Properties of Unshunted and Resistively Shunted Nb/AlO_x-Al/Nb Josephson Junctions with Critical Current Densities from 0.1 mA/μm^2 to 1 mA/μm^2

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***Abstract*—We investigated current-voltage characteristics of both unshunted and externally shunted Josephson junctions (JJs) with high critical current densities, J_c, in order to extract their basic parameters and statistical characteristics for JJ modeling in superconducting integrated circuits as well as to assess their potential for future technology nodes. Nb/AlO_x-Al/Nb junctions with diameters from 0.5 μm to 6 μm were fabricated using a fully planarized process with molybdenum or MoN_x thin-film shunt resistors with sheet resistance R_{sq} = 2 Ω/sq and R_{sq} = 6 Ω/sq, respectively. We used our current standard MIT LL process node, SFQ5ee to fabricate JJs with J_c = 0.1 mA/μm^2 and our new process node, $SFQ5_{hs}$ ('hs' stands for high speed) to make JJs with J_c = 0.2 mA/μm^2, and then with yet higher current densities up to about 1 mA/μm^2. Using resistively inductively capacitively shunted junction model we extract inductance associated with JJ shunt resistors of 1.4 pH/sq. The main part this inductance, about 1.1 pH/sq, is determined by the inductance of the 40-nm Mo resistor film, while the geometrical inductance of superconducting Nb wiring contributes the rest. We attribute this large inductance to 'kinetic' inductance arising from the complex conductivity of a thin normal-metal film in an electromagnetic field with angular frequency ω, $\sigma(\omega) = \sigma_0/(1+i\omega\tau)$, where σ_0 is the static conductivity and τ the electron scattering time. Using a resonance in a large-area unshunted high-J_c junction exited by a resistively coupled small-area shunted JJ, we extract the Josephson plasma frequency and specific capacitance of high-J_c junctions in 0.1 to 1 mA/μm^2 J_c range. We also present data on J_c targeting and JJ critical current spreads. We discuss the potential of using 0.2-mA/μm^2 JJs in VLSI Single Flux Quantum (SFQ) circuits and 0.5-mA/μm^2 JJs in high-density integrated circuits without shunt resistors.**

***Keywords (Index Terms)*— Josephson junctions, Josephson plasma resonance, kinetic inductance, Nb/AlO_x/Nb junctions, RSFQ, superconducting device fabrication, superconducting electronics fabrication, tunnel junction capacitance.**

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