Zero-conductivity state of Cooper-pair insulator

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We investigate low-temperature transport properties of thin TiN superconducting films, differing in the degree of disorder. At zero magnetic field, we find an extremely sharp separation between superconducting- and insulating phases, demonstrating a direct superconductor-insulator transition (SIT) without an intermediate metallic phase. As temperature decreases the conductivity of the insulating films in the critical region of the disorder-driven SIT undergoes a sequence of transitions from Efros-Shklovskii-like- to thermally activated (Arrhenius) behavior ; and finally, at very low temperatures, the system falls into a zero-conductivity state. The latter is destroyed by the magnetic field and voltage bias. We observe a sharp depinning transition at some threshold voltage, which plays the same role as critical current breaking down the zero-resistance state of superconducting films. The threshold voltage of the zero-conductivity state and the activation energy controlling Arrhenius conductivity are magnetic field dependent. These observations suggest formation of a distinct collective insulating state which, at very low temperatures, experiences a sharp transition into a zero-conductivity state dual to superconductivity in the films with low disorder.