IOP Publishing Superconductor Science and Technology
Supercond. Sci. Technol. **34** (2021) 115021 (15pp) https://doi.org/10.1088/1361-6668/ac2c0e

Superconducting critical temperature and softening of the phonon spectrum in ultrathin Nb and NbN/graphene hybrids

S L Prischepa[1,2], V N Kushnir[1,3], C Cirillo[4], V Granata[5], I V Komissarov[1,2], N G Kovalchuk[1], M M Mikhalik[1], A L Danilyuk[1], I A Svito[3], M Andrulevičius[6] and C Attanasio[5]

[1] Belarusian State University of Informatics and Radioelectronics, P. Browka 6, 220013 Minsk, Belarus
[2] National Research Nuclear University (MEPhI), Kashirskoe Highway 31, 115409 Moscow, Russia
[3] Belarusian State University, Nezalezhnasci av. 4, 220030 Minsk, Belarus
[4] CNR-SPIN, c/o Università degli Studi di Salerno, I-84084 Fisciano, SA, Italy
[5] Dipartimento di Fisica 'E.R. Caianiello', Università degli Studi di Salerno, I-84084 Fisciano, SA, Italy
[6] Institute of Materials Science, Kaunas University of Technology, Kaunas, 51423, Lithuania

E-mail: prischepa@bsuir.by

Received 11 June 2021, revised 5 September 2021
Accepted for publication 1 October 2021
Published 18 October 2021

Abstract

Superconductivity is studied in hybrids consisting of ultrathin superconducting film/few layer graphene. Two different superconductors are used for this purpose, Nb and NbN. An increase in the superconducting critical temperature T_c is observed when graphene is put into contact with Nb. The largest increase is obtained for the thinnest Nb layer, which has a T_c 8% larger with respect to the single Nb film. In the case of NbN the effect is not as pronounced. Experimental data are discussed by considering the possible modification of the phonon spectrum in the superconductor due to the presence of the graphene. Within an elementary one-dimensional model based on elastic coupling between nearest-neighbor atoms, we demonstrate that the phonon spectrum in the superconductor is modified at low energies with the subsequent enhancement of the effective electron–phonon coupling constant. While the strong oscillating nature of the electron–phonon interaction, $\alpha^2(\omega)$, in NbN could lead to the insensitivity of T_c on the low-energy phonons generated by the graphene, the almost constant behavior of $\alpha^2(\omega)$ in Nb favors the increase of the superconducting critical temperature.

Keywords: superconductors, graphene, thin films, phonon density of states, superconductor/graphene hybrids

(Some figures may appear in colour only in the online journal)

1. Introduction

The problem of tuning the critical temperature T_c by affecting the phonon spectrum of a superconducting material arose naturally after Eliashberg developed the equations of the theory of superconductivity [1, 2] (see also [3–8]) without limiting the value of the electron–phonon interaction (EPhI). The solution of the equations is expressed in terms of the Eliashberg spectral function $\alpha^2(\omega)\ F(\omega)$, the integral quantity, in which $\alpha^2(\omega)$ indicates the strength of the EPhI and $F(\omega)$ represents the phonon density of states (PhDOS) [9]. By calculating the spectral function, or by extracting it from tunneling measurements [1, 9–12], and then solving the Eliashberg equations, it is possible to fully describe the superconducting properties of the metal. However, the broad application of Eliashberg's theory to the interpretation of experimental results became possible only after the work of McMillan [4], reanalyzed later by Allen and Dynes [7]. Based on the approximated solution of

 © 2021 IOP Publishing Ltd Printed in the UK