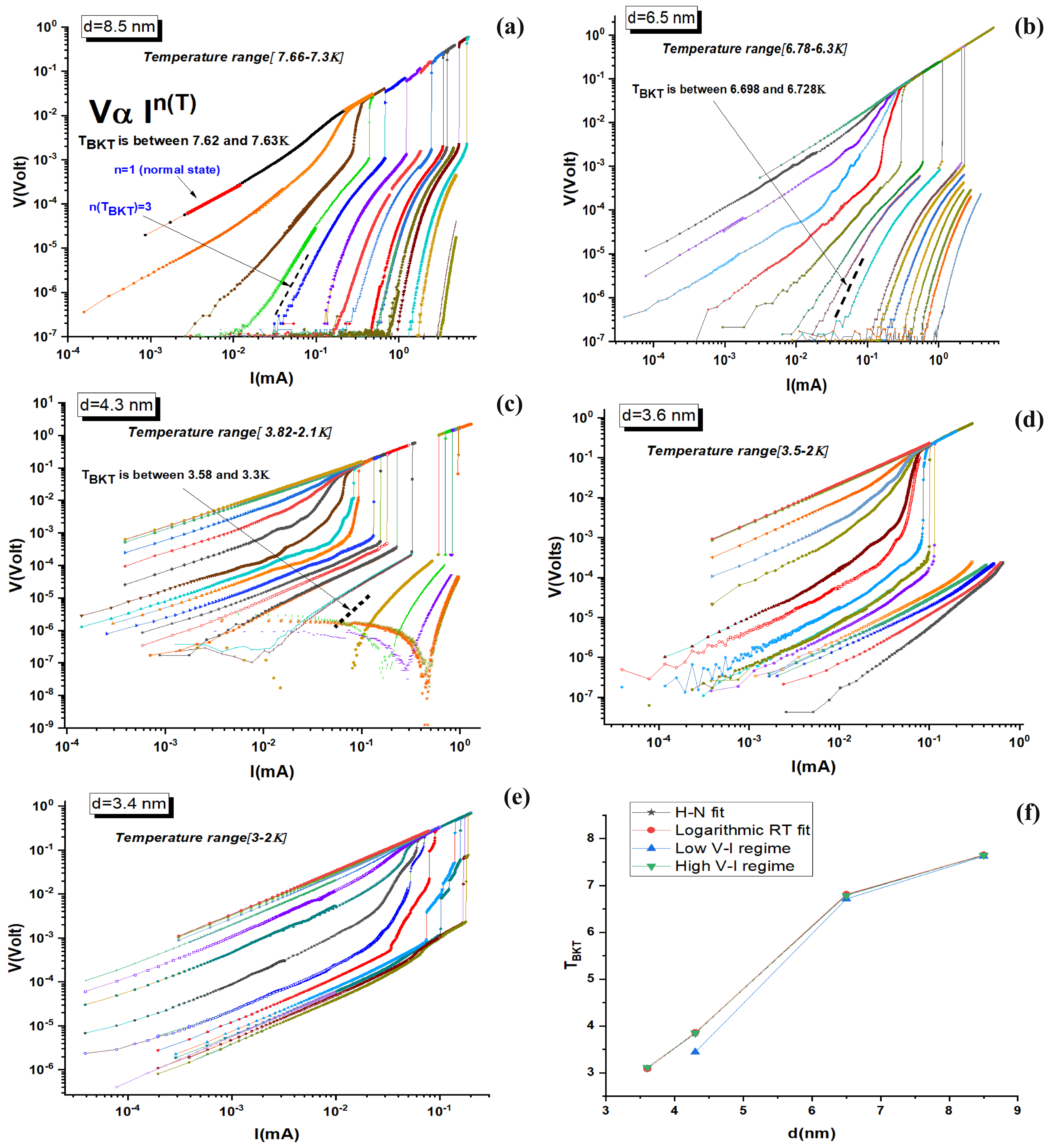

Fig.4. (a-e) Current-Voltage characteristics of Nb films of different thickness(d) in absence of magnetic field. The BKT temperature is extracted from the low V-I regimes. In figures(a, b&c), T_{BKT} can be ascribed to a global BKT transition which may not be the case in figures (d,e) due to strong disorder effects.(f) BKT temperature versus film thickness (d), extracted from RT models fitting and IV characteristics.

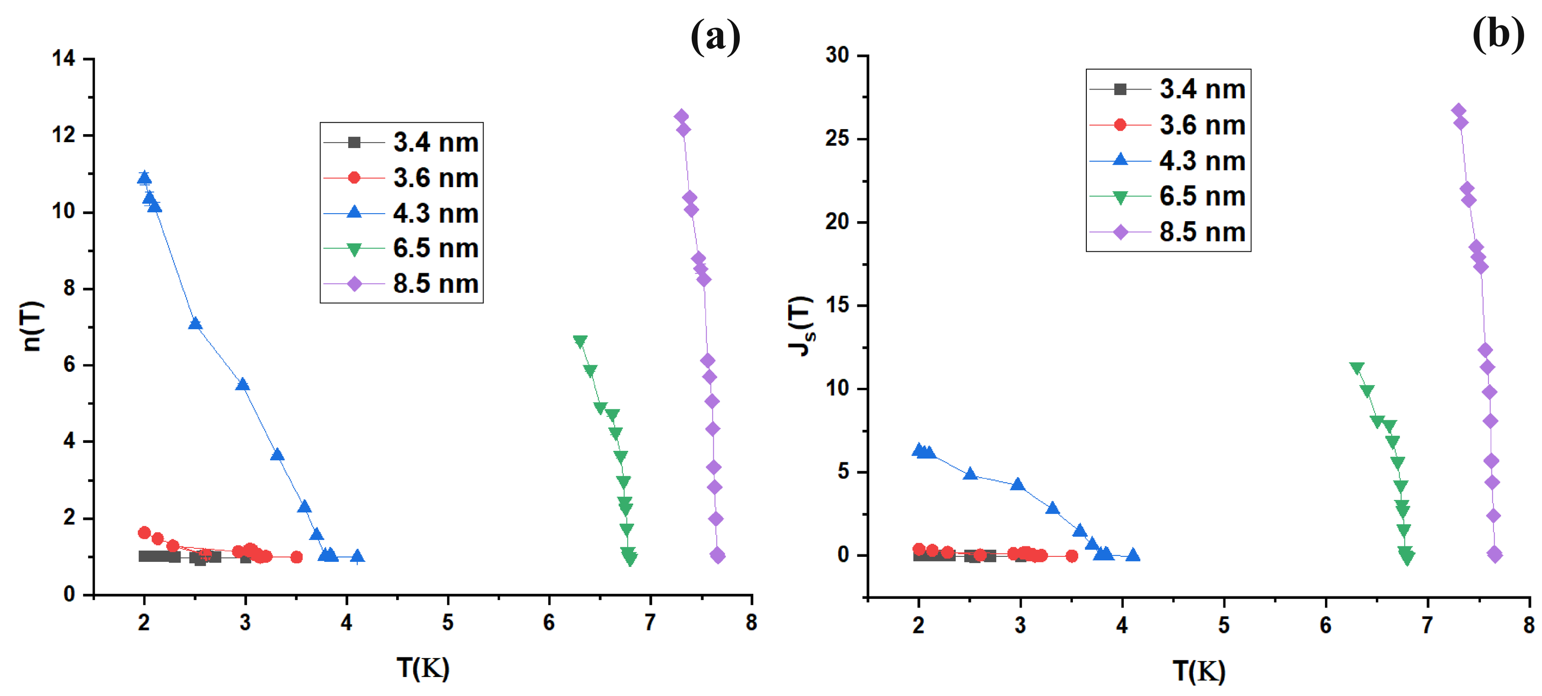

Fig.5.(a) Temperature dependence of the exponent n(T) and (b) the superfluid stiffness extracted from the I-V characteristics.Smearing of the universal BKT jump in the Js(T) appears upon lowering thickness due to the low vortex-core energy and inhomogeneity of the sample.

Conclusions

- *The BKT transition results from RT fitting to theoritical models for the Nb films are approximately consistent with those extracted from the low V-I 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 description becomes invalid 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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