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ELECTRON TUNNELLING IN HIGH-\(T_c\) \(\text{Nb}_3\text{Ge}\) FILMS

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Résumé.- La structure du paramètre d'ordre du supraconducteur \(\text{Nb}_3\text{Ge}\) a été mesurée dans la face normale d'un bilame \(\text{Al}-\text{Nb}_3\text{Ge}\). On discute la possibilité d'utiliser les bilames de ce type pour étudier la fonction spectrale \(\Delta^2\) dans \(\text{Nb}_3\text{Ge}\).

Abstract.— Energy gap structure associated with superconducting \(\text{Nb}_3\text{Ge}\) has been observed on the normal side of \(\text{Al}-\text{Nb}_3\text{Ge}\) proximity sandwiches. The possible use of tunnelling junctions of this type to study the electron-phonon spectra of \(\text{Nb}_3\text{Ge}\) is pointed out.

Single particle tunnelling measurements are in principle a powerful technique for obtaining the electron-phonon spectral function \(\Delta^2 F(\omega)\). While procedures for obtaining \(\Delta^2 F(\omega)\) from tunnelling data are well known, methods for fabricating useful tunnelling junctions on \(\text{Al}\) superconductors are not. Here we report the fabrication of proximity effect tunnelling junctions in the configuration \(\text{Nb}_3\text{Ge}-\text{Al-Al}_2\text{O}_3-\text{Pb}\). Such junctions in the case of \(\text{Nb}\) base layers are very clean \(\text{Nb}-\text{Al}\) interfaces and very thin \(\text{Al}\) layers have been shown to be useful in the quantitative determination of \(\Delta^2 F(\omega)\) for niobium /1/. A theoretical analysis, which enables one to obtain \(\Delta^2 F(\omega)\) of the superconducting layer when the normal layer is thin, by explicitly taking into account the electronic density of states in the normal layer has also been given recently /2/.

Tunnelling in high-\(T_c\) intermetallic compounds such as \(\text{Nb}_3\text{Ge}\) is somewhat more complicated than tunnelling into a pure metal such as \(\text{Nb}\). The problem of the short coherence length which is on the order of 50 \(\AA\), is compounded by the great difficulties in preparing single-phase high-\(T_c\) films which are homogeneous across their thickness and by the fact that the layers of material adjacent to a tunnelling barrier prepared by conventional thermal oxidation are rich in germanium /3/.

In the case of \(\text{Nb}_3\text{Ge}\) it is relatively easy to deposit films by sputtering, CVD or electron beam deposition and achieve \(T_c\)'s greater than 20 K. The primary problem is that \(\text{Nb}_3\text{Ge}\) is a metastable phase. We have found that \(\text{Nb}_3\text{Ge}\) films with a 20 K transition temperature may contain up to five \(\text{Nb}\)-Ge compounds. These are the \(\text{Al}_5\), \(\text{Nb}_2\text{Ge}_3(\text{H})\), \(\text{Nb}_3\text{Ge}_3(\text{T})\), a quasiamorphous phase characterized by well defined diffraction peaks at \(d=2.66 \text{\ Å}\) and \(d=1.33 \text{\ Å}\), and the amorphous phase.

![Fig.1: Phase relationships of sputter-deposited \(\text{Nb}_3\text{Ge}\) films. \(T_d\) is the substrate temperature during deposition](image-url)

Figure 1 shows the phase relationships we have found as a function of substrate deposition temperature and \(\text{Nb}/\text{Ge}\) ratio of the sputtering target. Domains where transition temperatures in excess of 21 K occur are also shown. Maximum \(T_c\)'s occur in regions very close to boundaries between two phases in fact, films with \(T_c\)'s > 21 K usually contain a small amount of second phase which is not an \(\text{Al}_5\).

As one moves away from these boundaries, \(T_c\) decreases slightly and the amount of non - \(\text{Al}_5\) phase increases. It is possible to produce films with \(T_c > 20 \text{ K}\) that are (1) single phase \(\text{Al}_5\) or (2) about 1/3 \(\text{Al}_5\), 2/3 non-\(\text{Al}_5\). Thus knowing that \(T_c\)
is high is not necessarily an indication that tunnelling data will accurately reflect the properties of the A15.

A second problem is illustrated in figure 2 which shows the localized chemistry at the top surface of a sputter-deposited Nb3Ge film with a $T_c > 21$ K. A pronounced Ge-rich layer exists in the first 50-70 A of the original surface. We have shown that this Ge-rich layer develops as the film is formed.

Fig. 2: Auger electron depth profile of an "Nb3Ge" film with a Ge rich layer of 70 A. $T_c$ was 21.8 K.

Thermal oxidation usually used to produce barriers is not necessarily appropriate when the electrodes are compounds. In general, preferential oxidation of one element occurs. For the specific case of Nb3Ge, the top surface of the electrode beneath the oxide no longer has the same composition as the bulk of the film, assuming that it was homogeneous in the first place, because as the oxide forms the remaining elements get concentrated directly beneath the oxide layer. In the case of Nb3Ge the oxidation process results in an enhancement of the Ge-rich layer. It is highly probable that such a layer was responsible for the lower energy gap observed by Rowell and Schmidt in their tunnelling studies of Nb3Ge /4/.

In our procedure for fabricating proximity effect tunnelling junctions we first sputter deposit single, or nearly single phase Nb3Ge films. A post-anneal of four hours at 550°C reduces the amounts of non-A15 phases to the detection limit of X-rays or below it without decreasing $T_c$. Next, the Ge-rich surface layer is removed by a low-voltage glow-discharge or by ion-milling in the Auger system. A thin layer of Al (50-70 A) is next deposited in a vacuum of $10^{-7}$ torr. This layer is then oxidized in air for three minutes. The Al layer is masked with collodion at the same time. Finally, a counterelectrode of Pb is deposited under UHV conditions.

Figure 3 shows the I-V characteristic at 4.2 K of one of the first Nb3Ge-Al-Al2O3-Pb junctions prepared this way. An energy gap structure which can be associated with Nb3Ge is clearly visible. We have not yet determined whether we have fabricated an artificial barrier Nb3Ge-Al-Al2O3-Pb junction or a proximity effect junction. In the former case it would be unnecessary to contend with the corrections for the aluminum density-of-states in analysing tunnelling data in order to study the strong-coupled phonon structure of Nb3Ge. The presence of two gaps in the I-V characteristic suggests that the surface layer is not single-phase Nb3Ge. It remains to be demonstrated that enriched surface layers can be removed and the surface appropriately annealed so that a single-gap characteristic of a homogeneous material can be obtained. However, this technique of junction fabrication appears to be sufficiently reproducible that a systematic study of the dependence of I-V characteristics on such treatment seems possible.
References


/2/ Arnold Gerald, B., Bull. Am. Soc. 23 (1978) 263 and to be published.
